ETIP SNET R&I Roadmap 2020–2030

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Please consider this publication as the final version of the ETIP SNET R&I Roadmap 2020-2030, which substitutes the previous published version released in January 2020.

ETIP SNET

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Disclaimer

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Glossary

Active Demand/Demand Side response	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.
Aggregation/Aggregator	A function performed by a natural or legal person who combines multiple customer loads or generated electricity for sale, purchase or auction in any electricity market.
Alternating current (AC)	An electric current which periodically reverses direction.
Ancillary services	A range of services beyond generation, transmission and distribution that are required to maintain grid stability.
API	Application Program Interfaces.
Asset	An asset is a resource with economic value. 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.
Carbon-neutral	Situations where the energy system consumes as much CO_2 as it emits; the CO_2 balance is equal to zero.
Citizen	Use for people who value the development of smart grids as an opportunity to realise "We-centred" needs or motivations, e.g. affiliation, selfacceptance or community. Citizens want to help ensure the quality of supply and support environmental preservation and the community.
Cogeneration	Cogeneration is the 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.
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, of the electric grid fails.
Concentrating Solar Power (CSP)	A plant where solar radiation is concentrated onto a receiver by using mirrors or lenses. Electricity is generated when the concentrated light is converted to heat (solar thermal energy), which drives a heat engine (usually a steam turbine) connected to an electrical power generator.
Customer/End-user	An end-user of energy.
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.
Digital twin	Refers to a digital replica of physical assets, processes and systems that can be used for various purposes. 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.
Electricity generation Efficiency (Efficency el.)	The ratio between the electrical energy generated (output) and the energy content of the fuel consumed (input). The ratio is a-dimensional and the Efficiency is expressed often as percentage.
Energy cell (Web of cells)	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 of embedded resources.
Energy communities	A legal entity where citizens, SMEs and local authorities come together, as final users of energy, to cooperate in the generation, consumption distribution, storage, supply, aggregation of energy from renewable sources, or offer energy efficiency/demand side management services.
Energy storage	System domain for appliances and assets storaging 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)	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.

Fuel conversion rate	The ratio between the sum of the electricity generated and the useful heat recovered (output) and the energy content of the fuel consumed (input). The ratio is a-dimensional and the Fuel Conversion Rate is expressed often as percentage.
FUNCTIONALITY	Range of impacts suited to achieve a specific purpose.
Gas Turbine Simple Cycle Plant (SCP)	In simple cycle gas turbine operates according the Brayton thermodynamic cycle: air is compressed, mixed with fuel (most frequently natural-gas), and the mixture is burned in a combustor. The resulting hot, pressurized gases are expanded through a turbine that drives the compressor and an electric generator.
Gas Turbine Combined Cycle Power Plant (CCPP)	It combines both Brayton and Rankine thermodynamic cycles: a gas turbine operates according to Brayton cycle, as in the Simple Cycle, generating power, while the high temperature exhaust gases are fed into a so-called Recovery Boiler, where they generate steam, which in turn is fed to a Steam Turbine, thus generating additional power.
Gas Turbine Combined Heat and Power plant (CHP)	The Gas Turbine generates power according the Simple Cycle, while the heat content in the turbine exhaust gases is recovered and fed to useful destination (e.g. industrial heat, district heating ...).
Gas-to-Heat (GtH)	Combustion of gases to generate heat.
Gas-to-Power-and-Heat (GtP&H)	Combustion of gases to generate at the same time and with high efficiency electricity and heat.
High voltage (HV)	Usually considered any AC voltage over approximately 35,000 volts. This is a classification based on the design of apparatus and insulation.
Holistic Architecture	Holistic energy system architectures facilitate all processes which are necessary for a reliable, economic and environmentally-friendly operation of smart electricity systems.
Incentive	Regulatory measures that are meant to steer behaviour in certain contexts, i.e. motivating to behave in a specific way or demotivating to behave in another way than desirable. Incentives are often of monetary nature but are not restricted to such.
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.
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 CO_2 balance (i.e. emissions vs. sinks) is almost zero.
Low voltage (LV)	Usually refers to AC voltages from 50 to 1,000 volts.
Medium voltage (MV)	Usually refers to AC voltages between 1,000 volts to 35,000 volts.
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.

Organic Rankine Cycle (ORC)	A thermodynamic Rankine cycle, where an organic, high molecular mass fluid, with a low-temperature liquid-vapor phase change and/or boiling point, is used instead of water. Such characteristics of the fluid allow the generation of steam from lower temperature sources such as biomass combustion, industrial waste heat, geothermal heat, solar ponds etc. The steam is then expanded in a suitable turbine, thus generating power.
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 CO_2 as input.
Power-to-Heat (PtH)	Conversion of electrical power into heating/cooling. The conversion can be done for example by using conventional electric heaters or heat pump systems.
Power-to-Liquid (PtL)	Conversion of synthetic gas (CO and H2) into a mix of raw products, suitable for further processing at refineries or in the chemicals industry in view of the transformation into industrial products.
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.
Reciprocating Simple Cycle Plant (SCP)	Power generation plant based on a heat engine that uses one or more reciprocating pistons to convert pressure into a rotating motion. The most diffused engine is the internal combustion engine.
Reciprocating engine-based Combined Heat and Power plant (CHP)	A reciprocating engine-based plant (mostly internal combustion engine), where the heat content in the engine exhaust gases is recovered and fed to useful destination (e.g. industrial heat, district heating …).
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.
Replicability	Denotes the property of a system that allows it to be duplicated at another location or time. Whereas spatial replicability compares the performance of a system for different boundary conditions at a same, given time, temporal replicability is concerned with the performance of a system when boundary conditions change during time.
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	Capable of being easily expanded on demand, e.g. to include more participants or a higher load.

Scaling-up	To increase the size, amount, or importance of something, usually an organization or process.
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.
Smart Grid	An electricity network that can intelligently integrate the actions of all actors connected to it — operators of storage capacity, 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.
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).
Vulnerability	The openness to attack or damage.

Executive Summary

Context

The production and use of energy, including that needed for transport, account for some 80% of the EU's greenhouse gas emissions. The strong commitment to cut the emissions by 80-95% below 1990 level within mid-century, requires a rapid and drastic decarbonisation of the European energy system. This process shall be carried out in compliance with the three main drivers of the clean energy development programmes, i.e protecting the environment, ensuring security, reliability and resilience of energy supply, while creating affordable and market-based energy services, thus fostering welfare and economic growth.

The energy system as envisaged by the European Technology and Innovation Platform (ETIP) on Smart Networks for the Energy Transition (SNET) has been described in the Vision 2050, presented and published in June 2018, where the European target system is imagined as "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".

Legislative Effects on Innovation

Recent European legislation requires that DSOs must create an "EU DSO Entity", which will need to contribute to, among others, cooperation with ENTSO-E regarding the development of the electricity infrastructure planning. The traditional energy system silos for electricity generation and end-use, for gas transport, for heating & cooling, and for mobility must be coupled and optimised as one overall Integrated Energy System. At the building level, the operation shall be supported by a smart readiness indicator.

The recent clean energy legislation requires that Electricity Markets are created with "active customers/ consumers and citizens" and "energy communities". Renewables self-consumers are to be 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. Final customers (such as household customers), are entitled according to recent legislation to participate in a renewable energy community, while maintaining their rights or obligations as final customers. Cities and their citizens play a leading role in deciding on, developing and implementing city-related decarbonisation strategies.

The new legislation also asks for enhanced roles of DSOs, particularly in procurement of ancillary services, flexibility, data management and integration of electric vehicles. Markets must encourage development of more flexible generation and demand and Member States must eliminate obstacles to market-based pricing. Bidding zones must be reviewed by TSOs and possible alternative concepts must be proposed. DSOs must adapt network access and congestion tariffs and charges.

Member States must remove regulatory distortions, enable scarcity pricing, interconnection, Demand Side Response (DSR) and storage before Capacity Remuneration Mechanisms (CRM) can be introduced. Capacity must be procured separately from balancing energy by TSOs and may be facilitated on a regional basis. Final customers and small enterprises must be enabled to buy electricity generation from aggregated, multiple power-generating facilities or load from multiple demand response facilities to provide joint offers on the electricity market and be jointly operated in the electricity system. Smaller-scale producers must be directly or indirectly responsible for selling on the market the electricity they generate. Citizens must be offered competitive prices, efficient investment signals and higher standards of service so that they can contribute to security of supply and sustainability. Membership of citizen energy communities must be open to all categories of entities.

Digitalisation is key through the integration of innovative technologies with the electricity system by interoperable, standardised data architectures and related communication together with smart-ready buildings and electric vehicles. The ENTSO for Electricity (ENTSO-E) and the EU DSO entity must respectively promote and contribute to the digitalisation of the systems. The growing electrification and the more decentralized deployment of renewable power generation require reinforced and smarter electricity networks, able to accommodate both centralized and decentralized elements and to make the best of RES allocation over the European territory. Pervasive network digitalisation, supported by high-capacity cyber-secure communication networks, ensure decentralized monitoring and control.

The future energy system will rely on much higher balancing capacities, including flexible generation units, increased demand response and conversion and storage technologies, together with better interconnections at all grid levels. Increasing system flexibility must be achieved also through policies, measures and regulations compatible with further market integration, increased competition and the achievement of climate and energy objectives. The recent clean Energy legislation requires that renewable heating and cooling must contribute to the progressive increase of the share of renewable energy. Provisions shall be included, at national, regional and local level, for the integration and deployment of renewable energy, including for renewables self-consumption and renewable energy communities, and the use of unavoidable waste heat and cold when planning, including early spatial planning, designing, building and renovating urban infrastructure, industrial, commercial or residential areas and energy infrastructure, including electricity, district heating and cooling, natural gas and alternative fuel networks.

An integrated system approach is required to put the transport sector on a sustainable path. Central elements of such approach include action on overall vehicle efficiency, promoting low- and zero emission vehicles and infrastructure, and the long-term switch to low- and zero-carbon electricity and to alternative and net-zero-carbon fuels for transport, together with further encouraging multi-modal integration and shifts towards more sustainable transport modes. Conditions must ensure the effective deployment of publicly accessible and private recharging points for electric vehicles and the efficient integration of vehicle charging into the system.

Approach for Building the ETIP SNET R&I Roadmap 2020-2030

The path towards 2050 shall be adequately planned and executed by means of a sequence of targets and milestones and the progressive implementation of the FUNCTIONALITIES that will enable the transformation. These FUNCTIONALITIES will range across the energy system value chain (from generation to energy storage, transmission, distribution and end-use), its stakeholders (from the customer, to the market, network and service operators), its different vectors (from electricity to gas, heating and cooling, transport, water etc.) and the related non-technical issues (legislation, regulation, markets etc.).

The sequence and timing of implementation of the FUNCTIONALITIES towards the Vision 2050 is considered in the present document by means of a "screenshot" at the intermediate step in 2030. The FUNCTIONALITIES considered in this roadmap to be implemented in the period 2020-2030 are the following:

Table 1: 12 FUNCTIONALITIES to be achieved by the year 2030

Building blocks (ETIP SNET Vision 2050)	FUNCTIONALITY (Full name)	Short FUNCTIONALITY[1]
The efficient organisation of energy systems	F1 Cooperation between system operators	F1 Cooperation
	F2 Cross-sector integration	F2 Cross-Sector
	F3 Integrating the subsidiarity principle - The customer at the center, at the heart of the Integrated Energy System	F3 Subsidiarity
Markets as key enablers of the energy transition	F4 Pan-European wholesale markets	F4 Wholesale
	F5 Integrating local markets (enabling citizen involvement)	F5 Retail
Digitalisation enables new services for Integrated Energy Systems	F6 Integrating digitalisation services (including data privacy, cybersecurity)	F6 Digitalisation
Infrastructure for Integrated Energy Systems as key enablers of the energy transition	F7 Upgraded electricity networks, integrated components and systems	F7 Electricity Systems and Networks
	F8 Energy System Business (incl. models, regulatory)	F8 Business
	F9 Simulation tools for electricity and energy systems (software)	F9 Simulation
Efficient energy use	F10 Integrating flexibility in generation, demand, conversion and storage technologies	F10 Flexibility
	F11 Efficient heating and cooling for buildings and industries in view of system integration of flexibilities	F11 Heating & Cooling
	F12 Efficient carbon-neutral liquid fuels & electricity for transport in view of system integration of flexibilities	F12 Transport

These FUNCTIONALITIES are chosen in such a way that together and in accordance with the Building Blocks defined in the ETIP SNET Vision 2050, they represent the set of features enabling the functioning of an integrated energy system by the year 2030. These functionalities are described in Chapter III.

The present roadmap addresses the R&I[2] activities to be carried out in view of the practical achievement of the FUNCTIONALITIES and implementation by 2030, as well as those that must be started and conducted in the next ten years, even when a further target of implementation later than 2030 is foreseen. The research activities to be conducted in the reference period are organised in this roadmap according to the following Research Areas:

1 The "Short FUNCTIONALITY Name" is used in some of the table headers for space reasons

2 R&I meaning Research and Innovation; R&I projects comprise Research and Demonstration tasks (followed by Deployment projects, with typically non-public funding)

Table 2: Research Areas (RA) with Research Sub-Areas (RSA) and Number of tasks per RSA

Research Areas (RA)	Research Sub-Area Number	Research Sub-Areas (RSA)	Number of tasks associated to the RSA
1. CONSUMER, PROSUMER and CITIZEN ENERGY COMMUNITY	1.1	Social campaigns and social studies (related to societal acceptance and environmental sustainability of energy infrastructures)	3
	1.2	Adaptive consumer/user behaviour including energy communities (interaction, incentives by dynamic tariffs)	2
	1.3	Consumer and prosumer device control	2
2. SYSTEM ECONOMICS	2.1	Business models (including Aggregators)	5
	2.2	Market design and governance (Retail, Wholesale; Cross-border; Ancillary services; Flexibility markets)	9
3. DIGITALISATION	3.1	Protocols, standardisation and interoperability (IEC, CIM, Information models)	4
	3.2	Data Communication (ICT) (Data acquisition, Smart Meter, Sensors (monitoring), AMR, AMM, smart devices)	4
	3.3	Data and Information Management (Platforms, Big Data, Software, IoT)	2
	3.4	Cybersecurity (vulnerabilities, failures, risks) and privacy	4
	3.5	End-to-end architecture (integrating market, automation, control, data acquisition, digital twin, end-users)	3
4. PLANNING – HOLISTIC ARCHITECTURES and ASSETS	4.1	Integrated Energy System Architectures (design including new materials and hybrid AC/DC grids)	9
	4.2	Long-term planning (System development)	7
	4.3	Asset management and maintenance (maintenance operation, failure detection, asset lifecycles, lifespan and costs, ageing)	9
	4.4	System Stability analysis	7
5. FLEXIBILITY ENABLERS and SYSTEM FLEXIBILITY	5.1	Demand flexibility (household and industry related)	4
	5.2	Generation flexibility (flexible thermal, RES such as Hydro, PV and wind generators)	7
	5.3	Storage flexibility & Energy Conversion flexibility (PtG&H, PtG, GtP, PtL, LtP; PtW; WtP)	5
	5.4	Network flexibility (FACTS, FACDS, smart transformers and HVDC)	4
	5.5	Transport flexibility (V2G/EV; railway, trams, trolleybus)	3

Research Areas (RA)	Research Sub-Area Number	Research Sub-Areas (RSA)	Number of tasks associated to the RSA
6. SYSTEM OPERATION	6.1	Supervisory control and State estimation	3
	6.2	Short-term control (Primary, Voltage, Frequency)	3
	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
	6.4	Preventive control/restoration (Contingencies, Topology (including Switching) optimisation, Protection, Resilience)	8
	6.5	Control Center technologies (EMS, platforms, Operator training, Coordination among Control Centers)	7
Total number of Tasks			120

Each of these 6 Research Areas is composed of several Research Sub-Areas (in total 24 Research Sub-Areas). Each Research Sub-Area is composed of several tasks (in total 120 associated Tasks). The ETIP SNET stakeholders have determined the potential for contributions of each of these tasks for achieving the above-mentioned FUNCTIONALITIES.

This roadmap synthesizes consolidated and balanced stakeholders' views for the future R&I needs of the Integrated Energy System with electricity as its backbone. It relies on a detailed analysis of monitored and reviewed national, European and international R&I projects, on experts revising tasks of the previous roadmap, several intermediate consultations and a multi-year series of regional workshops involving national stakeholders of ongoing or recently finished R&I projects.

This ETIP SNET R&I roadmap covering 2020-2030 is the update and integration of the previous ETIP SNET R&I Roadmap 2017-2026. The profound review was deemed necessary to take into account the development path drawn by the ETIP SNET Vision 2050 and the very clear policy messages outlined in the legislative package "Clean Energy for all Europeans". It considers systematically the encompassing interaction among the different sectors linked with energy (i.e. electricity, gas, heating and cooling, transport, water, communication etc.), addressing the flexibility needs and the related conversion, storage and solutions integration towards a thorough decarbonisation.

Budget of the ETIP SNET R&I Roadmap 2020-2030

ETIP SNET has defined 5 BUILDING BLOCKS[3] and 12 FUNCTIONALITIES[4], which are expected to be implemented (deployed) in the real-world energy system by the year 2030, and 120 Tasks, whose Research and/or Demonstration goals have not yet been fully achieved by 2018.

According to ETIP SNET, there is the need of a total budget of approx. 4 000 M€[5] for achieving all tasks and thus contributing to FUNCTIONALITIES and BUILDING BLOCKS in the period 2020-2030. 75% of the 4000 M€ are expected to be spent on Demonstration tasks (which also includes Research) and related BUILDING BLOCKS with their associated FUNCTIONALITIES, 25% are expected to be spent on Research tasks during 2020-2030.

The following Table 3 shows how expected total budget of 4000 M€ for the period 2020-2030 are divided among Research Areas with their contributions to each of the five building blocks.

3 These **Building Blocks** have been defined in The ETIP SNET Vision 2050 and are: 1- Efficient organisation of energy systems; 2- Markets as key enablers of the energy transition; 3- Digitalisation enables new services for integrated energy systems; 4- Infrastructure for integrated energy systems. A fifth building block "Efficient energy use" was extracted from the fourth building block.

4 The five ETIP SNET VISION 2050 BUILDING BLOCKS can be found at: https://www.etip-snet.eu/wp-content/uploads/2018/06/VISION2050-DIGITALupdated.pdf

5 All budgetary figures are coming from a "token"-based approach: the value of the token is derived empirically at the light of the total budget and the total number of tasks per RSA considered. Each demonstration task (D-Task) is assumed to have a budget need of D-R-Factor (1.7) times the budget needs of a Research task (R-Task). Due to the fact that a task contributes towards a distinct number of FUNCTIONALITIES (see Annex II), tasks with more FUNCTIONALITIES get higher budgets. This was validated through an expert-based approach conducted on the budget for the first IP period of activity, i.e. the 2021-2024 ETIP SNET R&I Implementation Plan.

Table 3: Roadmap Period 2020-2030 with expected budgets (the higher the budget, the darker the background)

		Building Blocks (ETIP SNET Vision 2050)					
	Budgets ETIP SNET R&I Roadmap 2020-2030 for five Building Blocks and six Research Areas	The efficient organisation of energy systems	Markets as key enablers of the energy transition	Digitalisation enables new services for Integrated Energy Systems	Infrastructure for Integrated Energy Systems as key enablers of the energy transition	Efficient energy use	
	FUNCTIONALITIES	F1, F2, F3	F4, F5	F6	F7, F8, F9	F10, F11, F12	TOTALS
Research Areas	1. CONSUMER, PROSUMER and CITIZEN ENERGY COMMUNITY	42M€	42M€	29M€	29M€	73M€	215M€
	2. SYSTEM ECONOMICS	90M€	91M€	31M€	96M€	122M€	430M€
	3. DIGITALISATION	255M€	136M€	222M€	397M€	151M€	1161M€
	4. PLANNING - HOLISTIC ARCHITECTURES and ASSETS	121M€	74M€	53M€	291M€	226M€	765M€
	5. FLEXIBILITY ENABLERS and SYSTEM FLEXIBILITY	134M€	59M€	56M€	206M€	271M€	726M€
	6. SYSTEM OPERATION	109M€	72M€	67M€	234M€	221M€	702M€
	TOTALS	752M€	474M€	457M€	1253M€	1065M€	4000M€

Table 3 shows at a glance, how each of the six research areas contributes to building blocks (each with associated functionalities) of the European Energy System in the year 2030. The Research areas with large budgets during the period 2020-2030 are in expected budget-descending order:

(right-side column) Research Area 3 (Digitalisation) with 1 161 M€, Research Area 4 (Planning – Holistic architectures and assets) with 765 M€, Research Area 5 (Flexibility enablers and system Flexibility) with 726 M€, Research Area 6 (System operation) with 702 M€, Research Area 2 (System economics) with 430 M€ and Research Area 1 (Consumer, Prosumer and Citizen energy community) with 215 M€.

(bottom row) These Research areas and the underlying Tasks will have different effects on the five building blocks (in descending order): Building Block "Infrastructure for Integrated Energy Systems as key enablers of the energy transition" has the highest associated budget need of 1 253 M€ followed by Building Block "Efficient energy use" with 1 065 M€, followed by Building Block "The efficient organisation of energy systems" with 752 M€, followed by Building Block "Markets as key enablers of the energy transition" with 474 M€ and Building Block "Digitalisation enables new services for Integrated Energy Systems" with 457 M€.

Figure 1 shows the budgets for the RM Period 2020-2030 split by Research Area (RA) in graphical form.

Figure 2 shows the budgets for the RM Period 2020-2030 split by FUNCTIONALITY in graphical form.

Figure 1: Expected Budget needs for ETIP SNET R&I Roadmap 2020-2030 per Research Area (RA)

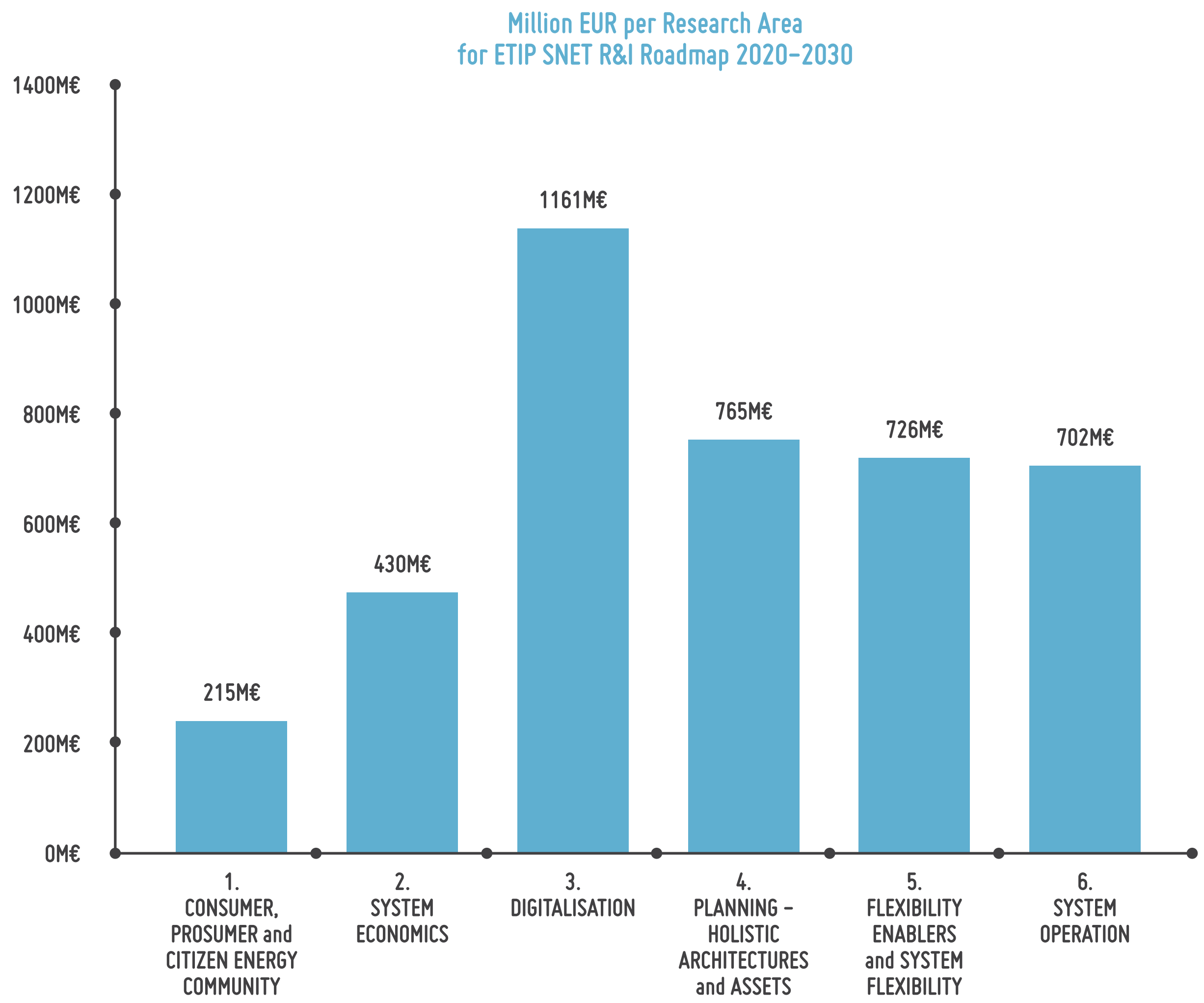
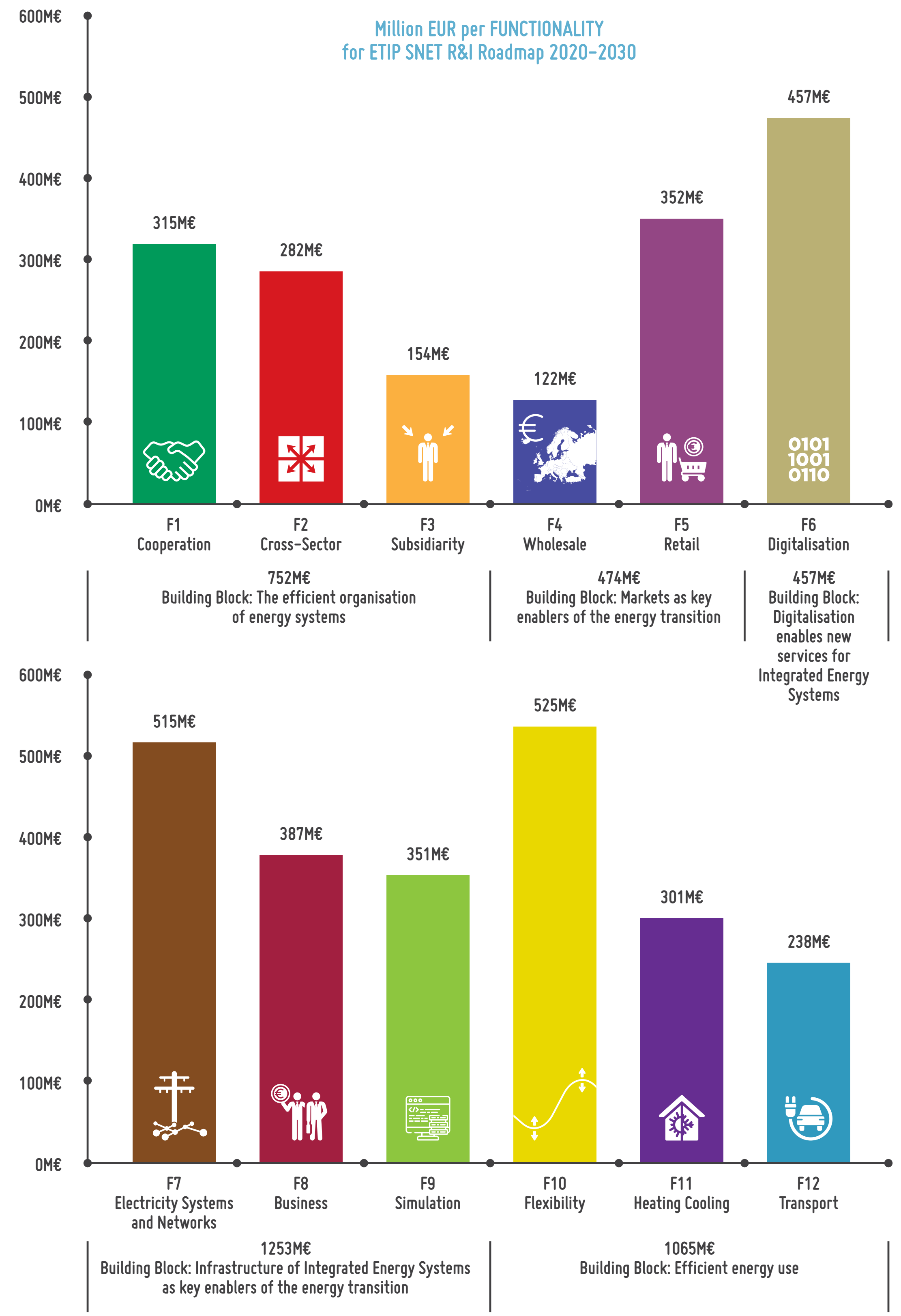


Figure 2: Expected budget needs for ETIP SNET R&I Roadmap period 2020-2030 per Building Block



Structure of the ETIP SNET R&I Roadmap 2020-2030

Chapter II describes the evolution of the energy system, starting from the present day towards 2030 and 2050. The ETIP SNET Vision 2050 gives insights into the evolution of the energy system and its stakeholders towards 2050 - with the electricity system as the backbone. In addition, with the support of several analytical studies and European scenario documents, this chapter II gives indications on societal evolutions related to the sustainability, affordability and security of supply of the energy system by 2050. This roadmap incorporates in Chapter II an analysis of the main guidelines of the EU Climate and Energy policies published and adopted since the previous ETIP SNET R&I Roadmap 2017-2026 which yield impacts on the future integrated energy system. The impacts are then used to derive FUNCTIONALITIES of the integrated energy system by the year 2030. They represent those challenges for the stakeholders including system operators, market aggregators, consumers in citizen energy communities which need to be realised or built by the year 2030. These FUNCTIONALITIES are associated to building blocks defined in the ETIP SNET Vision 2050.

Chapter III, in direct connection to the ETIP SNET Vision 2050 building blocks, describes the FUNCTIONALITIES needed for the European energy systems to achieve the "2030 Climate and Energy Framework" goals. To have these FUNCTIONALITIES successfully implemented in parts of the European energy system, R&I activities must be undertaken and finished by approximately 2027 with the idea that three more years remain for full implementation to reach 2030 goals. Chapter III discusses the Why, What and Goals (tasks) for each such FUNCTIONALITY in the year 2030, using a progressively more detailed approach (from a high level description of the FUNCTIONALITIES, to an identification of the characteristics of each FUNCTIONALITY considered): the R&I needs to be satisfied to enable a successful real-world implementation of the FUNCTIONALITY, the main tasks to be developed during the time of validity of the roadmap to ensure the availability of the FUNCTIONALITIES in due time.

Chapter III also discusses what research areas and tasks are needed to achieve the 2030 FUNCTIONALITIES and goals. It gives insights into budgetary requirement for the various research areas during the time period 2020-2030. With the decribed research, demonstration and deployment needs 2020-2030, ETIP SNET lays the foundation for the upcoming four-year ETIP SNET Implementation plan 2021-2024 with detailed proposals for TOPICS[6] with the goal to achieve the required FUNCTIONALITIES by 2027 and their full implementation by 2030.

Chapter IV presents a panorama of funding instruments that can be leveraged to make the R&I activities addressed in this roadmap happen. Chapter IV deals with the budgetary needs for the R&I activities described, built with a bottom-up approach for the estimated amounts for each task within each research area.

Chapter V concludes this ETIP SNET R&I Roadmap 2020-2030 with a set of recommendations.

6 The RSA (Research Sub Area) are called TOPIC in the ETIP SNET R&I Implementation Plan 2021-2024. Please consider therefore RSA as synonymous with TOPIC.

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I. Introduction

The present ETIP SNET R&I Roadmap 2020-2030, together with its four planned detailed Implementation Plans 2021-2024, 2023-2026, 2025-2028 and 2027-2030[7], addresses the framework in which the European energy system shall develop along the path toward the goal of a full decarbonisation by 2050. In particular it focuses on the intermediate step of 2030, identifying the system FUNCTIONALITIES to be ensured and considers the related tasks that need to be solved during the next decade to enable the FUNCTIONALITIES and to prepare for the further steps toward 2040 and 2050.

Details of the immediate R&I activities (i.e. for the next IP time period 2021 until 2024) are described in the ETIP SNET Implementation plan 2021-2024. The ETIP SNET R&I Roadmap is planned to be updated every four years and is valid for a time frame of approximately 10 years.

This ETIP SNET Roadmap can also support the EC and national authorities in the process of R&I Project Calls and the definition of deployment instruments. Also, it can enable the R&I project proposers to make highest impact proposals with goals and results to be achieved within the timeframe of the funded R&I projects.

As visualized in Figure 3, chapter II describes the evolution of the energy system, starting from the present day towards 2030 and 2050. The ETIP SNET Vision 2050[8] gives insights into the evolution of the energy system and its stakeholders towards 2050 - with the electricity system as the backbone. In addition, with the support of several analytical and European scenario documents, this chapter II gives indications on societal evolutions related to the sustainability, affordability and security of supply of the energy system by 2050.

Chapter III, in direct connection to the ETIP SNET Vision 2050 building blocks, describes the FUNCTIONALITIES needed for the European energy systems to achieve the "2030 Climate and Energy Framework" goals. To have these FUNCTIONALITIES successfully implemented in parts of the European energy system, R&I activities (R&I comprising research and Demonstration/Pilots) must be undertaken and finished by approximately 2027 with the idea that three more years remain for full deployment to reach 2030 goals.

Chapter III discusses what research areas and tasks are needed to achieve the 2030 FUNCTIONALITIES and goals. It gives insights into budgetary requirement for the various research areas during the time period 2020-2030. With the described research, demonstration and deployment needs 2020-2030, ETIP SNET lays the foundation for the upcoming four-year ETIP SNET Implementation plan 2021-2024 with detailed proposals for TOPICS using the tasks defined in this roadmap with the goal to achieve the required FUNCTIONALITIES by 2027 and their full implementation by 2030.

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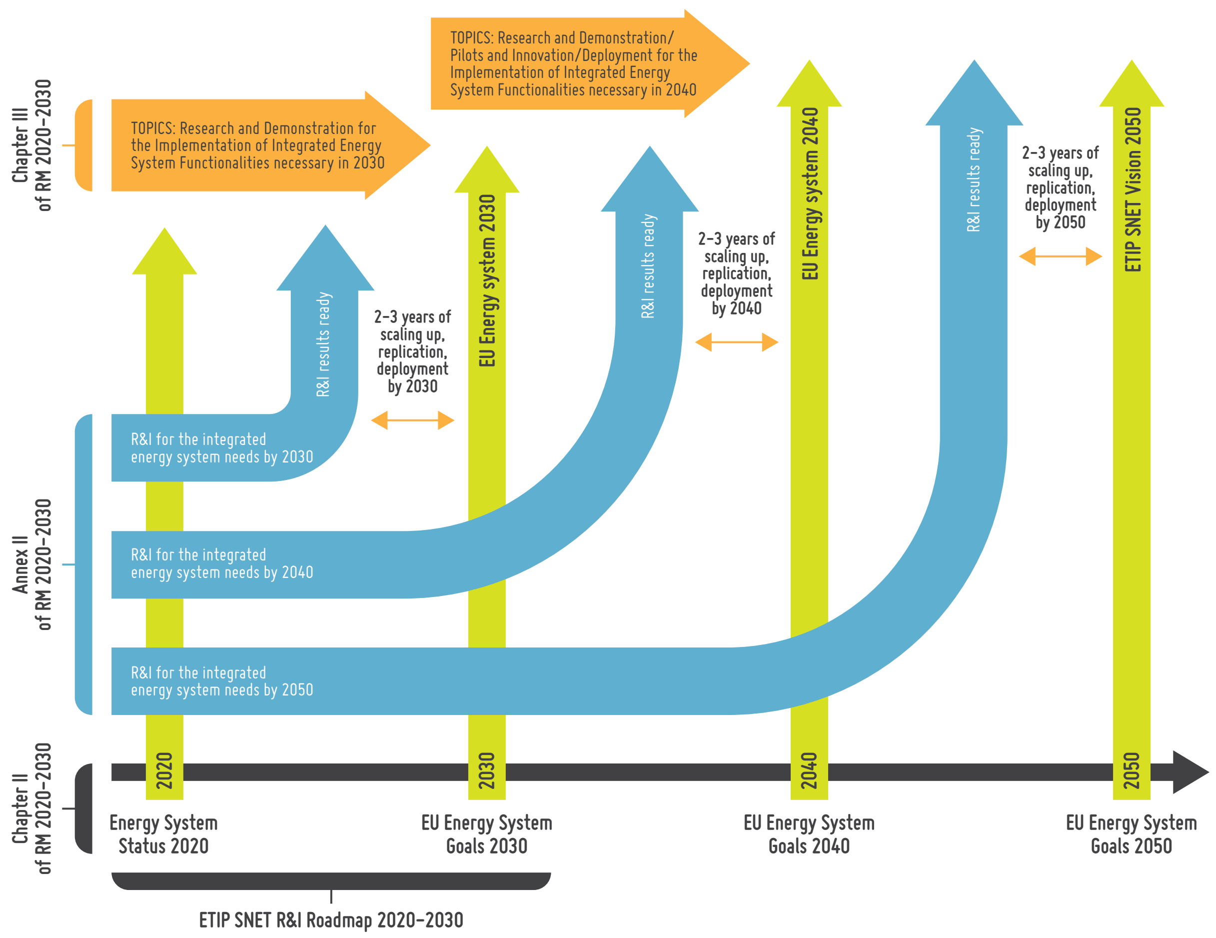
Chapter V concludes this ETIP SNET R&I Roadmap 2020-2030 with a set of recommendations.

7 As stated in the ETIP SNET Vision 2050 (see Chapter "ETIP SNET CALL FOR ACTION", page 48), the Implementation Plans set Europe's R&I priorities for a smarter energy transition as specified in this ETIP SNET 10-year R&I Roadmap. Such plans have a time horizon of approximately four years, presenting the TOPICS for the most urgent Research and Demonstration tasks and their related Functionalities.

8 https://www.etip-snet.eu/etip-snet-vision-2050/

Figure 3: Structure of the ETIP SNET R&I Roadmap 2020–2030



II. Description of the Evolution of the High-Level Functionalities: The Path to the Energy System 2050

The European Union has committed, in compliance with the engagements undersigned within the Paris agreement[9], to undertake action to keep global warming of the planet well below 2°C above pre-industrial 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[12], with an intermediate milestone of reducing by 40% by 2030. 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 growth and carbon-intensive energy consumption.

EU policies on the way to the Paris objectives

The first explicit energy and climate policy package that addressed emissions reduction at the same time as energy sector reform was the 20-20-20 targets launched in 2007, with the EU Emissions Trading System (EU ETS) improvements, the Renewable Energy Directive[14], the Energy Efficiency Directive[15] as well as the 3rd package of energy market liberalisation[16]. 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, first of all the "2030 Climate and Energy Framework", updated in 2018.

9 https://ec.europa.eu/clima/policies/international/negotiations/paris_en

10 In order to restrain the cumulated global GHG emissions under a certain limit, it may be necessary to adopt measures to substract GHG from to global balance: exampes can be CO2 sinks, use of CCS techniques on biomass power plants etc.

11 Communication from the Commission, A Roadmap for moving to a Competitive Low Carbon Economy in 2050. COM(2011) 112 final

12 The overall target addressed by the EC is related to the entire economical system. ETIP SNET in its vision indicates higher targets, because they are related to the energy system alone.

13 https://ec.europa.eu/transparency/regdoc/rep/1/2018/EN/COM-2018-716-F1-EN-MAIN-PART-1.PDF

14 Directive 2009/28/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC

15 Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC Text with EEA relevance

16 Directive 2009/72/EC of the European Parliament and of the Council of 13 July 2009 concerning common rules for the internal market in electricity and repealing Directive 2003/54/EC
REGULATION (EC) No 713/2009 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 13 July 2009 establishing an Agency for the Cooperation of Energy Regulators
REGULATION (EC) No 714/2009 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 13 July 2009 on conditions for access to the network for cross-border exchanges in electricity and repealing Regulation (EC) No 1228/2003
REGULATION (EC) No 715/2009 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 13 July 2009 on conditions for access to the natural gas transmission networks and repealing Regulation (EC) No 1775/2005

Clean energy for all Europeans

The “Clean energy for all Europeans” package adopted by the EU Council on May 22nd 2019, addresses all 5 dimensions of the Energy Union: Energy security; the internal energy market; energy efficiency; decarbonization of the economy; and: research, innovation and competitiveness. It is composed primarily of the following elements:

1. **Energy efficiency first:** the revamped directive on energy efficiency sets a new, higher target of energy use for 2030 of 32.5%, and the new Energy Performance of Buildings Directive maximizes the energy saving potential of smarter and greener buildings.

2. **More renewables:** an ambitious new target of at least 32% in renewable energy by 2030 has been fixed, with specific provisions to foster public and private investment, in order for the EU to maintain its global leadership on renewables.

3. **A better governance of the Energy Union:** A new energy rulebook under which each Member State drafts National Energy and Climate Plans (NECPs) for 2021-2030 setting out how to achieve their Energy Union targets, and in particular the 2030 targets on energy efficiency and renewable energy. These draft NECPs are currently being analysed by the Commission, with country-specific recommendations to be issued before the end of 2020.

4. **More rights for consumers:** the new rules make it easier for individuals to produce, store or sell their own energy, and strengthen consumer rights with more transparency on bills, and greater choice flexibility.

5. **A smarter and more efficient electricity market:** the new laws will increase security of supply by helping integrate renewables into the grid and manage risks, and by improving cross-border cooperation.

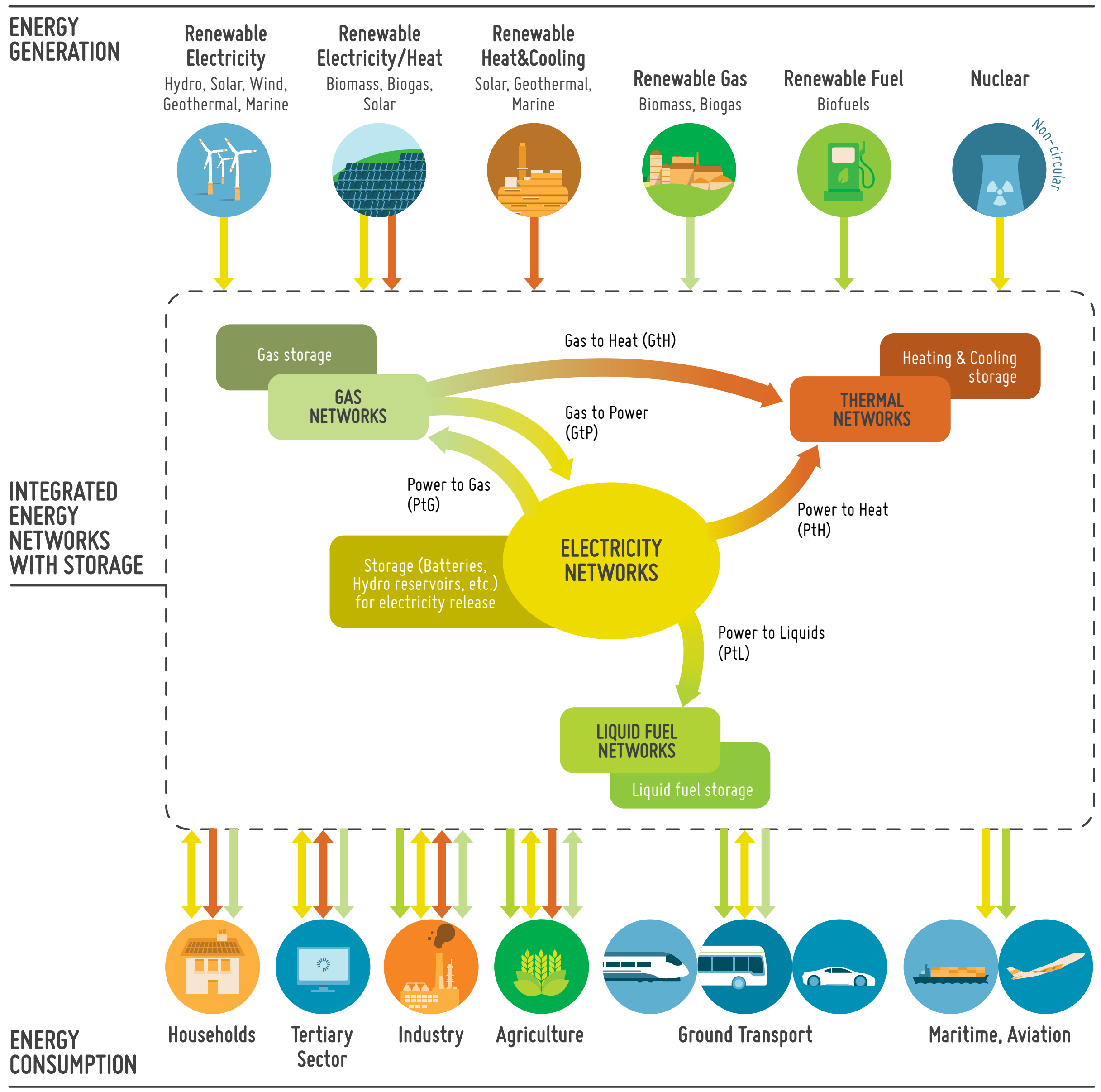
The “Clean Energy for All Europeans” has been translated into detailed legislation, in particular for the “Market Design” which introduces new provisions closely related to the digitalisation of the electricity sector. The provisions stand within the newly adopted “Electricity Directive on demand response, dynamic prices, flexibility procurement, access to data, interoperability and data management”. The “Energy Performance of Buildings Directive” promotes digitalisation of buildings through the establishment of a smart readiness indicator for buildings and through the introduction of requirements for the deployment of recharging infrastructure for electric vehicles. For heating and cooling, the revised “Energy Efficiency Directive” requires a transition to remote readable metering devices in district heating and cooling networks and in sub-metering systems within multi-apartment and multi-purpose buildings.

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” and the “In depth analysis in support to the Communication”, both issued in November 2018. Here the EU Commission presented its 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, a chapter is dedicated to the Energy supply issue: 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.

Figure 4: The future Integrated Energy Systems with Conversion, Storage between Energy Carriers, their networks and Electricity Networks as its backbone (Source: ETIP SNET Vision 2050)



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 2030. Key factors for the success of this integration are identified in the Digitalisation and in a "smart" regulatory framework.

The 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.

Development scenario for the European Energy System to 2050

Several studies and scenarios[17] depict the possible technological, economic, societal pathways for a full decarbonisation of the European energy system along different time horizons. Among them, recently published studies[18] offer support and guidelines to the present Roadmap, depicting and analysing integrated system development scenarios towards the objective (2050), with intermediate sustainable and realistic milestones (2030).

The key elements for the decarbonisation of the energy system, as discussed by the analytical scenarios considered[19], are founded on a gradual, yet significant, change from the current situation to reach, by 2050, a full decarbonisation of the energy system. Remaining emissions, that cannot be abated by 2050, will need to be balanced out with negative emissions. Technology options for further decarbonising the energy sector are, to a large extent, available although at different levels of readiness (TRL): some of them are ready for commercialisation and adoption.

The building blocks paving the path towards decarbonisation comprise and further elaborate most of the elements of the ETIP SNET Vision 2050 and can be summarised as follows:

- A very **extensive electrification** in (nearly) all sectors of the energy system[20];
- Deep energy **efficiency improvements** in all sectors[21];
- Extensive use of **carbon neutral fuels** (and hydrogen in industry, power generation, transport and buildings[22]);
- Adoption of a widely **circular approach** with high re-using, repairing, refurbishing and recycling rates[23];
- **Sustainable buildings** – Net Zero Emissions Buildings (NZEB)[24];
- Progressive **societal changes**, considering the shift of business and consumption patterns towards a more circular economy, increase in climate awareness of citizens translating in lifestyle changes and consumer choices more beneficial for the climate: less carbon intensive diets, sharing economy in transport, mobility as a service, alternatives to air travel, more rational use of energy demand for heating and cooling;
- **Widespread digitalisation**: digital technologies[25] represent the widest and more extensive innovation also in the frame of the fully decarbonised energy system: most integrated technologies will model, simulate, monitor, observe, control, enable services and protect the smart supply and use of energy. Internet of Things (IoT), Industrial Internet of things (IIoT), big data, blockchain, artificial intelligence, machine-based learning, digital twin and other developments, all present in the system, will change the energy system planning and operation and transform the energy markets.

The main outcomes of the scenario are briefly illustrated in the following, first dealing with the global energy system and then with a focus on electricity.

The energy system transition towards 2050[26]

The supply for all energy system needs is nearly decarbonised by 2050: complying with the commitments of the Paris agreement, the European Energy Union has actively worked to translate its decarbonisation targets into a concrete legislation. In terms of renewable energy, the Union should retain and reinforce its world leadership. This is not only a matter of security of supply and responsible climate change policy: it is also an industrial policy imperative to fully exploit the European green growth potential. The target of at least 32% of renewable energy in gross final energy consumption in 2030 is supported by ambitious measures addressing untapped potential for renewables in heating, cooling and transport. Measures must be put in place to facilitate the participation of citizens in the energy transition through the establishment of energy communities and the enhancement of the sustainability of bioenergy. A significant revision of electricity market rules underpins the European Union's ambition to further boost penetration of renewables in the power system.

In the perspectives towards 2050, in terms of energy mix to cover the gross inland consumption, the European energy system will continue its progression towards renewables, moving away from fossil fuels. **Fossil fuels** that will remain in the system will be, to a large extent, assigned to non-energy uses, i.e. used as raw material in the industry (e.g. to produce plastics). Solid fossil fuels shall totally disappear from the energy system. The share of **natural gas** (excluding non-energy uses) will remain stable, close to 20%, until 2030, and will decrease more sharply, reaching less than 5% by 2050. Importantly, natural gas will partially be substituted by **carbon neutral gas** (i.e biogas, syngas etc.), which then represents 4%-6% of the gross inland consumption in 2050. Overall, the decreasing roles of fossil oil and natural gas in the energy mix will contribute to improving the security of fuel supply of the EU.

17 World Economic Forum, "The future of Electricity", REF 030317, 2017; World Energy Council, "World Energy Scenarios – Composing energy future to 2050", 2013; ASSET Project, "A foresight perspective of the electricity sector evolution by 2050", December 2017; Capgemini, "World Energy Market Observatory", 19th edition, 2017

18 "A Clean Planet for all A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy" - In-Depth Analysis In Support Of The Commission Communication COM(2018) 773 - Brussels, 28 November 2018: https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf

19 The pathway of decarbonisation described in this Roadmap considers the main elements of the most challenging scenarios of [15]. In fact, the most important elements having an impact on the R&I needs are common to all scenarios. For the sake of completeness, specific reference is made to the scenario named "1.5 LIFE" which is mostly in line with ETIP SNET vision as it considers not only the energy and emission targets but also the societal targets for Europe.

20 As stated in the ETIP SNET Vision 2050: "[.] The electrification of Europe's energy systems will be the backbone of its societies and markets [.]";

21 this aspect is considered in the ETIP SNET Vision 2050, which states: "[.] The 2050 energy system will use overall less energy than today, due to energy efficiency for instance in industry and in buildings [.]";

22 this concept is illustrated in the ETIP SNET Vision 2050 by: "Europe's security of energy supply is ensured mainly by minimising fossil-fuel imports thanks to energy efficiency policies, the production of low-carbon fuels within Europe [.]"

23 the ETIP SNET Vision 2050, in fact, considers that "all the components of energy generation, storage, transmission and distribution, and consumption be designed and manufactured to be almost fully recyclable";

24 an entire chapter of the ETIP SNET Vision 2050 is dedicated to the efficient use of energy, with special reference to heating and cooling of buildings

25 DIGITALISATION OF THE ENERGY SYSTEM AND CUSTOMER PARTICIPATION: Description and recommendations of Technologies, Use Cases and Cybersecurity ETIP SNET Position Paper - https://www.etip-snet.eu/wp-content/uploads/2018/11/ETIP-SNET-Position-Paper-on-Digitalisation-short-for-web.pdf

26 The references for the figures considered in the path to 2030 are taken from "The pathway of decarbonisation" described in this Roadmap. It considers the main elements of the most challenging scenarios ["A Clean Planet for all A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy" - In-Depth Analysis In Support Of The Commission Communication COM(2018) 773 - Brussels, 28 November 2018: https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf]. Specific reference is made to the scenario named "1.5 LIFE" which is mostly in line with ETIP SNET Vision 2050 as it considers not only the energy and emission targets but also the societal targets for Europe.

In the long term, carbon-neutral gases and liquids may contribute in a sustainable way to grid stability and permanent security of supply. The share of **nuclear energy** in gross inland consumption (14% in 2015) will remain stable or will increase slightly. The share of **renewables will increase** swiftly, from 13% in 2015 to 25% in 2030, and will exceed 60% in 2050. The integration of such high shares of variable renewables will require significant system optimisation especially at distribution level (demand-side response, storage, interconnections, distributed generation and prosumers). The future energy system will have to rely on much better balancing capacities, including:

- better interconnections on all grid levels, extending pan-European, national electricity grids and connection to neighbouring areas with high renewable potential that would improve the match between supply and demand and unlock the potential of large offshore wind farms (e.g. in the North Sea) or solar energy (e.g. in the south of Europe);
- more storage capabilities, helping to match demand and supply more locally and over multiple time frames;
- better demand response, with special reference to the potential from the residential sector;
- low carbon flexible generation units (e.g. geothermal, biomass);
- effective enegy conversion (PtX) options and integration of different energy vectors (electricity, gas, heating/cooling, water etc.).

Energy efficiency – the new fuel: one of the major driving forces for the achievement of the GHG emission reduction lays on energy efficiency. EU energy consumption gradually decreased between 2006 (its highest point) and 2014, with the primary consumption reducing by 12% over the period (-1.5% per year) and the final demand reducing by 11% (-1.4% per year). Here again, the European legislation motivates continuous improvements.

In 2050 the reduction of final energy demand by up to around 50% with respect to 2005 (according to COM(2018)773) 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.

Electricity as the dominant energy carrier: Electricity becomes the dominant energy carrier and its share grows strongly, from 22% in 2015 to 29% in 2030 and then, in 2050, exceeds 50%. Deployment of carbon-free energy sources in power generation makes electricity a carbon-free energy carrier. As it is a versatile carrier usable for most of the final energy uses, increased electrification takes place in transport, residential and industrial applications compared to levels achieved in 2030. In 2050, transport sees the most spectacular development of electricity use, which expands up to 10-fold compared to 2015 and 4-fold compared to 2030. Residential sector and industry also go through increased electrification, respectively increasing electricity use in 2050 (compared to 2030) by more than 30% in residential and up to 50% in industry. The further penetration of electricity in the tertiary sector is more limited – up to 25%.

Evolution of Distributed Heating and Cooling: Distributed Heating and Cooling is another energy carrier that today accounts for only 4% of final energy consumption. It is today mostly delivered by large CHP plants for district heating and is largely based on fossil fuels. Over the period up to 2050 district heating and cooling for buildings and distributed industrial heat (mostly delivered from co-generation) will increase by more than 50% using renewable fuels, such as biomass, biogas, geothermal heat and electricity as energy sources, since the fossil fuels shall be phased out post 2030.

New energy carriers: 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 (H_2) and its carbon derivatives obtained by reaction with CO_2 like carbon-neutral gas (carbon neutral-CH_4) and carbon neutral liquids are considered as possible options for decarbonisation of transport, buildings, industry and in power generation. These new carriers, to be themselves considered as carbon-free, will have to rely in particular on availability of carbon-free electricity. 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 renewables-based electricity supply. In particular, in a power system largely based on variable renewable sources, hydrogen could be produced at times of low electricity demand providing additional flexibility. Hydrogen can be blended with natural gas so as to make use of the existing gas transport infrastructure up to 15% (or 20% in the future) by volume; in the mid-term the existing gas infrastructure will be retrofitted to enable the transport of a higher share of renewable gas. Hydrogen can also be stored at large scale, e.g. in salt caverns and other facilities or converted to synthetic hydrocarbons by reacting, using electricity, with CO_2. Carbon neutral fuels have the advantage that, once produced, they can be distributed via existing transmission/distribution systems and used by existing installations/applications.

Sector coupling: Many of the energy technologies, infrastructures and sectoral systems (electricity, gas, heat and transport) can further optimise their contribution to decarbonisation 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. Sectoral integration 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 generation decarbonises. This integration will build on the interdependency of energy transformation sectors (power, heating, production of new fuels) with industry, mobility, buildings sector, and other energy using activities. There are, however, multiple ways to substitute heating without electrification such as by burning biomass.

Efficient energy markets: The energy transition requires efficient energy markets that provide a level playing field for all stakeholders involved, non-discriminatory open access, and preclude cross-subsidies. To this aim: energy markets provide coherent price signals for required investments, consumers of any size can access directly or indirectly energy markets to sell (as prosumers) and buy energy, power capacity and flexibility services to satisfy their needs via low-cost, cyber-secure communication and Internet services, flexible energy storage, power conversion and demand flexibility play a key role as products and services; in energy markets. Compatible market platforms are implemented to ensure the data exchange between all market players using open, transparent and standardized interfaces.

Regulatory evolution: 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 as long as 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 stabilizing 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 framework and market design for the provision of grid services that 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.

Resilience: The required automation and digitalisation of power network operation should not increase the system vulnerability (i.e. exposure to cyber-attacks, which could jeopardize security of supply and/or the data privacy of consumers). Adequate solutions should be developed to make the system more resilient against attacks and other failures. Cyber security represents a new, emerging dimension of the energy security sphere that the plans required under the Regulation on gas security of supply and the Regulation on electricity risk preparedness should address. Member States are encouraged to identify other types of risks, such as those associated with raw material supply, the impacts of climate change or accidental, man-made, natural or terrorist threats to critical energy infrastructure, in the perspective of an approach to resilience.

Focus on the electricity system

Electricity demand will increase significantly by 2050[24]. Increased electrification will take place in most sectors compared to levels achieved in 2030. As stated above, transport will be widely affected by electrification. Residential and industry also go through increased electrification, respectively increasing electricity use in 2050 (compared to 2030) by up to 30% in residential and up to 50% in industry. The further penetration of electricity in the tertiary sector will be more limited – up to 25%, where electrification is counterbalanced by energy efficiency improvement in this sector. In addition to increased final demand of electricity, the development of carbon neutral fuels also creates a new need for electricity supply. As a consequence of both changes in the final energy demand and the production of carbon neutral fuels, the gross electricity generation in 2050 will double when compared to 2030. The additional electricity demand will be satisfied by production using resources from the EU territory, mostly local wind and solar, but also nuclear.

The **overall net installed electricity capacities** will reach in 2050 around 2500 GW, more than doubling the value of 2015 (985 GW) and nearly doubling that foreseen for 2030 (1250 GW). The changes in electricity generation mix illustrate the **strong shift towards carbon-neutral or carbon-free energy sources**, in a context of overall increase in electricity production. **Fossil fuels**, which represented 43% of the electricity production in 2015, become marginal contributors in the decarbonised power system. In fact, by 2050, **natural gas will be the only fossil fuel left** in the mix, with a share (of the production) falling from 16% in 2015 to 12% in 2030 and then in 2050 to between 5% and 1%. **Renewables will become increasingly competitive**: the share of renewables in gross electricity generation will reach 81%-85% in 2050 (compared to 57% in 2030 and 30% in 2015) and remain at this level afterwards. Among renewables, wind is clearly the dominant technology, representing in 2050, 50-55% of the yearly electricity production. The share of solar energy grows from 3% in 2015 to 11% in 2030 and up to 15-16% in 2050. Households, collectives, small and medium-size enterprises (SMEs) and public entities may play an outstanding role in the production of renewable electricity. Up to 1500 TWh (equivalent to 32% of electricity production) of solar PV and wind power may be produced by these stakeholder groups by 2050. **The share of biomass** and waste will remain quite stable over the period (7-8% with significant development of BECCS[27]). **Hydro and pumping hydropotential** will be developed as much as possible due to its actual characteristics: renewable, cost efficient, energy efficient and fully dispatchable. The **nuclear energy share** in 2050 will remain close to 10-15%, compared to 26% in 2015. The gas network will progressively be decarbonised using low-carbon and carbon-neutral of carbon-free gases. **Hydrogen** will provide important services as a chemical **storage**.

While electricity supply grows, **electricity storage plays an increasingly prominent role**: the deployment of renewables is facilitated by the possibility of storage in pumped hydro plants, stationary and mobile (in EVs) batteries and, indirectly, in hydrogen and carbon-neutral-fuels in connection with flexible generation as well as via demand side management. The amount of electricity to be stored in 2050 increases some 10 times compared to 2015[28], while at the same time demand for electricity, including for production of carbon neutral fuels (where applicable), increases between one third and nearly 1.5 times. Electricity from renewables increases between roughly 3 and 6 times over the same period. The considerably increased storage systems, including the power-to-X units, operate following a pattern that help increasing the share of renewables, as they not only provide possibilities for locally balancing the more volatile demand and production of energy but could also be used to maintain power quality and frequency stability. The amount of **storage** necessary by 2050 to cope with the requests linked with RES integration in electricity amounts to **250 TWh**. In terms of electricity storage in the form of pumped hydro storage or stationary batteries grows from 30 TWh today to 70 TWh in 2030 up to 170 TWh in 2050[29]. Stationary batteries may play a larger role in the future, growing from 40 TWh in 2030 (from negligible amounts today) to 110 TWh, especially if one considers limited development of carbon neutral fuels.

27 Bio-energy with carbon capture and storage

28 A Clean Planet for all - A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy" - In-Depth Analysis In Support Of The Commission Communication COM(2018) 773 - Brussels, 28 November 2018 https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf

29 A Clean Planet for all - A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy" - In-Depth Analysis In Support Of The Commission Communication COM(2018) 773 - Brussels, 28 November 2018 https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf

Some long-term scenarios suggest that about 83% of all EU households could be actively supporting the deployment of renewables, either by producing energy themselves or by providing the flexibility services for better local balancing of demand and productions and decentralized power network operation. Interconnections between national markets represent the missing link for completing the Union internal electricity market, ensuring security of supply, reaping the full potential of renewable energy sources, and facilitating sector coupling and integration.

III. The ETIP SNET R&I Roadmap 2020-2030

The ETIP SNET R&I Roadmap 2020-2030 addresses various concepts specified in the paragraphs below:

The ETIP SNET **VISION 2050**[30] details specific goals and BUILDING BLOCKS, constituting the ground for defining the specifications of further research and innovation activities required to meet the energy transition. The Vision 2050 defines 5 BUILDING BLOCKS which are associated to the 12 FUNCTIONALITIES to be developed in details below.

Table 4: Building blocks of the ETIP SNET Vision 2050 and their association to the FUNCTIONALITIES of the ETIP SNET R&I Roadmap

The ETIP SNET BUILDING BLOCKS	BUILDING BLOCK 1 The efficient organisation of energy systems	BUILDING BLOCK 2 Markets as key enablers of the energy transition	BUILDING BLOCK 3 Digitalisation enables new services for Integrated Energy Systems	BUILDING BLOCK 4 Infrastructure for Integrated Energy Systems as key enablers of the energy transition	BUILDING BLOCK 5 Efficient energy use
Associated FUNCTIONALITIES	F1, F2, F3	F4, F5	F6	F7, F8, F9	F10, F11, F12

The Year 2030 FUNCTIONALITIES are to be realised by 2030 in the European energy system to reliably operate the transition towards 2050. They are based on climate-science, integrated energy-system science insights. Most of them have been translated during the recent decade and most recently by the European Clean Energy Legislation into corresponding legal requirements on the society. The implementation of these FUNCTIONALITIES in the energy system 2030 is urgently needed and requires preceding research, small-scale pilots and large-scale demonstrations and finally, deployment of products and services to enable the replicated, scaled-up real-world implementation of these FUNCTIONALITIES in the period until 2030.

30 ETIP SNET VISION 2050 Integrating Smart Networks for the Energy Transition: Serving Society and Protecting the Environment, June 2018

Table 5: FUNCTIONALITIES[31] for the Integrated Energy System 2030

Building blocks (ETIP SNET Vision 2050)	FUNCTIONALITY (Full name)	Short FUNCTIONALITY[31]
The efficient organisation of energy systems	F1 Cooperation between system operators	F1 Cooperation
	F2 Cross-sector integration	F2 Cross-Sector
	F3 Integrating the subsidiarity principle – The customer at the center, at the heart of the Integrated Energy System	F3 Subsidiarity
Markets as key enablers of the energy transition	F4 Pan-European wholesale markets	F4 Wholesale
	F5 Integrating local markets (enabling citizen involvement)	F5 Retail
Digitalisation enables new services for Integrated Energy Systems	F6 Integrating digitalisation services (including data privacy, cybersecurity)	F6 Digitalisation
Infrastructure for Integrated Energy Systems as key enablers of the energy transition	F7 Upgraded electricity networks, integrated components and systems	F7 Electricity Systems and Networks
	F8 Energy System Business (incl. models, regulatory)	F8 Business
	F9 Simulation tools for electricity and energy systems (software)	F9 Simulation
Efficient energy use	F10 Integrating flexibility in generation, demand, conversion and storage technologies	F10 Flexibility
	F11 Efficient heating and cooling for buildings and industries in view of system integration of flexibilities	F11 Heating & Cooling
	F12 Efficient carbon-neutral liquid fuels & electricity for transport in view of system integration of flexibilities	F12 Transport

31 The 12 Functionalities have been derived from the building blocks of the ETIP SNET Vision 2050.
32 The "Short FUNCTIONALITY Name" is used in the tables for space reasons.

Research Areas (RA) and Research Sub-Areas (RSA)

These FUNCTIONALITIES which are to be implemented for the real-world Integrated Energy System by the year 2030, will be realized by the implementation of products and solutions derived by **120 Research and Demonstration tasks** (see Annex II of this ETIP SNET R&I Roadmap 2020-2030) described by this ETIP SNET R&I Roadmap 2020-2030. Each task is related to a **Research Area (RA)** and to a **Research Sub-Area (RSA)**. Each task has impacts on one or more FUNCTIONALITIES that must be realised before 2030. The expected impacts of each task on what FUNCTIONALITIES are also indicated in the Annex II.

The Research areas are listed in the table below:

Table 6: Research Areas

RA No.	Research Area (RA)	RA-Explanation
1	CONSUMER, PROSUMER and CITIZEN ENERGY COMMUNITY	Citizen and prosumer information, empowerment and engagement
2	SYSTEM ECONOMICS	Business models, market design and market-governance
3	DIGITALISATION	Communication and data handling for the digitalisation of energy systems functionalities (including Data, Cyber and System security)
4	PLANNING – HOLISTIC ARCHITECTURES and ASSETS	Energy system architectures, design and planning; technology solutions, asset management, maintenance; System Stability and resilience.
5	FLEXIBILITY ENABLERS and SYSTEM FLEXIBILITY	Adapting all energy components to provide flexibility to the system (Flexibility in Demand, Generation, Storage & Energy Conversion, Network, Transport).
6	SYSTEM OPERATION	System supervision, monitoring, control, reliability, resilience and automation (State estimation and supervision, short-term, medium and long-term control), and control room operators' skills enforcement

Each Research Area has dedicated Research Sub-Areas (RSA) with associated tasks. **The tasks** were taken from the R&I-project coverage assessment 2018 of the ETIP SNET R&I Roadmap 2017-2026[33]. They were partially removed, merged, updated and complemented by new ones through a large stakeholder consultation process and then adjusted following the publication of the ETIP SNET R&I Implementation Plan 2021-2024 in May 2020. Each of these newly defined tasks is part of this Roadmap. Each task has been mapped to a single (primary) Research Sub-area of the above-mentioned six Research Areas. The last column of Table 7 shows the number of tasks associated to each RSA.[34]

33 In this document, experts assessed the tasks 2017-2026 and made suggestions of merging or modifications

34 The update of this roadmap considers 120 tasks following the publication of the ETIP SNET R&I Implementation Plan 2021-2024 in May 2020. The link between the 261 stakeholders tasks of the January 2020 version of the ETIP SNET R&I roadmap 2020-2030 and the current version of the ETIP SNET R&I Roadmap 2020-2030 can be found at https://www.etip-snet.eu/wp-content/uploads/2020/05/ETIPS-NETStakeholderTasks202001.pdf.

Table 7: Research areas (RA) with Research Sub-Areas (RSA) and number of tasks per RSA

Research Areas (RA)	Research Sub-Area Number	Research Sub-Areas (RSA)	Number of tasks associated to the RSA
1. CONSUMER, PROSUMER and CITIZEN ENERGY COMMUNITY	1.1	Social campaigns and social studies (related to societal acceptance and environmental sustainability of energy infrastructures)	3
	1.2	Adaptive consumer/user behaviour including energy communities (interaction, incentives by dynamic tariffs)	2
	1.3	Consumer and prosumer device control	2
2. SYSTEM ECONOMICS	2.1	Business models (including Aggregators)	5
	2.2	Market design and governance (Retail, Wholesale; Cross-border; Ancillary services; Flexibility markets)	9
3. DIGITALISATION	3.1	Protocols, standardisation and interoperability (IEC, CIM, Information models)	4
	3.2	Data Communication (ICT) (Data acquisition, Smart Meter, Sensors (monitoring), AMR, AMM, smart devices)	4
	3.3	Data and Information Management (Platforms, Big Data, Software, IoT)	2
	3.4	Cybersecurity (vulnerabilities, failures, risks) and privacy	4
	3.5	End-to-end architecture (integrating market, automation, control, data acquisition, digital twin, end-users)	3
4. PLANNING – HOLISTIC ARCHITECTURES and ASSETS	4.1	Integrated Energy System Architectures (design including new materials and hybrid AC/DC grids)	9
	4.2	Long-term planning (System development)	7
	4.3	Asset management and maintenance (maintenance operation, failure detection, asset lifecycles, lifespan and costs, ageing)	9
	4.4	System Stability analysis	7
5. FLEXIBILITY ENABLERS and SYSTEM FLEXIBILITY	5.1	Demand flexibility (household and industry related)	4
	5.2	Generation flexibility (flexible thermal, RES such as Hydro, PV and wind generators)	7
	5.3	Storage flexibility & Energy Conversion flexibility (PtG&H, PtG, GtP, PtL, LtP; PtW; WtP)	5
	5.4	Network flexibility (FACTS, FACDS, smart transformers and HVDC)	4
	5.5	Transport flexibility (V2G/EV; railway, trams, trolleybus)	3
6. SYSTEM OPERATION	6.1	Supervisory control and State estimation	3
	6.2	Short-term control (Primary, Voltage, Frequency)	3
	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
	6.4	Preventive control/restoration (Contingencies, Topology (including Switching) optimisation, Protection, Resilience)	8
	6.5	Control Center technologies (EMS, platforms, Operator training, Coordination among Control Centers)	7
Total number of Tasks			120

The Research Areas and their Sub-Areas together with the associated 120 tasks are described in detail in the Annexes I and II of the present document. The main chapters of this roadmap 2020-2030 concentrate on the FUNCTIONALITIES (Chapter III) including the contributions of Research Sub-Areas (and implicitely their tasks, described in the Annex II) towards these FUNCTIONALITIES.

In the following each of the 12 FUNCTIONALITIES is described thereby highlighting the Why? and What? and describing the expected R&D path toward the effective implementation with respect to each of the above-mentioned Research Sub-Areas.

FUNCTIONALITIES 2030

In this chapter the building blocks of the ETIP SNET Vision 2050 are translated[35] into FUNCTIONALITIES which need to be realised in the Integrated Energy System by the year 2030.

The Efficient Organisation of Energy Systems[36]

F1[37] – Cooperation between system operators

WHY F1[38]?

The recent clean energy legislation requires that system operators must cooperate with each other in planning and operating their networks. 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 these grids). System Operators need to support all measures for reinforcing competitive energy markets. Moreover, all DSOs must together create an "EU DSO entity", which will need to contribute to, among others, cooperation with ENTSO-E.

WHAT FUNCTIONALITIES F1 can be expected by the year 2030 in the transition towards 2050?

In 2050, network operators intervene mainly when capacities and other rated constraints such as system frequency, voltages, gas pressures, temperature levels, and water reservoir levels approach their limits due to minimum costs and maximum welfare operations. In 2030, network operators are facing significant changes and are transitioning from their more traditional roles to facilitate the market uptake of new services, to ensure secure and reliable operation of the system in an increasingly challenging environment, and by this, to promote active customer participation in the energy transition. In 2030, full automation of electricity transmission network operation and full compatibility to short-term (15-minute) markets is achieved. This automation includes handling congestions also caused by contingencies. Network operators, however, have the final decision in special circumstances.

In 2030 gas and heat are still largely provided by thermal, fossil power plants with increasing intensities. Processes for PtG&H (cogeneration) are not yet fully coupled and automated. Electricity, gas and heating/cooling operators are beginning to coordinate their operations.

In 2050, European transmission and distribution networks operations leverage the dynamic cooperation of their respective operators. In 2030 the integration of different vectors is not yet fully developed at Pan-European level, but it has been achieved at a certain scale at local level (citizen energy communities, communities, cities) by integrated, standardised, interoperable protocols, data, platforms, regulation. Moreover, by 2030, renewable hydrogen generation is well developed in demonstration sites and renewable methane, blended (and distributed) with natural gas projects are implemented at Pan-European level.

35 For explanations related to the methodology used in this chapter, see Annex III.

36 Section titles at this section level come from the "ETIP SNET Vision 2050 Building block"

37 Functionalities are numbered from F1 to F12.

38 Sample from the following references: EU legislation "Electricity Regulation -EU- 2019/943", Regulation on Risk-Preparedness in the Electricity Sector -EU- 2019/941 and Regulation on the European Union Agency for the Cooperation of Energy Regulators -EU- 2019/942

In 2050, electricity system operation is based on the highly automated optimisation of the grid, power generation, market systems and of all types of energy consumption. In 2030, observability is achieved for 80% of the high voltage and medium voltage substations and 25% of low voltage substations.[39]

In 2050, stationary or mobile gas infrastructure and storage play a key role in the sustainable, circular energy systems. In 2030, it still plays a minor role.

In 2050 the various energy systems infrastructures (electricity, gas, heat and cooling) will be planned and developed in a coordinated way. In 2030 the infrastructure owners will have established fora for exchanging information on network expansions/changes.

F2 – Cross-sector integration

WHY F2[40]?

The traditional energy system silos for electricity generation and end-use, for gas transport, for heating & cooling needs and for mobility must be coupled and optimised as one overall, Integrated Energy System. 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. At the building level, the operation shall be supported by a smart readiness indicator[41].

WHAT FUNCTIONALITIES to achieve objective F2 can be expected by the year 2030 in the transition towards 2050?

In 2050, integrated energy networks for electricity, gas, and heating and cooling can handle the available capacities. By 2030, there is still separate handling of available capacities of electricity, gas and heating/cooling.

In 2050 the various energy systems infrastructures (electricity, gas, heating and cooling) will be planned and developed in a coordinated way. In 2030 the infrastructure owners will have established fora for discussing network expansions/changes. In 2030 gas and heating/cooling end-use is beginning to be coupled to electricity, however not yet fully automated. Electricity, gas and heating/cooling operators are beginning to merge their operations. By 2030, EU TSO's will benefit from the automatization of transmission line flow limits based on dynamic rating methods corroborated with weather forecasting and RES diversity. But research is undertaken for an integrated approach going beyond silos. By 2030, tools for facilitating design, planning and operation of integrated energy networks have been developed and validated by experimental and live field applications.

39 Strategic Energy Technology Plan Implementation Plan - Temporary Working Group 4, "Increase the resilience and security of the energy system" – January 2018

40 European Parliament's Committee on Industry, Research and Energy (ITRE), "Sector coupling: how can it be enhanced in the EU to foster grid stability and decarbonise?", November 2018, http://www.europarl.europa.eu/supporting-analyses

41 Smart readiness indicator: measure the capacity of buildings to use information and communication technologies and electronic systems to adapt the operation of buildings to the needs of the occupants and the grids and to improve the energy efficiency and overall performance of buildings, including its flexibility.

F3 – Integrating the subsidiarity principle[42] — The customer at the center, at the heart of the Integrated Energy System

WHY F3?

Implementing the subsidiarity principle is a prerequisite for a well functioning Integrated Energy System because of the upcoming masses of distributed energy resources such as electricity generating PV-cells on the roofs, on the walls of building, on the terrasses and lawns of citizens, on the roofs of EV cars, but also of active consumers. The recent clean energy legislation requires that Electricity Markets are created with "active customers/consumers and citizens" and "energy communities"[43]. Renewables self-consumers are to be 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. Final customers (such as household customers), are entitled to participate in a renewable energy community, while maintaining their rights or obligations as final customers. Cities and their citizens play a leading role in deciding on, developing and implementing city-related decarbonisation strategies.

WHAT FUNCTIONALITIES F3 can be expected by the year 2030 in the transition towards 2050?

In 2050, the subsidiarity principle is applied to European energy systems. By 2030, this presumes clarification on legal (on EU level) changes in the existing roles and responsibilities i.e. partial transfer of balancing responsibility to distribution network operators due to the physical nature of some of the involved energy carriers. In 2030, communities who participated in large-scale energy community demonstration projects during 2020-2030, are able to handle, through proper interaction and validation from network operators, the variability and peaks for their net energy consumption, but also for their net excess energy production in times of high amounts of community-PV infeed. By 2030, they are enabled due to smart decentralized optimisation and control solutions for balancing community demand, generation and conversion of different energy carriers (electricity, gas, etc.) to and from locally connected storage.

The following table 8 displays the **Research** and **Demonstration** tasks with associated expected budgets needed for the FUNCTIONALITIES F1, F2 and F3 per research sub area (RSA) in the time periods 2021-2024, 2023-2026, 2025-2028 and 2027-2030. The effort needed is materialised by **red-colored circle areas** and **orange-colored areas**. **Demonstration** may also imply supporting Research.

The main outputs of the table 8 are highlighted below:

- Within the RA 1, the FUNCTIONALITY F3 requires the most demonstrations activities and budgets in all 4 IP time periods (2020-2030) for RSA 1.1 (Social issues) and 1.2 (Community). No research and demonstration tasks were identified regarding F1 and F2 for RSA 1.2 and 1.3 (User devices).
- For RA 2, the FUNCTIONALITIES F1 and F2 need the most demonstration activities and budgets for the four time periods and specifically for the RSA 2.2 (Market). No effort was identified for F1 regarding RSA 2.1 (Business).
- Looking at RA 3, the FUNCTIONALITY F1 will need the most demonstration activities and budgets and specifically for RSA 3.1 (Standards), RSA 3.3 (Data and Info) and RSA 3.5 (Software architecture) – apart for the last period. No effort is identified for F2 and F3 for RSA 3.3 (Data and info), neither for F2 related to RSA 3.4 (Cybersecurity) and nor for F3 related to RSA 3.5 (Software architecture).
- Looking at RA 4, the FUNCTIONALITIES F1 and F2 will be the ones with more demonstration , research activities and budgets for RSA 4.1 (Energy system Architectures). No effort was identified for F1, F2 and F3 for RSA 4.3 (Assets) as well as for their last periods for RSA 4.4 (Stability).
- For RA 5, the FUNCTIONALITY F2 will be the one needing the most demonstration and research activities for the RSA 5.1, 5.2, 5.3 and 5.5 (respectively Demand, Generation, Storage and conversion, Transport). No effort is identified for F1 regarding RSA 5.3 (Storage and conversion), neither for F3 regarding RSA 5.2, 5.4 and 5.5 (respectively Generation, Network and Transport).
- Finally, within RA 6, The FUNCTIONALITIES F1 and F2 will be the ones with the most demonstration and research activities (and budgets) regarding RSA 6.5 (Control center). No effort is expected for the 3 FUNCTIONALITIES regarding RSA 6.2 (Short-term control) as well as for FUNCTIONALITY F2 for RSA 6.3 (Longer-term control).

To summarize, **for F1, F2 and F3**, most budgets are needed in terms of research and demonstration for the RSA 2.2 (Market), 3.1 (Standards) and 4.1 (Energy System Architecture).

F3 is the FUNCTIONALITY with the least activities and budget needs (154 M€) compared with F1 (315 M€) and F2 (282M€).

42 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.

43 Electricity Regulation -EU- 2019/943, In addition to the Electricity Directive 2009.

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The ETIP SNET R&I Roadmap 2020-2030

Table 8: R&I journey from Research via Demonstration towards Deployment to achieve FUNCTIONALITIES F1, F2 and F3 (Research (red); Demonstration (orange)

Note: Circle area size corresponding to number of tasks contributing to the functionality by the relevant IP-Period; Darker background indicate higher expected budgets.

R&I-Journeys from Research via Demonstration towards Deployment			2021-2024	2023-2026	2025-2028	2027-2030	2021-2024	2023-2026	2025-2028	2027-2030	2021-2024	2023-2026	2025-2028	2027-2030
THE ETIP SNET BUILDING BLOCKS ==>			The efficient organisation of energy systems											
THE ETIP FUNCTIONALITIES ==>														
Research Areas (RA)	RSA No.	Short RSA	F1 Cooperation between system operators				F2 Cross-sector integration				F3 Integrating the subsidiarity principle - The customer at the center, at the heart of the integrated energy system			
1. CONSUMER, PROSUMER and CITIZEN ENERGY COMMUNITY	1.1.	Social issues												
	1.2.	Community												
	1.3.	User Devices												
2. SYSTEM ECONOMICS	2.1.	Business												
	2.2.	Market												
3. DIGITALISATION	3.1.	Standards												
	3.2.	Communication												
	3.3.	Data & Info												
	3.4.	Cybersecurity												
	3.5.	Software Architecture												

R&I-Journeys from Research via Demonstration towards Deployment			2021-2024	2023-2026	2025-2028	2027-2030	2021-2024	2023-2026	2025-2028	2027-2030	2021-2024	2023-2026	2025-2028	2027-2030
THE ETIP SNET BUILDING BLOCKS ==>			The efficient organisation of energy systems											
THE ETIP FUNCTIONALITIES ==>														
Research Areas (RA)	RSA No.	Short RSA	F1 Cooperation between system operators				F2 Cross-sector integration				F3 Integrating the subsidiarity principle - The customer at the center, at the heart of the integrated energy system			
4. PLANNING - HOLISTIC ARCHITECTURES and ASSETS	4.1.	Energy System Architecture												
	4.2.	Planning												
	4.3.	Assets												
	4.4.	Stability												
5. FLEXIBILITY ENABLERS and SYSTEM FLEXIBILITY	5.1.	Demand												
	5.2.	Generation												
	5.3.	Storage & Conversion												
	5.4.	Network												
	5.5.	Transport												
6. SYSTEM OPERATION	6.1.	System State												
	6.2.	Short-term control												
	6.3.	Longer-term control												
	6.4.	Preventive control												
	6.5.	Control center												
			315M€				282M€				154M€			
			752M€											

Markets as key enablers of the energy transition

F4 – Pan-European wholesale markets

WHY F4[44]?

The new legislation asks for enhanced roles of DSOs, particularly in procurement of ancillary services, flexibility, data management and integration of electric vehicles. Markets must encourage development of more flexible generation and demand and Member States must eliminate obstacles to market-based pricing. Bidding zones must be reviewed by TSOs and possible alternative concepts must be proposed. DSOs must adapt network access and congestion tariffs and charges. Member States must remove regulatory distortions, enable scarcity pricing, interconnection, DSR and storage before Capacity Remuneration Mechanisms (CRM) can be introduced. Capacity must be procured separately from balancing energy by TSOs and may be facilitated on a regional basis.

WHAT FUNCTIONALITIES F4 can be expected by the year 2030 in the transition towards 2050?

In 2050, the transaction volumes on European energy and flexibility markets are much larger than today. In 2030, in terms of deployment, the Net Transfer Capacity (NTC) at EU level shall be such that >15% of national electricity demand can potentially be imported or exported. This enables higher transaction volumes on the flexibility and the energy market. Moreover, in average, the existing interconnectors should be used efficiently; for alternating current (AC) interconnectors the net transfer capacity should be indicatively doubled[45] compared to today. The public involvement in the relevant infrastructure projects should be made easy and effective. The currently applied methodological approach of measuring interconnectivity is adapted by 2030, depending on technology development[46].

In 2050, short-term (seconds-minutes-hours) electricity imbalances are handled by highly efficient, electricity market-based operations. By 2030, to accommodate the power generation from most variable renewable energy sources (vRES), energy markets will have to evolve towards dynamic market intervals (possibly down to 5-minute for wholesale markets and – probably later than 2030 – even lower-time intervals such as 15 seconds intra-day products eg. coming from battery storage), providing adequate rules allowing for this, at the same time guaranteeing that grid-flow and systems constraints are not violated. The goal being to enable to better reward flexibility from generation, demand or storage.

In 2050, today's marginal, variable energy cost electricity markets have evolved with new markets and services able to incentivise market-driven investments into a 100%-renewable energy mix with very low marginal energy generation costs. By 2030, market mechanisms provide liquidity and flexibility necessary on the power market, and those market-based instruments, such as auctioning, bring down costs for renewables generation significantly. Already in 2019 in Portugal there was an auction for 1400 MW, and the lowest price attained was 14,8 €/MWh, with most investors offering less than 20 €/MWh, while the reference price was defined as 45 €/MWh. This transition to 2050 will happen in a gradual way: by 2030, all long-term investments for renewables shall be market/auction based in contrast to subsidisation today; in 2030, these competitive investment costs for PV-renewables can be offset by smart balancing operation of these renewables within energy communities and as a consequence reduced electricity grid capacity needs and

44 Sample from the following legislations : Renewable Energy Directive -EU- 2018/2001, Governance of the Energy Union and Climate Action Regulation -EU- 2018/1999, Electricity Regulation -EU- 2019/943, Electricity Directive -EU- 2019/944, Regulation on the European Union Agency for the Cooperation of Energy Regulators -EU- 2019/942

45 Towards a sustainable and integrated Europe - Report of the Commission Expert Group on electricity interconnection targets, November 2017

46 From "Towards a sustainable and integrated Europe - Report of the Commission Expert Group on electricity interconnection targets - November 2017" (pages 6, 7)

grid use costs. As example, a study[47] demonstrates that alternative system flexibility solutions for meeting the UK 2030 carbon intensity target (100gCO2/kWh) can save up to £4.7 bn/year. The savings are obtained from the reduction in system capacity requirement (low-carbon generation, conventional generation, transmission, interconnection, distribution assets) and lower operating cost (due to energy curtailment avoidance, CO2 cost savings, and reduced fuel usage).

In 2050, carbon-neutral energy systems supported by electricity and gas transmission networks are the main way to connect Europe's renewable energy generation at all sizes with large-scale consumption centres (industries and cities) that are often located far from RES generation sites. This transition to 2050 will be based on the development by 2030 of flow-based market coupling demonstrations and the settlement of new modelling approaches and simulation tools, at different geographical coverages. In 2030, in terms of regional deployment, Carbon-neutral gas production (and storage) is already commercial locally (bio-methane) and can be consumed locally or transported via gas grids. By 2030, these technologies have been brought upfront by adjusting gas distribution for integration of different types of gas (converted gas, renewable gas, low carbon gas) with the aid of gas smart metering. This has opened doors for more interoperable functions between the gas and electricity grid. Increasing yet still small quantities of hydrogen will -up to 2030- be transported through existing gas grids blended with methane. This hydrogen will mainly be used to replace existing grey (fossil) hydrogen demand in industry[48] while its potential as fuel in power generation will be demonstrated.

In 2050, the single pan-European wholesale electricity and gas markets are fully implemented to address dynamic market-time intervals, dynamic price zones and grid-constraints. In this aim, by 2030, flow-based market-coupling approaches shall be extended geographically and temporally to cover all European countries.

In 2050, flexible energy storage, power conversion and demand flexibility play a key role as products and services in energy markets. In 2030, flexible demand will be supported by controllable PtX (X of PtX being: water in hydro storage, gas in storage reservoirs; heat in thermal storage; to a much smaller part chemistry in batteries) and XtP (X of XtP being in 2030: discharging of hydro storage; of energy from and to battery storage; efficient use of fossil natural gas, still strongly used in 2030). PtG will only be used marginally in 2030 but must be ready to be deployed by 2040 and later.

F5 – Integrating local markets (enabling citizen involvement)

WHY F5[49]?

Final customers and small enterprises must be enabled to buy electricity generation from aggregated, multiple power-generating facilities or load from multiple demand response facilities to provide joint offers on the electricity market and be jointly operated in the electricity system. Smaller-scale producers must be directly or indirectly responsible for selling on the market the electricity they generate. Citizens must be offered competitive prices, efficient investment signals and higher standards of service so that they can contribute to security of supply and sustainability. Membership of citizen energy communities is open to all categories of entities. A manual of procedures is to be made available to facilitate the understanding of procedures for project developers and citizens wishing to invest in renewable energy.

47 A. Shakoor, G. Davies, G. Strbac, D. Pudjianto, F. Teng, D. Papadaskalopoulos, et al., "Roadmap to Flexibility Services 2030: A report to the Committee on Climate Change May 2017," May 2017.

48 From Gas for Climate "The optimal role for gas in a net-zero emissions energy system", 2019 (pages 89, 91, 172)

49 Sample from the legislation: Renewable Energy Directive -EU- 2018/2001, Governance of the Energy Union and Climate Action Regulation -EU- 2018/1999, Electricity Regulation -EU- 2019/943, Electricity Directive -EU- 2019/944, Regulation on the European Union Agency for the Cooperation of Energy Regulators -EU- 2019/942

WHAT FUNCTIONALITIES F5 can be expected by the year 2030 in the transition towards 2050?

In 2050, local retail markets ensure high-quality, efficient operations with high security of supply. In 2030, Citizen Energy Communities[50] have clear rules about how to integrate them into the system compatible to existing regulation and legislation. Those citizen energy communities will be enabled to actively participate in the provisioning of new energy services to the system operators. By 2030, energy communities contribute with their flexibility to the resolution of congestion management and local balancing issues, with the proper DSO coordination. They support the operation of the electricity system by controlled charging and discharging of batteries and demand response, optionally combined with heating/cooling energy systems, thus allowing their participation to the regional energy market and their contribution by their flexibility to the handling of regional balancing and distribution system constraints[51].

In 2050, consumers and prosumers are enabled to plan, predict and adjust their consumption needs almost in real-time using peer-to-peer energy services. To enable the transition, by 2030, new business models, providing multiple user benefits, will help in reducing energy consumption and related emissions and increasing demand-side flexibility in private households. Citizens – in the role of consumers, prosumers or customers - are engaged and empowered to participate in decision-making, in energy markets and demand response by cybersecure automation and ICT systems. They share related data with DSOs, and thus share benefits of lower system costs. In 2030, smarter grids play a key role to coordinating system operation with market activities, creating a cost-effective environment to enable customer active participation. In 2030, innovation, piloting and demonstration, supported and monitored by regulation, has been shown to be fundamental to anticipate needs which are consistent with EU market design principles in a fast-evolving context. In 2030, consumers are enabled to participate in open, transparent energy markets through aggregators using data platforms or peer-to-peer technologies offering Demand Response (DR) directly or through aggregators. They can generate, store, share, consume or resell energy to the markets.

In terms of Data analytics as a service (DAaaS), Non-Intrusive Load Monitoring (NILM) systems are implemented by 2030. From the aggregate energy consumption data obtained by smart meters, the existence and the energy consumption allocated to the main residential appliances or energy services are identified (pattern recognition, clustering, time series, multivariate modelling, machine learning among others). Complementary to this approach, by 2030, the bottom-up aggregation of forecasts provided by these individual devices themselves is enabled by e.g. connected Active Buildings. This will foster a better segmentation of the prosumers and improve load forecasting for optimized intra-daily energy market usage. As example, some authors[52] claim that using smart meter data and clustering techniques achieved a reduction of the average absolute error of intra-day load forecasting by 0.5% to 1.07 %.

Care should be taken however, since the load accuracy depends on the size of the region and also on time. It should be noted that the accuracy of peak load forecasting is much more valuable for the intra-day market from both the TSO (adequacy) and from the market participants (effect on prices) points of view.

In 2050, data on customer's past, actual and predicted behaviour (for example with people commuting or for energy in relation to weather conditions) enables model-based forecasting and the real-time optimisation of the energy systems' operations at all levels. In this aim in 2030, local and regional demonstrations of Active Demand Response are implemented. In terms of digitalisation, the user is put at the center:

- Energy related services can be accessed by a user at any time and any place using device-independent web-based user interfaces. Sensors are picking up data in users living environments. The interaction is two-sided since processed information also comes to users in a digital way by the same screens.
- Implementation of digitalisation requires already by 2030 a strong user-centric focus, with a sound business model which underpins customer engagement.
- In 2030, social media through mobile apps and data analytics can greatly[52] help in pinpointing crucial factors and barriers in specific user experience.
- In 2030, the consumer will be guaranteed full data privacy[53] and Cybersecurity.

50 Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market in electricity (recast). https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019L0944&from=EN

51 Towards a sustainable and integrated Europe - Report of the Commission Expert Group on electricity interconnection targets, November 2017

52 Franklin L. Quilumba, Wei-Jen Lee, Heng Huang, David Y. Wang, Robert L. Szabados, "Using Smart Meter Data to Improve the Accuracy of Intraday Load Forecasting Considering Customer Behavior Similarities", IEEE TRANSACTIONS ON SMART GRID, VOL. 6, NO. 2, MARCH 2015.

The following table 9 displays the number of **Research** and **Demonstration** tasks needed for the FUNCTIONALITIES F4 and F5 per research sub area (RSA) in the time periods 2021-2024, 2023-2026, 2025-2028 and 2027-2030. The effort needed is materialised by **red-colored circles** and **orange-colored circles**. **Demonstration** may also imply supporting Research.

The main outputs of the table 9 are highlighted below:

- Within RA 1, the FUNCTIONALITY F5 is the one needing the most demonstration activities for the three first time periods for RSA 1.1 (Social issues), when both F4 and F5 will need demonstrations activities for RSA 1.2 (Community). No effort was identified for F4 regarding RSA 1.1 (Social issues) and for RSA 1.3 (User devices).
- Within RA 2 a strong effort in terms of research and demonstration is expected for the first time periods for FUNCTIONALITIES F4 and F5 specifically for RSA 2.2 (Market).
- Within RA 3, mainly FUNCTIONALITY F5 needs research and demonstration activities, for all the RSA (Respectively Standards, Communication, Data &Info, Cybersecurity and Software Architecture). No effort was identified for F4 for RSA 3.2 (Communication), RSA 3.3 (Data & info), RSA 3.4 (Cybersecurity) and RSA 3.5 (Software architecture).
- Within RA 4, F5 is the FUNCTIONALITY expected to need most demonstration activities for RSA 4.1 (Energy System Architecture). No effort was identified for F4 regarding RSA 4.4 (Stability)
- Within RA 5, demonstrations activities will be needed for FUNCTIONALITY F5, mainly for RSA 5.3 (Storage and conversion). No effort is expected for both F4 and F5 regarding RSA 5.2 (Generation) neither for F4 regarding RSA 5.3 (Storage and Conversion) and 5.5 (Transport).
- Regarding RA 6, activities in terms of demonstrations are mainly expected for FUNCTIOINALITY F5, and within RSA 6.5 (Control center). No efforts are expected for F4 regarding RSA 6.2 (Short term control) and RSA 6.5 (Control center).

To summarize, **for F4 and F5**, most efforts needed in terms of research and demonstration are expected for RSA 2.1 (Business) and RSA 2.2 (Market) .

The budget for F4 (122 M€) is smaller than the one for F5 (352 M€).

53 Just awareness, heads ups and visbility regarding consumers' consumption can have an immediate 10% effect. Getting into comparing customers Peer-to-Peer, sharing best practices and benchmarking combined with smart services (like flexibility) easily accessible through social channel communication with the customers (Web, Mobile, etc) can provide up to 40% benefits compared to Business As Usual.

54 User friendly, one-stop-shop democratised access to energy and energy services in terms of 1) visualisation of all existing European energy supply offers and services, 2) requesting a new supplier or a new service provider and 3) activating and releasing the service immediately; R&I Digital Platform development must solve this challenge.

Table 9: R&I journey from Research via Demonstration towards Deployment to achieve FUNCTIONALITIES F4 and F5 (Research (red); Demonstration (orange)

Note: Circle area size corresponding to number of tasks contributing to the functionality by the relevant IP-Period; Darker background indicate higher expected budgets

R&I-Journeys from Research via Demonstration towards Deployment to achieve the FUNCTIONALITIES			2021-2024	2023-2026	2025-2028	2027-2030	2021-2024	2023-2026	2025-2028	2027-2030
THE ETIP SNET BUILDING BLOCKS ==>			Markets as key enablers of the energy transition							
THE ETIP FUNCTIONALITIES ==>										
Research Areas (RA)	RSA No.	Short RSA	F4 Pan-European wholesale markets				F5 Integrating local markets (enabling citizen involvement)			
1. CONSUMER, PROSUMER and CITIZEN ENERGY COMMUNITY	1.1.	Social issues								
	1.2.	Community								
	1.3.	User Devices								
2. SYSTEM ECONOMICS	2.1.	Business								
	2.2.	Market								
3. DIGITALISATION	3.1.	Standards								
	3.2.	Communication								
	3.3.	Data & Info								
	3.4.	Cybersecurity								
	3.5.	Software Architecture								

R&I-Journeys from Research via Demonstration towards Deployment to achieve the FUNCTIONALITIES			2021-2024	2023-2026	2025-2028	2027-2030	2021-2024	2023-2026	2025-2028	2027-2030
THE ETIP SNET BUILDING BLOCKS ==>			Markets as key enablers of the energy transition							
THE ETIP FUNCTIONALITIES ==>										
Research Areas (RA)	RSA No.	Short RSA	F4 Pan-European wholesale markets				F5 Integrating local markets (enabling citizen involvement)			
4. PLANNING - HOLISTIC ARCHITECTURES and ASSETS	4.1.	Energy System Architecture								
	4.2.	Planning								
	4.3.	Assets								
	4.4.	Stability								
5. FLEXIBILITY ENABLERS and SYSTEM FLEXIBILITY	5.1.	Demand								
	5.2.	Generation								
	5.3.	Storage & Conversion								
	5.4.	Network								
	5.5.	Transport								
6. SYSTEM OPERATION	6.1.	System State								
	6.2.	Short-term control								
	6.3.	Longer-term control								
	6.4.	Preventive control								
	6.5.	Control center								
			122M€				352M€			
			474M€							

Digitalisation enables new services for Integrated Energy Systems

F6 – Integrating digitalisation services (including data privacy, cybersecurity)

WHY F6[55]?

The future electricity system should make use of all available sources of flexibility, particularly demand side solutions and energy storage. The key is digitalisation through the integration of innovative technologies with the electricity system by interoperable, standardised data architectures and related communication; and with the electricity system and smart-ready buildings and electric vehicles. The ENTSO for Electricity (ENTSO-E) and the EU DSO entity must respectively promote and contribute to the digitalisation of the systems.

Data Privacy: The recent clean energy legislation requires that the smart metering systems must accurately measure actual electricity consumption and must be capable of providing to final customers information on actual time of use. For this, the privacy of final customers and the protection of their data must comply with relevant Union data protection and privacy rules. The smart readiness indicator for buildings shall be built on initiatives at national level, while considering the principle of occupant ownership, data protection, privacy and security.

Cyber Security: The recent clean energy legislation requires that Member States must ensure the highest level of cybersecurity and data protection as well as the impartiality of the entities which process data. Cyber-incidents must be identified as a risk, and measures must be taken to address them in risk-preparedness plans. System operators are respectively responsible (TSO) and supporting (EU DSO) data management, cyber security and data protection. The Commission is empowered to adopt network codes related to sector-specific rules for cyber security aspects of cross-border electricity flows. The Smart Readiness indicator of buildings considers the principle of occupant ownership, data protection, privacy and security.

WHAT FUNCTIONALITIES F6 can be expected by the year 2030 in the transition towards 2050?

In 2050, digitalisation provides better, user-friendly services (data collection, elaboration and sharing of energy services and offers) to all kinds of customers for planning, maintenance and operational issues, fostering the acquisition of data (observability), its transmission (connectivity), the extraction of information and the transformation into knowledge (analytics). In terms of deployment in 2030: user-friendly services and products will be offered for the user or community-based energy system.

In 2050, digitalisation facilitates services and the full integration of all kinds of energy systems.

- Several million households actively participate in real-time, automated demand response (electricity, heating and cooling) with connected appliances and equipment, in addition to the existing and emerging solutions for industry and commerce. To enable a smooth transition, in 2030, regional demonstrations are implemented: energy communities with a high share of community-RES actively participate in mandatory user-parametrized, real-time, automated demand response (electricity, heating and cooling) with connected appliances and equipment, in addition to the existing and emerging solutions for industry and commercial sector.

- Aggregation of smart charging technologies for electric vehicles, stationary batteries, heat pumps and power-to-gas, power-to-fuels and/or power-to-chemicals provides controllable electricity loads. The potential and needs of flexibility have been assessed for 3 different scenarios (2030 – 2050) and a large number of technologies, and for different kind of flexibility (hour, week, season).[56] As example, up to 108 GW of electricity storage (batteries and pumped hydro storage) would be necessary for the EU-28 (97 GW for EU-27), with a large development of stationary batteries. In 2030, regional demonstrations are set: easy, reliable, interoperable and scalable solution examples for the cyber-secure and privacy-guaranteeing aggregation of any measured electricity quantity (beyond energy) need to be implemented.

- Decentralised control techniques and peer-to-peer electricity trade permeates local energy communities and their interconnection to the electricity system. In 2030, regional demonstrations for peer-to-peer energy (service) trade are implemented including selected test communities across Europe with a high share of community-RES.

- Shared platforms facilitate data exchange and decision-making in all parts of the integrated energy systems, thus enabling advanced planning, operation, protection, control and automation of the energy systems. As example in the project Flexiciency a Cloud shared platform is developed between the “publishers” who are Grid System Operators and the “subscribers” who are the ESCOs, Retailers and aggregators. In 2030, regional demonstrations are implemented. Shared platforms must be realised:

    - for all interested users in newly formed energy communities with a high share of RES or flexible demand,
    - for the most sensitive electricity system related integration needs (for data and for decision making) such as:
        - smart metering active and reactive power, voltage magnitude, network topology and model parameters, device power, thermal and other limits,
        - sub-system reliability and resilience parameters,
        - user decision-related parameters (service options and energy prices) and bidding possibilities.

- Digitalisation supports optimised and interconnected services, providing real-time information – if needed - to operators and aggregators as well as to users connected to any energy network thereby enhancing system balancing and resilience at all time scales from seconds to weeks and in the case of any unforeseen, sudden contingencies. In 2030 digitalisation for electricity needs must be available to system operators and all those communities with a high share of RES. Digitalisation for the integration of the other energy carriers is advanced only in those regions and (large-scale) demonstration sites where gas, heating & cooling needs are satisfied by nearly carbon neutral gases and liquids.

In 2050, rights for privacy are fully guaranteed to all stakeholders including for data ownership, especially information from smart meters about consumer (and prosumer) energy and service use. In 2030 Privacy rights are digital technology agnostic, but technology can help supporting privacy systematic check solutions. Moreover, in 2030, solutions shall be available to prevent the need for sensitive data to leave the customer premises by taking local decisions or processes and inherently offer such privacy by design.

In 2050, energy systems are not vulnerable to cyberattacks even under strong growth of IoT and rapid changes in digital technologies and decentralisation. In 2030, clear and adequate EU-wide cyber security policies and standards need to be well established and applied as a universal practice. Guidelines and European certification schemes must ensure a minimum level of security requirements for devices and systems. Cyber hygiene and security by design should be applied starting now, in view to reach a large proportion of communities with their individual consumers and prosumers across Europe with a high share of RES. Moreover, by 2030, Cybersecurity integration must be realised for the different domains (energy grids, components and systems, DER, prosumers, aggregation, retailing, etc.) and layers (infrastructure, information, FUNCTIONALITIES, services and business).

55 Sample from legislation: Electricity Regulation -EU- 2019/943

56 « Study on energy storage – Contribution to the security of the electricity supply in Europe » that has been done for the EC and published in march 2020. (EUROPEAN COMMISSION - Directorate-General for Energy - Directorate B — Internal Energy Market - Unit B4 — Security of Supply - Contact : Yolanda Garcia Mezquita).

The following table 10 displays the number of **Research** and **Demonstration** tasks and expected budgets needed for the FUNCTIONALITY F6 per research sub area (RSA) in the time periods 2021-2024, 2023-2026, 2025-2028 and 2027-2030. The effort needed is materialised by **red-colored circles** and **orange-colored circles**. **Demonstration** may also imply supporting Research.

The main outputs of the table 10 are highlighted below:

- For FUNCTIONALITY F6, most of the effort is expected in terms of research and demonstrations for:
  - RSA 3.1 (Standards)
  - RSA 3.3 (Data & info);
  - RSA 4.3 (Assets).
- No effort is expected for F6 regarding RSA 5.5 (Transport) and RSA 6.2 (Short-term control) and RSA 6.3 (Longer-term control) for the last periods.

To summarize, **for F6**, the highest effort is expected for RSA 3.3 (Data & Info) within the total budget of 457 M€.

Table 10: R&I journey from Research via Demonstration towards Deployment to achieve FUNCTIONALITIES F6 (Research (red); Demonstration (orange)

Note: Circle area size corresponding to number of tasks contributing to the functionality by the relevant IP-Period; Darker background indicate higher expected budgets

R&I-Journeys from Research via Demonstration towards Deployment to achieve the FUNCTIONALITIES			2021-2024	2023-2026	2025-2028	2027-2030
THE ETIP SNET BUILDING BLOCKS ==>			Digitalisation enables new services for Integrated Energy Systems			
THE ETIP FUNCTIONALITIES ==>			0101 1001 0110			
Research Areas (RA)	RSA No.	Short RSA	F6 Integrating digitalisation services (including data privacy, cybersecurity)			
1. CONSUMER, PROSUMER and CITIZEN ENERGY COMMUNITY	1.1.	Social issues				
	1.2.	Community				
	1.3.	User Devices				
2. SYSTEM ECONOMICS	2.1.	Business				
	2.2.	Market				
3. DIGITALISATION	3.1.	Standards				
	3.2.	Communication				
	3.3.	Data & Info				
	3.4.	Cybersecurity				
	3.5.	Software Architecture				

R&I-Journeys from Research via Demonstration towards Deployment to achieve the FUNCTIONALITIES			2021-2024	2023-2026	2025-2028	2027-2030
THE ETIP SNET BUILDING BLOCKS ==>			Digitalisation enables new services for Integrated Energy Systems			
THE ETIP FUNCTIONALITIES ==>			0101 1001 0110			
Research Areas (RA)	RSA No.	Short RSA	F6 Integrating digitalisation services (including data privacy, cybersecurity)			
4. PLANNING - HOLISTIC ARCHITECTURES and ASSETS	4.1.	Energy System Architecture				
	4.2.	Planning				
	4.3.	Assets				
	4.4.	Stability				
5. FLEXIBILITY ENABLERS and SYSTEM FLEXIBILITY	5.1.	Demand				
	5.2.	Generation				
	5.3.	Storage & Conversion				
	5.4.	Network				
	5.5.	Transport				
6. SYSTEM OPERATION	6.1.	System State				
	6.2.	Short-term control				
	6.3.	Longer-term control				
	6.4.	Preventive control				
	6.5.	Control center				
			457M€			
			457M€			

Infrastructure for integrated energy systems as key enablers of the energy transition

F7 – Upgraded electricity networks, integrated components and systems

WHY F7?

The growing electrification and the more decentralized deployment of renewable power generation will require reinforced and smarter electricity networks, able to accommodate both centralized and decentralized elements and to make the best of RES allocation over the European[57] territory[58]. Pervasive network digitalisation, supported by high-capacity cyber-secure communication networks, will ensure decentralized monitoring and control. Not only density of the network, but also interconnection capacities –with harmonized 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.

WHAT FUNCTIONALITIES F7 can be expected by the year 2030 in the transition towards 2050?

In 2050, electricity networks operate with very high penetration of power electronics and the associated monitoring and control equipment. In 2030, the penetration of power electronics is proportional to the amount of RES, relative to electricity demand and the capacity of batteries necessary to balance the variable and seasonal infeed of renewable energy.

In 2050, large quantities of electricity are produced from renewable energy sources flows across Europe using HVAC grids, HVDC grids (including off shore grids) and hybrid AC/DC grids. In 2030, in terms of deployment, the Net Transfer Capacity (NTC) at EU level shall be such that > 15% of national electricity demand can potentially be imported or exported. In 2030, High Voltage Direct Current (HVDC) technology which enables the transport of electricity over longer distances and makes HVDC-line flows controllable, will play an increasing role in the connection of offshore wind farms and help establishing a pan-European electricity super-grid. By 2030, HVDC admission procedures and opposition issues by the public must have been resolved by explaining the advantages of use of HVDC and thus enabling massive, remote wind-based renewables infeed. By 2030, all means must be available in terms of HVAC-HVDC network integration to guarantee a continued secure, reliable, resilient and market-compatible network operation.

In 2050, the electricity system can handle reduced inertia by adapted monitoring and control equipment and new protection solutions with associated cyber-secure, fast data communication. By 2030, due to the still relatively small contribution of RES and the still high contribution by rotating thermal and hydro generation, the effects of reduced inertia are not yet strongly visible on the interconnected Pan-European electricity system. However, by 2030, all necessary adaptations to the control and protection equipment must have been designed so that they can provide synthetic inertia and can sense faults in the real-world implementation towards 2040 and later to have continued secure, reliable and fully resilient electricity system operation with a strong increase of non-rotating renewable energy infeed.

In 2050, a full system monitoring and control approach ensures system support as well as optimisation of grid costs. By 2030, 80% of the high voltage and medium voltage substations and 25% of low voltage substations will be monitored (including state estimation). Such supporting systems must be implemented at those electric distribution system nodes and sites with high security, reliability and resilience sensitivities and where critical network-based system state quantities (voltage, flows) are near their limits. Methodologies must be in place how to scale up monitoring towards higher deployment of RES by 2040 and later. By 2030, all new equipment connected to the electricity grid after 2020 will be controllable and contribute to flexibility.

57 Communication on strengthening Europe's energy networks. COM(2017) 718.
58 In-depth analysis in support of the Commission Communication. COM (2018) 773

Further developments regarding emerging AC/DC and DC only microgrids, as well as DC-coupling between these microgrids and main grid can play an important role for increasing energy resilience and efficiency, reduce impacts on transmission grids by RES integrated in such microgrids (more predictability to main grid, less required flexibility, less inertia depreciation, etc.). Such grids shall be integrated with the urban e-mobility grids and e-charging station solutions.

In 2050, thermal power generation is mainly running with renewable energy sources. To operate smoothly the transition from fossil to renewable sources and to maintain enough flexibility in the electricity system, by 2030:

- RES, storage and synchronous power generation systems provide balancing based on services based on enhanced ancillary services, are well dispatchable, contribute to network stability, promote smart connection to the grid and a significant improvement of forecasting quality compared to today;
- decentralised control schemes are implemented on distributed generation, manageable loads and storage;
- control schemes are set for bi-directional power flows;
- the flexible thermal plants, achieved by technology upgrade or integrating other flexiblity options, provide doubling the present average ramping rates, 50% less losses for part-load operations and reduce minimum technical load by 30% compared to today;
- AC, hybrid AC/DC and a majority of DC microgrids are connected to AC transmission grids, for serving prosumers, local energy communities, synergies between main grid and urban e-mobility grids.

F8 – Energy System Business (includes models, regulatory)

WHY F8?

F8 is a direct consequence of the FUNCTIONALITY "F7 Upgraded electricity networks, integrated components and systems" which requires new forms of business models, of regulatory rules.

WHAT FUNCTIONALITIES F8 can be expected by the year 2030 in the transition towards 2050?

The FUNCTIONALITIES for F8 are strongly related to the expected FUNCTIONALITIES F7. These FUNCTIONALITIES for F8, however, do often not follow the R&I-Journeys. Business models are constantly to be adapted in real-world business. Related tasks are classified as "Research" indicating the permanent need to find the best solutions. F8 includes: Business models, market design, regulatory rules, market governance, business models adapted to energy and computer- ICT- and monitoring and control system architectures, managing grid-connected flexibilities and their optimal aggregation.

F9 – Simulation tools for electricity and energy systems (Software)

WHY F9?

F9 is (besides F8) a direct consequence of the FUNCTIONALITY "F7 Upgraded electricity networks, integrated components and systems" which requires new simulation tools and simulation results of electricity but also energy system beyond electricity.

WHAT FUNCTIONALITIES F9 can be expected by the year 2030 in the transition towards 2050?

The FUNCTIONALITIES for F9 are strongly related to the expected FUNCTIONALITIES F7. These FUNCTIONALITIES for F9 – like for F8 – do not necessarily follow the R&I-Journeys principle: Simulation-related tasks are classified as Research only with input from real-world use cases. F9 includes: Short-term market-related simulations including for handling security issues of all kinds, long- and medium-term integrated energy-system (heating and cooling, gas) and electricity system planning related models and simulations, electricity system congestion and stability-handling tools for all time intervals from seconds to hours; electricity system analysis, observation and optimisation tools and software; system-control-related model-predictive simulations and optimisations of the electricity system and life-cycle related ageing simulations.

The following table 11 displays the **Research** and **Demonstration** tasks needed for the FUNCTIONALITIES F7, F8 and F9 per research sub area (RSA) in the time periods 2021-2024, 2023-2026, 2025-2028 and 2027-2030. The effort needed is materialised by **red-colored circles** and **orange-colored circles**. **Demonstration** may also imply supporting Research.

The main outputs of the next table are highlighted below:

- Within RA 1, efforts in terms of research and demonstration are expected for FUNCTIONALITIES F7 and F8 mainly for RSA 1.1 (Social issues) and RSA 1.2 (Community). No effort is expected for F7, F8 and F9 regarding the RSA 1.3 (User devices). No effort is needed at all from FUNCTIONALITY F9 regarding the RA 1.
- Regarding RA 2, FUNCTIONALITY F8 is the one requiring the most efforts in terms of research and demonstrations for the RSA 2.2 (Market).
- Focusing on RA 3, FUNCTIONALITY F7 is the most requiring demonstration and research activities compared with F8 and F9 and mainly for RSA 3.1 (Standards) and RSA 3.2 (Communication). FUNCTIONALITY F8 requires the highest budget for all time periods for RSA 3.3 (Data & Info). No effort is expected for F9 on RSA 3.3 (Data & Info).
- Looking at RA 4, FUNCTIONALITIES F7 and F9 need the most efforts in terms of demonstration and research for all RSAs for the 2 first time periods (respectively Energy System Architecture, Planning, Assets and Stability).
- For RA 5, the main efforts needed are for FUNCTIONALITY F7, RSA 5.2 (Generation) and 5.4 (Network). No effort is identified for F7 regarding RSA 5.1 (Demand) and for F9 regarding RSA 5.5 (Transport).
- For RA 6, research and demonstrations will be needed mainly for FUNCTIONALITIES F7 and F9 related to RSA 6.4 (preventive control) and RSA 6.5 (Control center). No effort is expected for F8 regarding RSA 6.1 (System State), RSA 6.2 (Short-term control) RSA 6.3 (Longer-term control).

To summarize, **for FUNCTIONALITIES F7, F8 and F9**, tthe main efforts needed in terms of demonstrations and research will be expected for RSA 2.2 (Market) and for RSA 4.1 (Energy System Architecture) and RSA 6.4 (Preventive control). The highest budget will be dedicated to F8 for RSA 3.3 (Data & Info)

For the Period, F7 will need 515 M€, F8 will need 387 M€ and F9 351 M€.

Table 11: R&I journey from Research via Demonstration towards Deployment to achieve FUNCTIONALITIES F7, F8 and F9 (Research (red); Demonstration (orange)

Note: Circle area size corresponding to number of tasks contributing to the functionality by the relevant IP-Period; Darker background indicate higher expected budgets.

R&I-Journeys from Research via Demonstration towards Deployment to achieve the FUNCTIONALITIES			2021-2024	2023-2026	2025-2028	2027-2030	2021-2024	2023-2026	2025-2028	2027-2030	2021-2024	2023-2026	2025-2028	2027-2030
THE ETIP SNET BUILDING BLOCKS ==>			Infrastructure for Integrated Energy Systems as key enablers of the energy transition											
THE ETIP FUNCTIONALITIES ==>														
Research Areas (RA)	RSA No.	Short RSA	F7 Upgraded electricity networks, integrated components and systems				F8 Energy System Business (incl. models, regulatory)				F9 Simulation tools for electricity and energy systems (Software)			
1. CONSUMER, PROSUMER and CITIZEN ENERGY COMMUNITY	1.1.	Social issues												
	1.2.	Community												
	1.3.	User Devices												
2. SYSTEM ECONOMICS	2.1.	Business												
	2.2.	Market												
3. DIGITALISATION	3.1.	Standards												
	3.2.	Communication												
	3.3.	Data & Info												
	3.4.	Cybersecurity												
	3.5.	Software Architecture												

R&I-Journeys from Research via Demonstration towards Deployment to achieve the FUNCTIONALITIES			2021-2024	2023-2026	2025-2028	2027-2030	2021-2024	2023-2026	2025-2028	2027-2030	2021-2024	2023-2026	2025-2028	2027-2030
THE ETIP SNET BUILDING BLOCKS ==>			Infrastructure for Integrated Energy Systems as key enablers of the energy transition											
THE ETIP FUNCTIONALITIES ==>														
Research Areas (RA)	RSA No.	Short RSA	F7 Upgraded electricity networks, integrated components and systems				F8 Energy System Business (incl. models, regulatory)				F9 Simulation tools for electricity and energy systems (Software)			
4. PLANNING - HOLISTIC ARCHITECTURES and ASSETS	4.1.	Energy System Architecture												
	4.2.	Planning												
	4.3.	Assets												
	4.4.	Stability												
5. FLEXIBILITY ENABLERS and SYSTEM FLEXIBILITY	5.1.	Demand												
	5.2.	Generation												
	5.3.	Storage & Conversion												
	5.4.	Network												
	5.5.	Transport												
6. SYSTEM OPERATION	6.1.	System State												
	6.2.	Short-term control												
	6.3.	Longer-term control												
	6.4.	Preventive control												
	6.5.	Control center												
			515M€				387M€				351M€			
			1253M€											

Efficient energy use

F10 – Integrating flexibility in generation, demand, conversion and storage technologies

WHY F10?

The operational efficiency of the future energy system will be influenced by the ability to feed power generated from different sources — with different degrees of inertia and start-up times — into the grids in a reliable way. The future energy system will therefore have to rely on much higher balancing capacities, including: (a) flexible generation units, (b) increased demand response and (c) conversion and storage technologies, together with better interconnections at all grid levels. Increasing system flexibility must be achieved also through policies, measures and regulations compatible with further market integration, increased competition and the achievement of climate and energy objectives.

WHAT FUNCTIONALITIES F10 can be expected by the year 2030 in the transition towards 2050?

In 2050, PtG and PtH conversion allows for the efficient coupling of electricity, gas and heat networks, together with Gas-to-Power-and-Heat (GtP&H[59]) and Gas-to-Heat (GtH) conversion technologies. By 2030, flexibilities combined with high energy efficiency in these conversion devices for electricity-system integration needs must have reached a mature demonstration level for deployment towards 2040 and later. One fundamental requirement for such efficient and flexible coupling, is the capability to modulate the electricity consumption in a sufficiently deterministic and fine-granular manner in response to a flexibility need.

In 2050, coupling heat and electricity production impacts the gas grid. To reach this objective, in 2030 local demonstrations are implemented: Energy communities up with a high share of community-RES (relative to community gross electricity demand) test fully coupled energy systems with a selection of PtH + HtP, PtG + GtP&H,PtL + LtP&H conversion to achieve highest possible autonomy for heat and electricity demand throughout the year. In 2030 hydrogen can be blended with natural gas to make use of the existing gas transport infrastructure up to 15%-20% by volume.

In 2050, coupling electricity and gas networks with electrolyser and methanation units enables long-term (seasonal) storage, and flexibility options for the electricity grids (PtG and GtP&H) and supply for the transport and industry sectors. By 2030, (fossil) natural gas to power (combined with heat) conversion and CCUS (Carbon Capture, Utilization and Storage) technology will still play an important role. However, demonstrations for integrations of conversion of power towards carbon-free or carbon-neutral gases or fuels (hydrogen, synthetic methane or methanol), and the integrated use of these carbon-neutral gases and liquids must be successfully proven by 2030. The goal is to integrate by 2040 and 2050 much larger quantities of carbon-neutral and renewable energy and power to industry, buildings and transport without loss of utility and – through the use of carbon-neutral methane and partial infeed of hydrogen into gas grids - providing longer use of the existing natural gas infrastructure.

59 Cogeneration

F11 – Efficient heating and cooling for buildings and industries in view of system integration of flexibilities

WHY F11?

The recent clean Energy legislation requires that renewable heating and cooling must contribute to the progressive increase of the share of renewable energy. Provisions shall be included, at national, regional and local level, for the integration and deployment of renewable energy, including for renewables self-consumption and renewable energy communities, and the use of unavoidable waste heat and cold when planning, including early spatial planning, designing, building and renovating urban infrastructure, industrial, commercial or residential areas and energy infrastructure, including electricity, district heating and cooling, natural gas and alternative fuel networks.

WHAT FUNCTIONALITIES F11 can be expected by the year 2030 in the transition towards 2050?

In 2050, the heating and cooling of buildings is powered by renewable energy sources. Electricity is the main energy source for new buildings and to a large extent for refurbished buildings. In 2030, electricity generation and cogeneration from any types of primary sources are more efficient than today. In 2030, in terms of deployment, near-zero energy building (NZEB) projects, at least for the new constructions are well implemented. By 2030, flexibility of these NZEB must be proven in pilot and/or local demonstration of real-time flexibility services operation by heating and cooling systems and district distribution.

The Electrical Efficiency and fuel conversion rate of the different types of generation, both for 2020 and 2030, are reminded below:

		2020		2030	
		Efficiency el.	Fuel conversion rate	Efficiency el.	Fuel conversion rate
Gas turbine based:					
	SCP	42%	–	> 43%	–
	CCPP	63%	–	> 65%	–
	CHP	–	85%	–	> 90%
Thermal plants		49%	–	> 52%	–
	(steam cycle) fossil				
	(steam cycle) biomass	49%	–	> 52%	–
	(ORC) waste heat	9-18%	–	11-21%	–
	(ORC) biomass	14-30%	85-90%	18-33%	90%
Reciprocating					
	SCP	49%	–	> 52%	–
	CHP	–	91%	–	up to 95%
CSP		15-30%		20-35%	
Geothermal		12%	–	13%	–
Gas turboexpanders		75%	n/a	75%	n/a
Fuel cells (cover all types)		30-70%		32% - 80%	
PV		17-18%		19-20%	
Wind based		35-45%	–	>45%	–

In 2050, heat in low-carbon district networks, is produced from heat pumps, biomass, biogas or Synthetic Natural Gas (SNG)-powered boilers. By 2030 renewable heating and cooling technologies could supply over half of the heat used in Europe[60]. In most of Europe, biomass is used for various scale heating as well as industrial processes; 2nd and 3rd generation biofuels will also play important role.

In terms of deployment 2030:

- Improved compact and seasonal thermal energy storage systems will be crucial to meeting the heating and cooling requirements in buildings;
- In most of Europe, biomass will be used for small-scale heating as well as industrial processes; 2nd and 3rd generation biofuels will also play an important role;
- Solar thermal will satisfy approx. 15% of the overall European low temperature heat demand and it will be increasingly able to meet the heat demand of medium and higher temperature industrial processes;
- Geothermal heat pumps and geothermal direct use will be firmly established, especially in agricultural applications and for pre-heating industrial processes requiring heat over 250°C.

In terms of Local and/or Regional Demonstration:

- By 2030, in selected regional demonstration projects, a smart energy exchange network will enable the use of flexibility of heat at different temperatures from multiple low-carbon energy sources to be shared efficiently between different customers.

In 2050, waste heat recovery solutions are deployed for most buildings in the commercial and tertiary sectors. In 2030, Regional Demonstrations of large-scale heat recovery systems including their flexibility means for residential and commercial building are implemented.

In 2050, various renewable energy sources, such as bioenergy, solar energy, geothermal energy and power-to-heat conversion are used to produce heat for industrial purposes. Moreover, waste heat recovery solutions are implemented in all industrial sites to improve energy efficiency. In 2030, these technologies are already replicated and implemented, especially in medium- and high-energy intensive industries and in industrial areas/districts. By 2030, demonstrators show their flexibility offered to the electricity system combined with the use of cogeneration that can greatly contribute to higher efficiency levels.

60 From " 2020 – 2030 – 2050. Common Vision for the Renewable Heating & Cooling sector in Europe" ETIP-RHC European Technology Platform on Renewable Heating and Cooling, 2011

F12 – Efficient carbon-neutral liquid fuels & electricity for transport in view of system integration of flexibilities

WHY F12?

The 2011 "White Paper on Transport" and the 2016 EU "Low-emissions mobility strategy" have already shown that an integrated system approach is required to put the transport sector on a sustainable path. Central elements of such approach include action on overall vehicle efficiency, promoting low- and zero emission vehicles and infrastructure, and the long-term switch to low- and zero-carbon electricity and to alternative and net-zero-carbon fuels for transport, together with further encouraging multi-modal integration and shifts towards more sustainable transport modes. Conditions must ensure the effective deployment of publicly accessible and private recharging points for electric vehicles and the efficient integration of vehicle charging into the system.

WHAT FUNCTIONALITIES F12 can be expected by the year 2030 in the transition towards 2050?

In 2050, in addition to improving efficiency of all relevant energy conversion processes, the availability of liquid fuels is part of an overall carbon neutral fuel strategy for all energy producing and consuming sectors, including for mobility and heating. By 2030, demonstrations for the integrated use of these Carbon-neutral liquids must be successfully proven by 2030, in order to provide by 2040 and 2050 much larger quantities of (low cost) Carbon-neutral and renewable energy and power to industry, buildings and transport without loss of utility.

In 2050, the vehicle-based mobility system has shifted strongly towards electricity but continue to rely on liquid carbon-neutral fuels (PtL and biofuels) and gases (synthetic methane and hydrogen), driven by environmental, operational, technological and economic considerations. In 2030, Power-to-Liquid Pilot projects and Local Demonstrations will be implemented and demonstrate the flexibility to be offered to the electricity systems and how to cover the winter electricity demand by much more renewables in 2040 and later.

The following table 12 displays the **Research** and **Demonstration** tasks and budgets needed for the FUNCTIONALITY F10, F11 and F12 per research sub area (RSA) in the time periods 2021-2024, 2023-2026, 2025-2028 and 2027-2030. The effort needed is materialised by **red-colored circles** and **orange-colored circles**. Demonstration may also imply supporting Research.

The main outputs of the table 12 are highlighted below:

- For RA 1, few research and demonstrations activities are expected for FUNCTIONALITIES F10, F11 and F12. Lower efforts are needed regarding RSA 1.3 (User devices).
- For RA 2, the most efforts needed in terms of research, demonstrations and budgets are for FUNCTIONALITY F10, F11 and F12 for RSA 2.2 (Market design).
- Regarding RA 3, most efforts in terms of demonstration and research are expected for FUNCTIONALITY F10, F11 and F12 for RSA 3.1 (Standards). No effort is identified for F11 and F12 for RSA 3.2 (Communication), RSA 3.3 (Data & Info), RSA 3.4 (Cybersecurity) and for the 3 FUNCTIONALITIES F10, F11 and F12 related to RSA 3.5 (Software Architecture).
- For RA 4, the main efforts are expected for FUNCTIONALITIES F10, F11 and F12 related to RSA 4.1 (Energy system Architecture) and 4.2 (Planning).
- Regarding RA 5: F10, F11 and F12 are the FUNCTIONALITIES requiring the most efforts in terms of research and demonstration for RSA 5.2 (Generation) and 5.3 (Storage and conversion). No effort is identified for F11 and F12 regarding RSA 5.4 (Network).
- Finally, for RA 6, main efforts are expected for F10, F11 and F12 for RSA 6.4 (Preventive control) and RSA 6.5 (Control center). Little or no efforts are required for FUNCTIONALITIES F10, F11 and F12 regarding RSA 6.2 (Short-term control).

To summarize, for **FUNCTIONALITIES F10, F11 and F12**, the main efforts needed in terms of demonstrations and research are expected for RSA 2.2 (Market), 4.1 (Energy system Architectures), 5.2 (Generation).

F10 will have the highest expected budget with 525M€, followed by F11 with 301 M€ and F12 with 238 M€.

Table 12: R&I journey from Research via Demonstration towards Deployment to achieve FUNCTIONALITIES F10, F11 and F12 (Research (red); Demonstration (orange)

Note: Circle area size corresponding to number of tasks contributing to the functionality by the relevant IP-Period; Darker background indicate higher expected budgets.

R&I-Journeys from Research via Demonstration towards Deployment to achieve the FUNCTIONALITIES			2021-2024	2023-2026	2025-2028	2027-2030	2021-2024	2023-2026	2025-2028	2027-2030	2021-2024	2023-2026	2025-2028	2027-2030
THE ETIP SNET BUILDING BLOCKS ==>			Efficient energy use											
THE ETIP FUNCTIONALITIES ==>														
Research Areas (RA)	RSA No.	Short RSA	F10 Integrating flexibility in generation, demand, conversion and storage technologies				F11 Efficient heating and cooling for buildings and industries in view of system integration of flexibilities				F12 Efficient carbon-neutral liquid fuels & electricity for transport in view of system integration of flexibilities			
1. CONSUMER, PROSUMER and CITIZEN ENERGY COMMUNITY	1.1.	Social issues												
	1.2.	Community												
	1.3.	User Devices												
2. SYSTEM ECONOMICS	2.1.	Business												
	2.2.	Market												
3. DIGITALISATION	3.1.	Standards												
	3.2.	Communication												
	3.3.	Data & Info												
	3.4.	Cybersecurity												
	3.5.	Software Architecture												

R&I-Journeys from Research via Demonstration towards Deployment to achieve the FUNCTIONALITIES			2021-2024	2023-2026	2025-2028	2027-2030	2021-2024	2023-2026	2025-2028	2027-2030	2021-2024	2023-2026	2025-2028	2027-2030
THE ETIP SNET BUILDING BLOCKS ==>			Efficient energy use											
THE ETIP FUNCTIONALITIES ==>														
Research Areas (RA)	RSA No.	Short RSA	F10 Integrating flexibility in generation, demand, conversion and storage technologies				F11 Efficient heating and cooling for buildings and industries in view of system integration of flexibilities				F12 Efficient carbon-neutral liquid fuels & electricity for transport in view of system integration of flexibilities			
4. PLANNING - HOLISTIC ARCHITECTURES and ASSETS	4.1.	Energy System Architecture												
	4.2.	Planning												
	4.3.	Assets												
	4.4.	Stability												
5. FLEXIBILITY ENABLERS and SYSTEM FLEXIBILITY	5.1.	Demand												
	5.2.	Generation												
	5.3.	Storage & Conversion												
	5.4.	Network												
	5.5.	Transport												
6. SYSTEM OPERATION	6.1.	System State												
	6.2.	Short-term control												
	6.3.	Longer-term control												
	6.4.	Preventive control												
	6.5.	Control center												
			525M€				301M€				238M€			
			1065M€											

IV. Funding needs to support the ETIP SNET R&I Roadmap 2020-2030

Budget Methodology for ETIP SNET R&I Roadmap 2020-2030

Continued strong research and related demonstration and pilot application efforts must be undertaken during the ETIP SNET R&I Roadmap period 2020-2030 on the many interlinked tasks, Research Sub-Areas and Research Areas having in mind the real world deployment of R&I results in order to reach the 2030 objectives and related FUNCTIONALITIES. All details are given in chapter III and the Annexes of this Roadmap.

By 2030, the EU goals as described in Chapter II must be implemented in the energy system world for all kinds of energy carriers with the electricity system as its backbone. For this to happen, to get maximum research knowledge and pilot and demonstration experience is a prerequisite. Integration means implementing integrated sensors, electronics, data handling, data aggregation and fitting, data communication, data security and privacy, data algorithms, user interaction and market processes, by innovative energy (conversion, transmission, distribution, generation, consumption, storage) equipment etc.

In this aim, considering the expected breakthroughs and starting from the total estimated budget of the previous ETIP SNET R&I Roadmap 2017-2026, the following table 13 proposes a budget for realising the proposed tasks for the time period 2020-2030 with Research and Demonstration tasks and related projects. The costs for deployment-related tasks are not considered in the ETIP SNET R&I Roadmap: due to upscaling needs for all from Research and Demonstration, it is expected to be considerably higher than for R&I tasks.

The budgets for each TOPIC were defined by a top-down stakeholder consultation combined with a bottom-up process starting at the task level, aggregating to Research Sub-Areas (RSA) and their Research areas. The table below shows the parameters (TOKENS) of the budget methodology applied to each task of each RSA of the ETIP SNET R&I Roadmap 2020-2030.

In the following, R stands for "Research" and D for "Demonstration". The following bottom-up calculation of each task budget was used.

Budget per task for RM Period 2020-2030 = $\sum_{i=1..4}$ R-Budget$_{IPi}$ + $\sum_{i=1..4}$ D-Budget$_{IPi}$

Where:

- R-Budget$_{IPi}$ = R-Token$_{Task}$ * "the number of involved FUNCTIONALITIES per Task", if task maturity in IP$_i$ is Research
- D-Budget$_{IPi}$ = D-Token$_{Task}$ * "the number of involved FUNCTIONALITIES", if task maturity in IP$_i$ is Demonstration
- IP$_i$: The R&I Implementation period i (i=1, 2, 3, 4 corresponding to 2021-2024, 2023-2026, 2025-2028, 2027-2030)

With:

- R-TOKEN$_{Task}$ = budget for a task and Research-TRL-Maturity (TRL 3-5) with a single FUNCTIONALITY. All tasks of a RSA have the same R-TOKEN.
- D-TOKEN$_{Task}$ = budget for a task and Demonstration-TRL-Maturity (TRL 6-8) with a single FUNCTIONALITY. All tasks of a RSA have the same D-TOKEN.
- Task-maturity: Each task may be elaborated by R&I projects in each of the four Implementation Plan periods (2021-2024, 2023-2026, 2025- 2028 and 2027-2030) during the ETIP SNET R&I Roadmap period 2020-2030. In each of these four periods, a task should reach either Research-TRL-maturity (TRL 3-5) or Demonstration-TRL-Maturity (6-8) or Deployment-TRL-Maturity (TRL 9). This so-called R&I Journey per task can be found in Annex II of this ETIP SNET R&I Roadmap 2020-2030.
- "the number of involved FUNCTIONALITIES per Task": Each task has an implied number of key FUNCTIONALITIES to which it contributes or with which it is involved.

- The methodology assumes a constant DR-Factor for all tasks. The DR-Factor represents the ratio between the budget for a Demonstration-task with one single FUNCTIONALITY and the budget for a Research-only task with one single FUNCTIONALITY.
  - DR-Factor = 1.7 = $\text{D-Token}_{\text{Task}}$ / $\text{R-Token}_{\text{Task}}$
- This budget methodology has been verified and been hardened by a consensual process of the ETIP SNET Stakeholders: They determined the individual budgets for each of the RSA (called TOPIC in the ETIP SNET R&I Implementation Plan 2021-2024) for the time frame 2021-2024 in a consultative process. Using the above parameters (R-TOKENTask and D-TOKENTask per associated RSA, one single DR-Factor), the values for the R-TOKEN and D-TOKEN per TOPIC and the DR-Factor have been determined in such a way that the total methodology-based, computed budgets for the tasks of each RSA of IP 2021-2024 is identical with the one as set by the ETIP SNET stakeholders for the same period. In addition, ETIP SNET Stakeholders estimated and fixed the total expected budget for the RM 2020-2030 to 4000 M€. I.e. the budget methodology reproduces the ETIP SNET stakeholder budgets for each of the defined RSA (TOPICS) for the ETIP SNET R&I Implementation plan 2021- 2024 (total: 955 M€). It also reproduces the total expected budget for the ETIP SNET R&I Roadmap 2020-2030 of 4000 M€.

ETIP SNET is fully aware that this methodology for expected budgets of this ETIP SNET R&I Roadmap 2020-2030 makes several assumptions; it has, however, been hardened by extensive stakeholder and expert consultations. ETIP SNET has formally validated the methodology by expert-based budget judgements for the four-year Implementation Plans (IP) period 2021-2024 and in total for the RM 2020-2030. ETIP SNET intends to adjust budgets and methodologies for the upcoming Implementation Plans beginning in 2023 based on latest learnings from ongoing projects.

Using this methodology, the following table 13 shows that from the total budget of approx. 4000 M€ for the period 2020-2030, a large part (75%) is expected to be spent on Demonstration-tasks and related FUNCTIONALITIES, 25% are expected to be spent on Research tasks and related FUNCTIONALITIES during 2020-2030. The largest budgets are expected for demonstration tasks of RA 3 (Digitalisation) with approx. 21% of total budgets, followed by demonstration tasks of RA 4 (Planning - Holistic Architectures and Assets) with 15% and RA 6 (System Operation) with a budget of 14%, followed by demonstration tasks of RA 5 (Flexibility Enablers and System Flexibility) with a budget of 11% for the whole RM period 2020-2030.

Table 13: ETIP SNET RM 2020-2030 – Expected budgets for Research Areas (RA)

Research area (RA)	Research	Demonstration	M€ per RA	Expected breakthroughs between 2020-2030
1. CONSUMER, PROSUMER and CITIZEN ENERGY COMMUNITY	0%	5%	215M€	Peer to peer trading, bottom-up aggregation, Operational market platforms for flexible generation and load and optimisation of load profiles including EVs, organisational changes (e.g. mutualised energy, peer-to-peer exchanges, new roles for cooperatives), Energy communities.
2. SYSTEM ECONOMICS	3%	8%	430M€	Markets for ancillary services, using flexibility, development of (local) markets combining various energy vectors, demonstrated benefits of flexibilities from demo projects / regions. Shift of CAPEX to OPEX with reduced TOTEX (CAPEX+OPEX), New reimbursement schemes for distributed resources.
3. DIGITALISATION	8%	21%	1161M€	End-to-End architecture, Cybersecurity and Internet of Things (IoT), Peer2Peer (eg. Blockchain) concepts for the secure, interoperable, privacy respecting connection starting from sensors in field devices, data, and services reaching energy communities and prosumers, to allow gradually increasing decentralized multi party control systems.
4. PLANNING – HOLISTIC ARCHITECTURES and ASSETS	4%	15%	765M€	Storage technologies, Integrated Energy System at local level, Large scale deployment of technology for connecting, monitoring and controlling DERs, Integrated smart grid system-of-systems, New topologies and devices to integrate all the energy carriers, resilient use cases, new network planning procedures to include DERs and grid flexibility methodologies, Large scale implementation of DER forecasting, Modernised control centers: Data management, Human Machine Interface, training, modelling, drones, augmented/virtual reality, wearables devices, Web of Cells architectures; Assets: Power electronics, Energy storage technologies; power plants.
5. FLEXIBILITY ENABLERS and SYSTEM FLEXIBILITY	7%	11%	726M€	Flexible resources, energy storage resources including EVs, TSO-DSO-Consumer markets in place, standardisation of the flexibility, Flexibility from variable RES thanks to the hybridization of technologies and better forecasting tools; unlocking of residential DR, Smart charging of EVs and V2G implemented, Flexibilities for islands; Flexibility from thermal power plants based on carbon-free and carbon-neutral fuels, flexibility from integration of renewable and decarbonised gases in the gas network, flexible operation of cogeneration, system flexibility through sector coupling.
6. SYSTEM OPERATION	3%	14%	702M€	Higher level of automation, more complex functionalities, operation tools for integrated systems, resilient use cases, new operational planning procedures, large-scale RES forecasting, modernised control centers, data management, MMI, AI, large AC-DC grids, web-of-cells.
TOTAL	25%	75%	4000M€	

Figure 5: Budget 2020-2030 (in M€) per FUNCTIONALITY

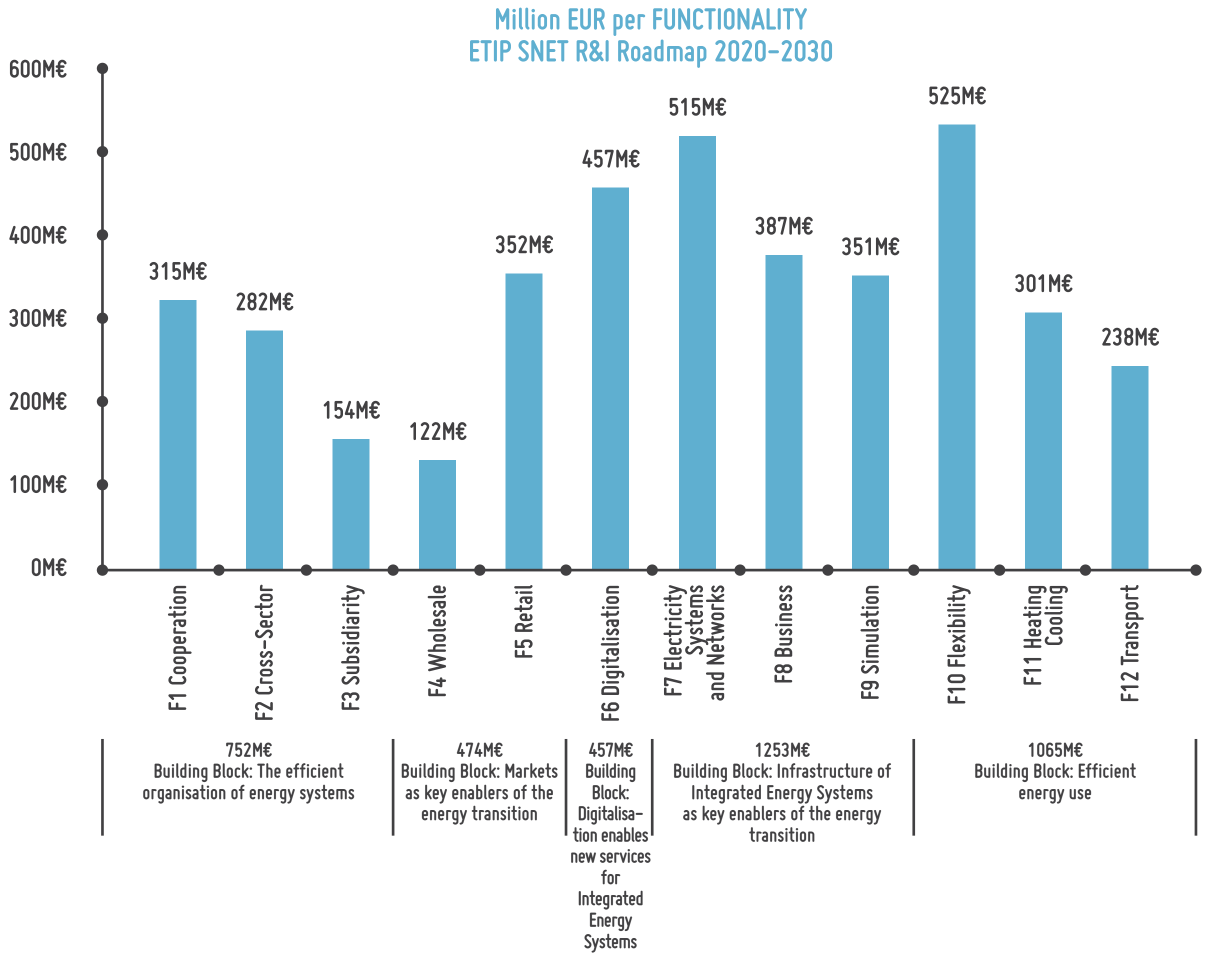


Figure 5 shows the expected total budgets over the whole RM period 2020-2030 for each of the 12 FUNCTIONALITIES and their Building Blocks (bottom part) during 2020-2030 based on the assumed R&I-Journey of tasks.

The highest three FUNCTIONALITY-related expected budgets are:

- F10 (Flexibility) with a 2020-2030 budget of 525 M€,
- F7 (Electricity Systems and Networks) with a 2020-2030 budget of 515 M€, and
- F6 (Digitalisation) with a 2020-2030 budget of 457 M€.

The lowest three FUNCTIONALITY-related expected budgets are:

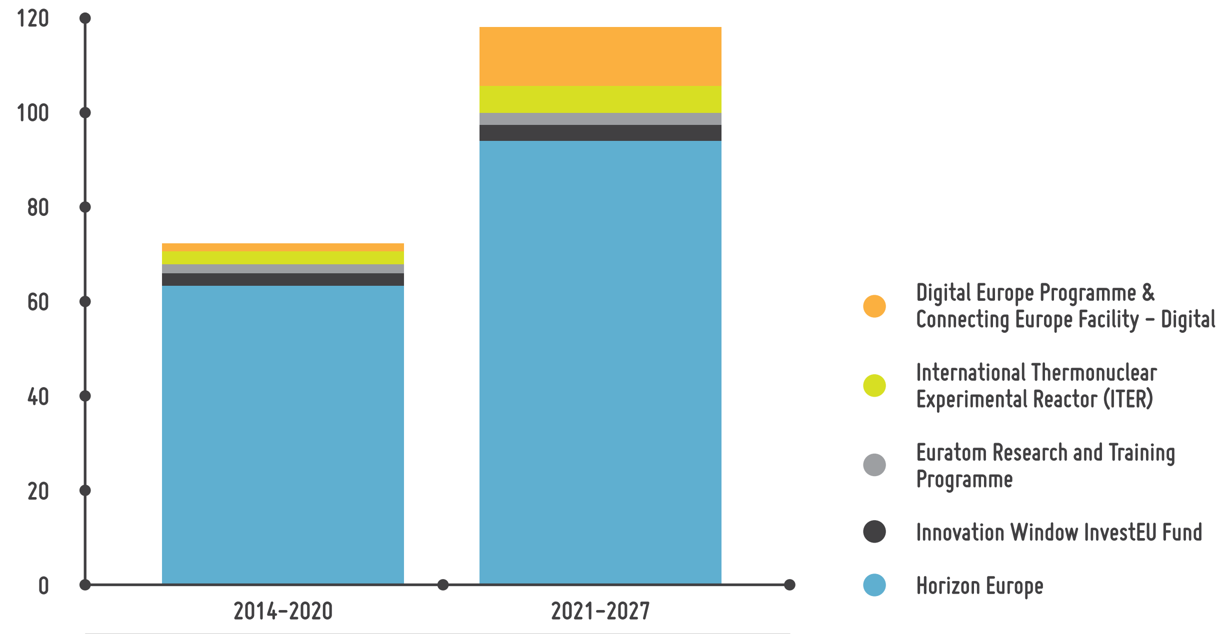
- F4 (Wholesale) with a 2020-2030 budget of approx. 122 M€,
- F3 (Subsidiarity) with a 2020-2030 budget of approx. 154 M€, and
- F12 (Transport) with a 2020-2030 budget of approx. 238 M€.

HORIZON EUROPE Instruments to support the goals of the ETIP SNET R&I ROADMAP 2020-2030

The ETIP SNET R&I Roadmap 2020-2030 will be implemented using various funding instruments (see table 14) and resources depending on the nature of the research, innovation priorities and the specific needs of the technologies. Several mechanisms for supporting investments in the development of the energy roadmap exist at European and national level. These mechanisms can address different project stages and can come from different sources.

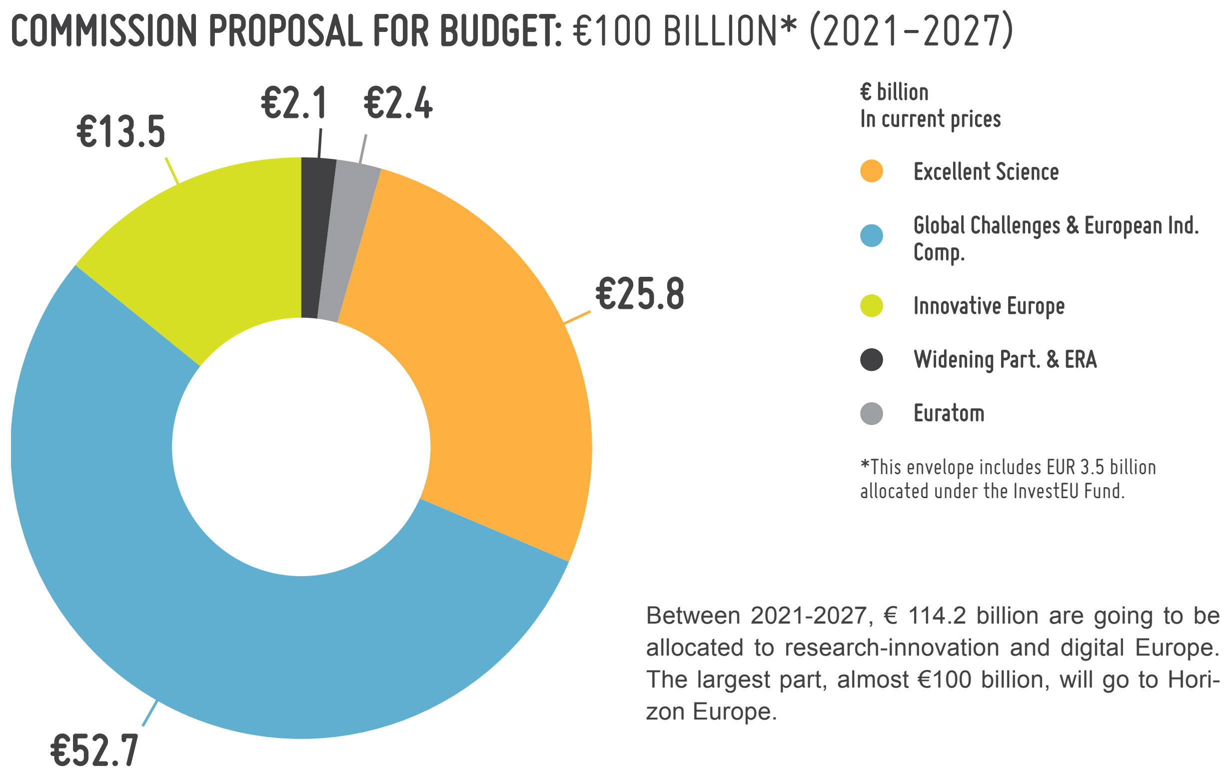
Overview of planned EU funding 2021-2027

Figure 6: EU Funding 2021-2027 [EU, May 2019]



Source: European Commission
Note: Compared to the Multiannual Financial Framework 2014-2020 at EU-27 (estimate)

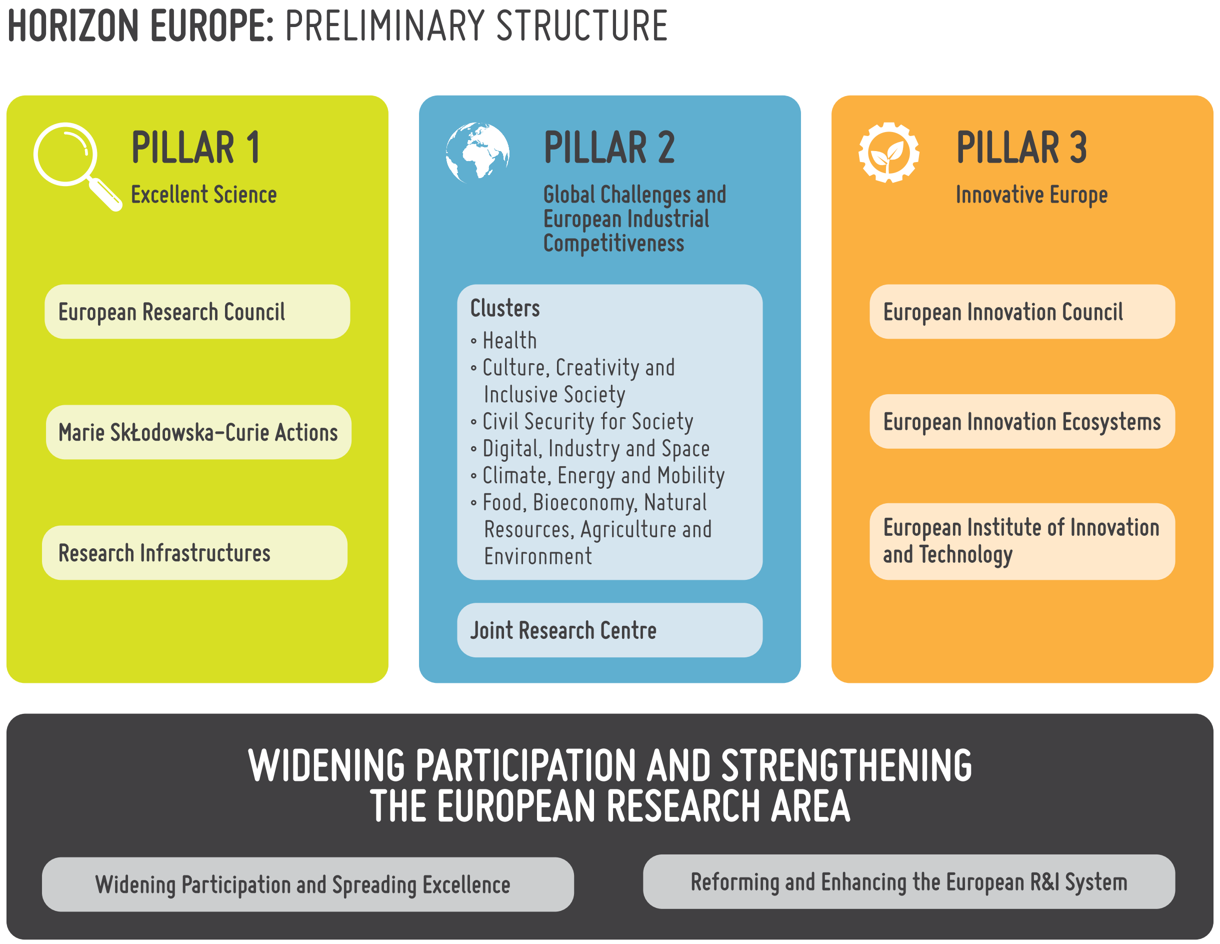
Figure 7: Allocation of the €100 billion to go to Horizon Europe



Between 2021-2027, € 114.2 billion are going to be allocated to research-innovation and digital Europe. The largest part, almost €100 billion, will go to Horizon Europe.

Horizon Europe structure and links to ETIP SNET R&I ROADMAP

Figure 8: Horizon Europe Structures, [EU, May 2019[61]]



61 https://ec.europa.eu/info/sites/info/files/research_and_innovation/strategy_on_research_and_innovation/presentations/horizon_europe_en_investing_to_shape_our_future.pdf

Within the Horizon Europe Structures, the ETIP SNET covers the R&I of the area Integrated Energy Systems. It is strongly linked to the Pillar 2 which has a total commission proposal for budget of € 52.7 billion, and its cluster “Climate, Energy and Mobility” with the following key research, demonstration and deployment areas:

- Climate science and integrated solutions;
- Energy systems and grids;
- Communities and cities;
- Industrial competitiveness;
- Smart mobility;
- Energy supply;
- Buildings and industrial facilities in energy transition;
- Clean, safe and accessible transport and mobility;
- Energy storage.

Integrated, sustainable, secure and affordable Energy Systems, however, also involve the following Horizon Europe clusters:

- Digital, Industry and Space (Energy System infrastructure manufacturing technologies and their advanced materials; next generation internet; circular industries; Space with Earth Observation for better forecasting; Key digital technologies, including quantum technologies; Artificial Intelligence and robotics; Advanced computing and Big Data; Low-carbon and clean industry);
- Inclusive Society (Democracy and Governance; Social and economic transformations; Cultural heritage and creativity: Consumer is at the center of the energy transition; subsidiarity is a key principle for introducing innovation to the energy systems, etc.);
- Resources and Environment (Environmental observation; Circular systems; Biodiversity and natural resources; Seas, oceans and inland waters: Energy is about primary resources, about infrastructures and their emissions, their influence on the environment, etc.);
- Health (Environmental and social health determinants such as through GHG and CO_2-Emissions).

Within the period 2020-2030, ETIP SNET will also contribute to creating more impact through mission-orientation and citizens involvement: ETIP SNET has proposed the Horizon Europe mission area “Energy Systems” and intends to contribute strongly to the European mission area “Climate-neutral and smart cities”.

With this roadmap, ETIP SNET harnesses the potential of innovation involving researchers, entrepreneurs, industry and society. ETIP SNET intends to contribute to an effective innovation ecosystem for integrated Energy Systems at European level which encourages cooperation, networking, exchange of ideas, funding and skills among national and local innovation ecosystems. ETIP SNET also supports those forms of European partnerships which contribute to integrated Energy Systems, such as:

- Key digital and enabling technologies (linked to ETIP SNET RA3 “DIGITALISATION”);
- Metrology (linked to ETIP SNET RA6 “SYSTEM OPERATION”),
- Hydrogen and sustainable energy storage[62]
- Clean, connected mobility & Aviation and rail[57]
- Sustainable bio-based solutions[57]

By its large number of more than 200 active stakeholders - which cover the major European associations with their affiliated industries, governmental representatives, researchers, and European countries - ETIP SNET is ready to tackle the R&I challenges 2020-2030: ETIP SNET has access to the Europe’s best talents, expertise and resources in the area of Integrated Energy Systems; it is ready to push innovative solutions. In the R&I processes towards these innovations, ETIP SNET fully supports mandatory open access to publications: beneficiaries shall ensure that they or the authors retain sufficient intellectual property rights to comply with open access requirements. In any case, open access to research data must be ensured. ETIP SNET strongly supports a fast track proposal procedure for funded projects of pillar II with a time-to grant from proposal submission not exceeding 6 months.

62 linked to ETIP SNET Research Area 5 “FLEXIBILITY ENABLERS AND SYSTEM FLEXIBILITY” and Research Area 4 “PLANNING - HOLISTIC ARCHITECTURES and ASSETS”

Interactions with national activities and Member States priorities will need to be deepened during 2020-2030 to better understand differences of energy-system related implementation issues and to align R&I activities so that national developments are becoming in line with European developments. To make this happen all SET-PLAN related initiatives will need to strengthen cooperation[63], and active international cooperation will need to be fostered[64]. Cooperation patterns have already been identified[65] and need to be pursued.

By doing research and working towards achieving desired FUNCTIONALITY by 2030, ETIP SNET also encourages a strong cooperation with other European Union Programmes, such as:

- Connecting Europe Facility[66] (CEF):
  - it supports the development of high performing, sustainable and efficiently interconnected trans-European networks in the fields of transport, energy and digital services;
- Digital Europe[67]:
  - focused on building the strategic digital capacities of the EU and on facilitating the wide deployment of digital technologies, to be used by Europe's citizens and businesses;
- Erasmus Programme[68]:
  - funding programme for education, training, youth and sport;
- European Regional Development Fund[69] (ERDF):
  - aims to strengthen economic and social cohesion in the European Union by correcting imbalances between its regions by innovation and research;
- European Single Market Programme[70]:
  - will strengthen the governance of the EU's internal market, support businesses and empower and protect consumers, enable SMEs to take advantage of the European single market;
- Innovation Fund[71] (replace NER300 programme):
  - Funding programmes for demonstration of innovative low-carbon technologies;
- Modernisation Fund[72]:
  - Support for modernisation of energy systems and just transition in 10 beneficiary Member States;
- Platform for coal regions in transition[73]:
  - aiming at providing technical assistance and advice to coal regions in transition, develop support material and connecting stakeholders;
- Clean energy for Islands initiative[74]:
  - Energy transition process with islands to support them in becoming more self-sufficient, prosperous and sustainable.

Such cooperations will be used much more intensively, if there is a harmonisation of funding rules, flexible co-funding schemes and in general a flexible pooling of resources at EU level.

63 Particular reference is made here to ETIPs, IWGs (Set Plan Implementation Working Groups), EERA Joint Programmes and ERA-Net (e.g. Smart Energy Systems – ERA-Net-SES, Regional Energy Systems ERA-Net REGSyS)

64 Reference is made to Mission Innovation, IEA Technology Collaboration Programmes and IRENA Working Groups

65 See Synergies and Complementarities of European and International Initiatives Towards Energy Transition - https://www.etip-snet.eu/wp-content/uploads/2019/03/European-And-International-Initiatives-Towards-Energy-Transition.pdf

66 https://ec.europa.eu/inea/en/connecting-europe-facility

67 https://ec.europa.eu/digital-single-market/en/news/digital-europe-programme-proposed-eu92-billion-funding-2021-2027

68 https://ec.europa.eu/programmes/erasmus-plus/node_en

69 https://ec.europa.eu/regional_policy/en/funding/erdf/

70 https://ec.europa.eu/growth/content/new-single-market-programme-empower-and-protect-europeans_en

71 https://ec.europa.eu/clima/policies/innovation-fund_en

72 https://ec.europa.eu/info/sites/info/files/innovation_and_modernisation_fund_ema.pdf

73 https://ec.europa.eu/energy/en/topics/oil-gas-and-coal/eu-coal-regions/secretariat-and-technical-assistance

74 https://euislands.eu/

The following table illustrates in which aspects the EU instruments developed under Horizon Europe would support the ETIP SNET R&I Roadmap 2020-2030[75]:

Table 14: EU instruments developed under Horizon Europe to support ETIP SNET R&I 2020-2030

Pre-commercial development (R&D)	Demonstration / - First of a kind	Uptake / Market readiness/ Roll out of technology
	Horizon Europe	
		CEF
		Digital Europe
ERASMUS		
	ERDF	
		Single Market Programme
	Innovation Fund (replace NER300 programme)	
		Modernisation Fund
		Platform for coal regions in transition
		Clean energy for Islands initiative

75 Categorization of EU instruments inspired by the Implementation Roadmap for Deep Geothermal: http://www.etip-dg.eu/front/wp-content/uploads/Roadmap_Final_-1.pdf

V. Recommendations

- In order to reach the overarching goal of limiting the global warming of the planet well **below 2°C** above pre-industrial levels, a dramatic reduction of emissions is urgently needed so that net zero GHG emissions are globally reached by 2050; 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;

- The European energy system must continue its **progression towards energy efficiency and renewables**, moving away from fossil fuels to cover the gross inland consumption;

- The integration of high shares of variable renewables is founded upon **a growing role of electricity** and requires significant **system optimisation** such as better interconnections on all grid levels, significant storage capabilities, demand response, low carbon flexible generation units, effective energy conversion (P2X) options and, at a later stage, integration of different energy vectors (electricity, gas, heating and cooling, water etc.);

- Measures must be put in place to **facilitate the participation of citizens** in the energy transition through the establishment of energy communities and the enhancement of the sustainability of bioenergy;

- The European Union must remain at the forefront of the global effort, actively engaging through **legislation, regulation and implementation of real measures**. In fact, in several sectors of the clean energy value chain, Europe owns a global leadership spreading through research, innovation and industrial achievements;

- Leveraging the "Clean Energy for all Europeans" package, adopted by the EU Council, as the backbone of the energy transition, **extensive R&I measures and programs must be implemented and pursued** to accomplish the two Missions dealing with the energy issue, and namely "Adaptation to Climate Change including Societal Transformation" and "Climate-Neutral and Smart Cities";

- The challenges towards decarbonisation of the energy system being so complex and urgent, **coordination and collaboration is needed among all stakeholders** including governments, European institutions, industries, network operators, technology and service providers, research centres, universities to **identify and prioritize R&I actions**. In this context, the role of the ETIP SNET, at the light of its wide representation of the stakeholders of the Integrated Energy System, is central in establishing a shared Vision 2050, and elaborating a consistent R&I strategy and Roadmap highlighting **activities to be conducted and funded in the coming decade**;

- The following **12 FUNCTIONALITIES,** identified in this ETIP SNET R&I Roadmap for the period 2020-2030, are considered as essential enablers towards the decarbonisation of the energy system and **must be implemented progressively during the next decade** to ensure the path to the Vision 2050:

Table 15: FUNCTIONALITIES[76] for the Integrated Energy System 2030

Building blocks (ETIP SNET Vision 2050)	FUNCTIONALITY (Full name)	Short FUNCTIONALITY
The efficient organisation of energy systems	F1 Cooperation between system operators	F1 Cooperation
	F2 Cross-sector integration	F2 Cross-Sector
	F3 Integrating the subsidiarity principle – The customer at the center, at the heart of the Integrated Energy System	F3 Subsidiarity
Markets as key enablers of the energy transition	F4 Pan-European wholesale markets	F4 Wholesale
	F5 Integrating local markets (enabling citizen involvement)	F5 Retail
Digitalisation enables new services for Integrated Energy Systems	F6 Integrating digitalisation services (including data privacy, cybersecurity)	F6 Digitalisation
Infrastructure for Integrated Energy Systems as key enablers of the energy transition	F7 Upgraded electricity networks, integrated components and systems	F7 Electricity Systems and Networks
	F8 Energy System Business (incl. models, regulatory)	F8 Business
	F9 Simulation tools for electricity and energy systems (software)	F9 Simulation
Efficient energy use	F10 Integrating flexibility in generation, demand, conversion and storage technologies	F10 Flexibility
	F11 Efficient heating and cooling for buildings and industries in view of system integration of flexibilities	F11 Heating & Cooling
	F12 Efficient carbon-neutral liquid fuels & electricity for transport in view of system integration of flexibilities	F12 Transport

- The implementation of the above FUNCTIONALITIES in the European energy system calls for the **conduction of a rational research and innovation plan, to be devised, planned and conducted according to schedules, priorities and interlinks as highlighted in this Roadmap 2020-2030**. The research route charted and shared by the stakeholders of the ETIP SNET is made of 120 tasks, grouped into 24 Research Sub-Areas and 6 main Areas of R&I activities.

- **120 tasks** have been identified in this ETIP SNET R&I Roadmap, each associated to one of the following **6 Research Areas** and contributing to one or more of the above mentioned **12 FUNCTIONALITIES**. These tasks must be realised in R&I-Projects and reach the necessary technology readiness levels, from lower and medium TRL-levels (Research) where necessary, going upward to higher TRL-levels (Demonstration), ending at the Deployment level, where products and services shall be ready for the market.

76 The 12 Functionalities have been derived from the building blocks of the ETIP SNET Vision 2050.

Table 16: Research Areas

RA No.	Research Area (RA)	Explanation
1	CONSUMER, PROSUMER and CITIZEN ENERGY COMMUNITY	Citizen and prosumer information, empowerment and engagement
2	SYSTEM ECONOMICS	Business models, market design and market-governance
3	DIGITALISATION	Digitalisation, communication and data handling (including Data, Cyber and System security)
4	PLANNING – HOLISTIC ARCHITECTURES and ASSETS	Energy system architectures, design and planning; technology solutions, asset management, maintenance; System Stability and resilience.
5	FLEXIBILITY ENABLERS and SYSTEM FLEXIBILITY	Adapting all energy components to provide flexibility to the system (Flexibility in Demand, Generation, Storage & Energy Conversion, Network, Transport).
6	SYSTEM OPERATION	System supervision, monitoring, control, reliability, resilience and automation (State estimation and supervision, short-term, medium and long-term control), and control room operators' skills enforcement

- A large effort has been made to identify the most rational **R&I Journey** for each task, based on the State of the Art, the monitoring of previous research activities conducted in the different fields by regional, national and European projects, the delivery of survey and workshops, the interaction among all stakeholders. It is considered that the R&I Journeys identified in this document represents faithfully the views of all the stakeholders and that **the programme illustrated in this Roadmap is a sound base to set up national, European and global R&I-project calls;**

- The roadmap gives indications on those tasks that shall be researched and/or demonstrated in each of the planned **time periods 2021-2024, 2023-2026, 2025-2028 and 2027-2030** so that they contribute to the required FUNCTIONALITIES in the year 2030. The particular tasks that shall be conducted in these four periods of the time frame 2020-2030 will be analysed and described in the corresponding **ETIP SNET Implementation Plans**.

Annex I: Research Areas

Table 17: Six Research Areas (RA) with Research Sub-Areas (RSA)

Research Areas (RA)	RSA	Research Sub-Areas (RSA)
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 behaviour 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

Research Areas (RA)	RSA	Research Sub-Areas (RSA)
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)

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 centredness of technologies, smart appliances, prosumer device control, solutions, APPs, market tools etc.);
- The solutions in the hand of the consumer that enable to be an actor in the energy system (roles and integration of consumer-owned DER, smart metering, storage, micro CHP, heat pumps, EV, smart appliances, incentives, dynamic tariffs, etc.);

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 (efficiciency), 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 servies, capacity, etc.).

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 measureable, 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 sector 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 software 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 exchange among the different energy systems actors (e.g. TSO/DSO communication interfaces), including information models (e.g. 61850), also from other industrial sectors.

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 uncertain 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-benefits 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.)

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 manage 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, carbon neutral fuels) and conversion (P-t-X);

- The combined flexibility options enabling grid operators, as well as aggregators/balancing parties to make optimal use of the flexibility resources, for example, cells[77] 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);

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, including 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 system development, management and operation to ensure adequate and uniform level of skills and approaches.

77 Cell refers here to a decentralized energy system (part), where smaller geographical areas (cfr energy communities, micro-grids) are managed as autonomous entities that coordinate with each other (Web-of-Cells concept)

Annex II: Tasks, Research Sub-Areas and FUNCTIONALITIES

This section lists of all tasks with their Research Sub-Areas and Research Areas which are according to ETIP SNET of high relevance in the period 2020-2030: this list of tasks will evolve and new tasks with new research (sub-) areas may be added. Others may be removed as soon as they reach the maturity beyond Demonstration.

For each Research Sub-area, the following table shows the involved tasks with their R&I-Journeys: The five columns 24, 26, 28, 30 and 30+ show – per task – the expected Research and Demonstration activities to be undertaken during the time of each of the upcoming four Implementation Plans, ending 2024, 2026, 2028 and 2030 and beyond 2030.

R(esearch)-Maturity for Integrated Energy System tasks typically refers to the TRL[78] 3-5. **D(emonstration)-Maturity** refers to TRL 6 – 8. Deployment Maturity refers to TRL 9.

For each task, a **red circle** indicates that in this time period, a certain Research maturity (TRL 3-5) shall be reached[79]. An **orange circle** indicates that for the task Demonstration maturity (TRL 6-8) is expected to be reached by the respective time period (for year, see column header).

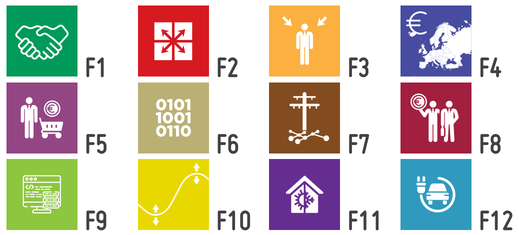
Some tasks have only **R-maturity** as goal and no follow-up **Demonstration maturity**. Some tasks already begin with **D-maturity** since **R-maturity** has already been reached before the IP-Period 2021-2024.

Some tasks do not show any **R** or **D** maturity level: This means that according to ETIP SNET Experts, all **R** and/or **D** -goals have already been achieved before the first IP-period 2021-24 and Deployment-maturity is given from the beginning. A Deployment-maturity corresponds to the year at which the task goals are assumed to be at product and service level, i.e. where task-related products and services can be bought on the market assuming increasing competitiveness among providers.

78 [https://ec.europa.eu/research/participants/data/ref/h2020/other/wp/2016-2017/annexes/h2020-wp1617-annex-ga_en.pdf] TRL 1 – basic principles observed; TRL 2 – technology concept formulated; TRL 3 – experimental proof of concept; TRL 4 – technology validated in lab; TRL 5 – technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies); TRL 6 – technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies); TRL 7 – system prototype demonstration in operational environment; TRL 8 – system complete and qualified; TRL 9 – actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies)

79 The duration of each task may span over more than one Implementation Plan.

RA	RSA	Task No	Tasks – ETIP SNET R&I ROADMAP 2020-2030	Involved FUNCTIONALITIES	24	26	28	30	30+
1	1.1	1.1.1	1. Methods and tools for for the effective stakeholders engagement to increase **public acceptance of new energy infrastructures**, including transmission lines (overhead lines and underground cables), substations, storage facilities, generation stations (thermal and RES, like hydro, wind, etc.), gas pipelines and conversion stations, etc. (links to Social Science and Humanities)	F1, F2, F3, F5, F6, F7, F8, F10	🟠	🟠	🟠	🟠	🟢
		1.1.2	2. Increase consumer understanding and **awareness of new electricity/energy systems and** particularly the consumer/prosumer central role as active participants in grid operation. Investigate the social and economic impact of the **citizen involvement in forming energy communities**, including increased system resilience and sustainability.	F3, F5, F6, F8, F10, F11, F12	🔴	🔴	🔴	🟠	🟠
		1.1.3	3. Studies to reduce or remove the **environmental impacts of energy infrastructures (visual, audible, etc.)**, e.g. for hydropower plants (hydropeaking effects, better sediment management, fish migration and fish protection, water quality, etc.), noise of transformers and transmission lines, more attractive designs for transmission line towers, changed visibility by undergrounding, etc.	F2, F3, F5, F6, F7	🟠	🟠	🟢	🟢	🟢
	1.2	1.2.1	1. Methods and Tools to support **consumers' and prosumers' adaptation of energy behaviour**, including on-line measurements of electricity consumption and generation, dynamic time-of use tariffs and behavioural studies considering the full environment, such as non-energy benefits, like comfort and security.	F3, F4, F5, F6, F7, F8, F10, F11, F12	🟠	🟠	🟠	🟠	🟠



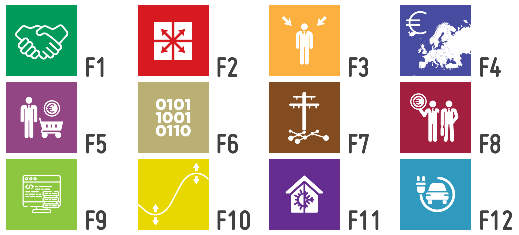
🔴 Research (TRL 3-5)

🟠 Demonstration (TRL 6-8)

🟢 Deployment (TRL 9)

RA	RSA	Task No	Tasks – ETIP SNET R&I ROADMAP 2020-2030	Involved FUNCTIONALITIES	24	26	28	30	30+
		1.2.2	2. Methods and tools including campaigns to support the **industry's consumption adaptation** in order to support the system	F3, F4, F10, F11	🟠	🟠	🟢	🟢	🟢
	1.3	1.3.1	1. **Wireless technologies for direct control** of prosumers' electricity consumption/generation using low-cost technologies (smart phones, etc.)	F3, F5, F6, F10, F11	🟠	🟠	🟠	🟢	🟢
		1.3.2	2. In-home **ICT technologies for smart appliances** (e.g. smart load controllers) for direct control of consumer demand, incl. visualization via in-home displays.	F3, F5, F6, F10, F11, F12	🟠	🟢	🟢	🟢	🟢
2	2.1	2.1.1	1. Business models for **prosumers providing ancillary services**, including EV owners with bidirectional capabilities and storage units..	F2, F4, F5, F6, F7, F8, F9, F10, F11, F12	🔴	🔴	🟠	🟠	🟢
		2.1.2	2. Business models for **retailers and aggregators, ESCOs and energy communities**, providing energy efficiency at end-user level.	F3, F4, F5, F6, F7, F8, F10, F11, F12	🔴	🔴	🟠	🟠	🟢
		2.1.3	3. Business models for **data analysis service providers** to energy using large-scale data bases and advanced data-mining techniques	F4, F5, F6, F7, F8	🔴	🟠	🟠	🟠	🟢
		2.1.4	4. Business models for **storage in electrical transportation networks** (e.g. tramways, trains, buses)	F4, F5, F6, F8, F9, F10, F11, F12	🔴	🔴	🟠	🟠	🟢
		2.1.5	5. Business models for **gas-fired or biomass fired CHP units** producing heat when residual loads are low, and electricity when residual loads are high or used as thermal storage.	F2, F4, F5, F8, F10, F11	🔴	🔴	🟠	🟢	🟢
	2.2	2.2.1	1. **Pan-European market design** to foster the integration of large scale RES, storage, demand response, EVs, etc. in coordination with network operation taking into account uncertainties of production and demand.	F1, F2, F4, F7, F8, F9, F10	🔴	🔴	🟠	🟠	🟢

RA	RSA	Task No	Tasks - ETIP SNET R&I ROADMAP 2020-2030	Involved FUNCTIONALITIES	24	26	28	30	30+
		2.2.2	2. Market design for TSOs with **cross-border coordination** that involve multiple DSOs and aggregators and multi-operation zones. Market design for cross-border ancillary services (including joint procurement of reserves, sharing of reserves, fast ramping services for frequency response, inertia response, reactive power, voltage control and power flow control)	F1, F2, F4, F5, F8, F10, F11, F12	🔴	🔴	🟠	🟠	🟢
		2.2.3	3. Market rules and coordination mechanisms for provision of **ancillary services by aggregated storage and virtual power plants**, comprising RES, flexible thermal generation (small and micro-CHP), heat-pumps, EVs, etc.	F1, F2, F3, F4, F5, F7, F8, F9, F10, F11, F12	🔴	🔴	🟠	🟠	🟢
		2.2.4	4. Market design and cost benefit analysis for the **provision of ancillary services between DSOs and TSOs** through coordinated communications, coordinated smart metering and platforms, and considering physical grid constraints.	F1, F2, F3, F4, F5, F6, F8, F10, F11, F12	🔴	🔴	🟠	🟠	🟢
		2.2.5	5. Design of **local markets and their interaction to central markets**. Retail (peer-to-peer) markets for Local Energy Communities with power balancing and coordinated LV/MV technical grid control.	F1, F4, F5, F6, F7, F8, F10	🔴	🔴	🟠	🟠	🟠
		2.2.6	6. Market design for **large-scale demand response, beyond electricity**. Market models expressing the price-sensitive nature of loads obtained by smart metering and metrology methods.	F1, F2, F3, F4, F5, F6, F8, F10, F11, F12	🔴	🟠	🟠	🟠	🟢
		2.2.7	7. Market design for **storage owners and operators**, including of EV. Market design for thermal storage in electricity and heating markets	F1, F2, F4, F5, F6, F7, F8, F10, F11, F12	🟠	🟠	🟠	🟠	🟢



🔴 Research (TRL 3-5)

🟠 Demonstration (TRL 6-8)

🟢 Deployment (TRL 9)

RA	RSA	Task No	Tasks - ETIP SNET R&I ROADMAP 2020-2030	Involved FUNCTIONALITIES	24	26	28	30	30+
		2.2.8	8. Market rules for the provision of **system services (balancing) by gas networks** in case of low (or negative) residual loads when producing and storing chemical energy.	F1, F3, F5, F8, F10	🔴	🔴	🟠	🟢	🟢
		2.2.9	9. Market design for system services (balancing) by **water cycle management operators**.	F2, F8, F10, F11	🟠	🟠	🟠	🟠	🟢
3	3.1	3.1.1	1. **Data exchange protocols / interfaces for a well-functioning market** between all players. Protocols for stochastic model-based handling of market operations on different timescales. Common, standardised models for encrypted and authenticated market orders	F1, F3, F4, F5, F6, F7, F8, F9, F10, F11	🔴	🟠	🟠	🟠	🟢
		3.1.2	2. **Standardized communication protocols and ICT infrastructure between devices and networks and also between devices and remote management platforms** to meet requirements of network operators, retailers and aggregators. Interoperability for devices and actors of the integrated energy system (e.g. prosumers, connected buildings, DSO, storage, RES, PV, EV) etc.	F1, F2, F3, F5, F6, F7, F8, F9, F10, F11, F12	🔴	🟠	🟠	🟠	🟢
		3.1.3	3. **Communication interfaces of smart substations**, especially on LV secondary substation level (interfaces for internal substation components and between substation with upper level and information systems, like EMS, SCADAS, legacy systems, etc.).	F2, F6, F7, F10	🔴	🟠	🟠	🟢	🟢
		3.1.4	4. Universal device interfaces and protocols to enable **DSO and TSO information exchanges**. Data interfaces for utility business models and **decision-making support functions**.	F1, F6, F7, F8, F10	🔴	🟠	🟠	🟢	🟢
	3.2	3.2.1	1. Communication infrastructures to support **demand aggregation and control**. M2M or AI2AI telecommunication solutions for services required by the energy grid (including AI algorithms for decision-making in device, MEC or cloud level).	F1, F2, F3, F5, F6, F7, F10	🔴	🔴	🟠	🟠	🟢
		3.2.2	2. ICT infrastructure for **monitoring and control of distributed generation**, e.g. PV systems, including standards and protocols.	F2, F6, F7, F10	🟠	🟠	🟠	🟠	🟢

RA	RSA	Task No	Tasks – ETIP SNET R&I ROADMAP 2020-2030	Involved FUNCTIONALITIES	24	26	28	30	30+
		3.2.3	3. Communication infrastructures for **smart meter data** for close to real-time monitoring in critical zones at critical moments (including non-GNSS (Global Navigation Satellite System) systems for time synchronisation and timestamping, consideration of latency, loss of packets, and jitter in end-to-end communications.)	F2, F5, F6, F7, F8	Research	Demonstration	Demonstration	Demonstration	Deployment
		3.2.4	4. Optimise installation of ICT infrastructure, including costs, accuracy, redundancy, etc. for data collection and processing used for **conditional and risk-based maintenance**.	F7, F9	Research	Research	Demonstration	Demonstration	Deployment
	3.3	3.3.1	1. **Big data management** from different sources: smart-meters, smart-sensors, social media, etc. for their use in planning tools, management tools, market platforms, etc. Data driven tools supported by data analytics, artificial intelligence, development of digital twins, etc.	F1, F5, F6, F8, F10	Research	Research	Demonstration	Demonstration	Deployment
		3.3.2	2. Investigate the use of **IoT technologies** in TSO and DSO planning, asset management, operational and market activities.	F6, F7, F8	Research	Research	Demonstration	Demonstration	Demonstration
	3.4	3.4.1	1. Methods and tools for **cyber security protection of grid infrastructures** to avoid injection of false data through physical installations, like primary and secondary substations, MV and LV lines, etc. Cybersecurity strategies for TSOs and DSOs	F1, F6, F7, F8, F9	Research	Demonstration	Demonstration	Demonstration	Demonstration
		3.4.2	2. Data protection and **GDPR-compliant methodologies for management of distributed energy resources**, including decentralized storage	F3, F5, F6, F8, F10	Research	Research	Demonstration	Demonstration	Deployment

Research (TRL 3-5)

Demonstration (TRL 6-8)

Deployment (TRL 9)

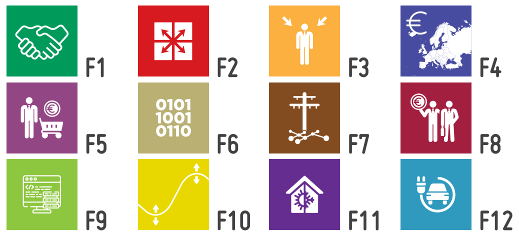
RA	RSA	Task No	Tasks – ETIP SNET R&I ROADMAP 2020-2030	Involved FUNCTIONALITIES	24	26	28	30	30+
		3.4.3	3. Risk and vulnerabilities for **parallel use of legacy SCADA systems** (as a traditional means to provide remote supervisory and control)	F1, F6, F7, F9	Research	Research	Research	Demonstration	Deployment
		3.4.4	4. Risks and vulnerabilities of using **public ICT and wireless infrastructures** for smart grid functionalities, e.g. connection with smart meters and energy boxes	F3, F5, F6	Research	Research	Demonstration	Demonstration	Deployment
	3.5	3.5.1	1. Digitalization of distribution and transmission networks. Creation of a **digital twin of interoperating grid and communication networks** to resolve performance problems and recovery from abnormal events.	F1, F5, F6, F7, F8, F9	Research	Demonstration	Deployment	Deployment	Deployment
		3.5.2	2. Enhanced architecture design for **data exchange at different system voltage levels**, at different time frames with enhanced TSO/DSO communication interfaces.	F1, F2, F5, F6, F7, F8	Research	Demonstration	Demonstration	Deployment	Deployment
		3.5.3	3. Application of **advanced ICT-based approaches** (IoT, edge computing, cloud computing, cyber-security, block-chain, etc) **for data storage** and computing on new (Hardware & Software) **architectural schemes**.	F1, F2, F6, F9	Demonstration	Demonstration	Deployment	Deployment	Deployment
4	4.1	4.1.1	1. Model of the energy system including all major energy carriers, encompassing the **whole energy chain** from prosumers, energy communities, e-transportation, distribution and transmission grids (LV, MV, HV), national and regional electrical and gas exchange, with clear boundary interaction.	F1, F2, F5, F7, F8, F9, F10, F11, F12	Demonstration	Demonstration	Demonstration	Demonstration	Deployment
		4.1.2	2. Coordinated HV (including Ultra-HV) and MV distribution systems. Electricity transmission systems with storage infrastructure and using gas and heat infrastructures. **Resilience oriented sizing and spatial positioning of assets**, in order to withstand the impact of extreme weather and grid events.	F1, F2, F7, F9, F10, F11, F12	Research	Research	Demonstration	Demonstration	Deployment
		4.1.3	3. Citizen energy communities, with energy management systems for **local multi-energy streams operation**, including electrical-storage, P2x generation and storage, and x2P (including CHP based on hydrogen and fuel-cells).	F3, F5, F7	Demonstration	Demonstration	Demonstration	Deployment	Deployment

RA	RSA	Task No	Tasks – ETIP SNET R&I ROADMAP 2020-2030	Involved FUNCTIONALITIES	24	26	28	30	30+
		4.1.4	4. **Multicarrier hybrid storage systems**, including their economic benefits in comparison to single storage units, their application to Power2Heat for balancing and storage, dynamic interaction between heat and electricity, their application at building level, dynamics of the coupled energy system considering the inertia of thermal loads (electricity-heating-buildings).	F2, F5, F7, F8, F10, F11, F12	Research	Research	Demonstration	Demonstration	Deployment
		4.1.5	5. **Optimally located, sized and coordinated electric energy storage at different voltage** levels in the power system (for fast and slow power response; for future ancillary supplementary services in the storage facility such as inertia support).	F1, F7, F8, F9, F10	Research	Research	Demonstration	Demonstration	Deployment
		4.1.6	6. **Optimally located, sized and coordinated** hydro, gas and chemical thermal and chemical **storage for seasonal needs**.	F1, F2, F9, F10, F11, F12	Research	Research	Demonstration	Demonstration	Demonstration
		4.1.7	7. **Web-of-Cells, decentralised, modular control architectures** for real-time voltage and frequency control (including AC, AC/DC hybrid and DC microgrids, local storage, smart transformers) utilizing flexibility from all energy carrier systems.	F1, F2, F3, F4, F5, F6, F7, F8, F9, F10, F11, F12	Demonstration	Demonstration	Demonstration	Demonstration	Deployment
		4.1.8	8. **Integrated electricity AC and DC distribution networks** including large-scale electrification of heating, domestic and commercial heat pumps, EV charging stations, etc. DC and hybrid AC/DC networks connected to AC through FACDS (Flexible Alternating Current Distribution System), Smart transformers, MV/LV DC, etc. AC, AC/DC hybrid and DC microgrids and local storage for providing locally flexibility.	F1, F2, F3, F5, F6, F8, F9, F10, F11, F12	Research	Demonstration	Demonstration	Demonstration	Demonstration

- Research (TRL 3-5)
- Demonstration (TRL 6-8)
- Deployment (TRL 9)

RA	RSA	Task No	Tasks – ETIP SNET R&I ROADMAP 2020-2030	Involved FUNCTIONALITIES	24	26	28	30	30+
		4.1.9	9. **HVDC meshed grids.** Optimization algorithms for HVDC grids design based on different optimization criteria (n-1 reliability criterion, loss of infeed risks, economic criteria, etc.) **and parallel routing of DC and AC lines** on the same tower or parallel paths to utilise existing infrastructure paths.	F7, F9	Research	Research	Demonstration	Deployment	Deployment
	4.2	4.2.1	1. **Planning of integrated (coupled) energy systems** (heat and cooling, gas, electricity networks with an extension to water -waste and drinking- and public transport networks in urban areas). Planning tools to optimize the development of the electricity networks taking into account energy efficiency policies at the urban/city but also rural scale (interaction with other energy network, spatial planning).	F1, F2, F3, F7, F8, F9, F10, F11, F12	Research	Research	Demonstration	Demonstration	Deployment
		4.2.2	2. Cost-effective, coordinated **investment planning in RES at EU level** (covers all time horizons and markets (from investment planning until real-time) and taking into account the effects of alternative market designs and the requirements for infrastructure development. Consider all flexibility means (demand response, energy storage, generation, transmission), including cross-carrier flexibility.	F4, F5, F8, F9	Research	Demonstration	Demonstration	Demonstration	Deployment
		4.2.3	3. Electricity System **Planning for resilience**, including Grid designs, PV, Wind and Hydropower generation, storage and demand flexibilities against natural disasters (storms, floods, wildfires, etc) and human attacks, resilience oriented operational planning using stochastic approaches including multi-contingencies occurrence	F10	Demonstration	Demonstration	Demonstration	Deployment	Deployment
		4.2.4	4. **DER solutions to handle network constraints in planning.** HV, MV and LV network reinforcements and LV, MV grid expansion planning considering the flexibility offered by controlling RES, demand, energy storage, power electronics, etc. (includes the use of data coming from the field (smart meters, monitoring systems at all levels, fault detection, etc.))	F1, F7, F9, F10, F11	Research	Demonstration	Demonstration	Demonstration	Deployment

RA	RSA	Task No	Tasks – ETIP SNET R&I ROADMAP 2020–2030	Involved FUNCTIONALITIES	24	26	28	30	30+
		4.2.5	5. **Probabilistic planning taking into account the DER stochasticity**, i.e. RES, demand response, storage, self-consumption, and their uncertainty including for heating and cooling and the demand for mobility	F2, F4, F5, F7, F8, F9, F10, F11, F12	🟠	🟠	🟢	🟢	🟢
		4.2.6	6. Distribution System planning and asset management to cater for the integration of **massive integration of EVs** with fast, very fast, and inductive recharge technologies. (short-, medium- and long-term scenarios for the implementation of the adequate charging infrastructures, incl. battery swapping infrastructures	F7, F8, F9, F10, F11, F12	🟠	🟠	🟠	🟠	🟢
		4.2.7	7. Planning of **LV and MV DC industrial and residential grids**. Added value of DC grids in integrating DER, incl. lower costs of BoS (Balance of System). Taking care for safety, especially in homes.	F5, F6, F7, F9, F10, F11, F12	🔴	🔴	🔴	🟠	🟢
	4.3	4.3.1	1. Development of ageing and failure models for **condition (risk) in planning LV/MV based maintenance**, considering maintenance cycling profiles (including extreme events), different time scales (from operation to planning) both for power system components (lines, substations, transformers, switches, breakers, etc.), ICT infrastructures (sensors, communication infrastructures) and smart meters.	F4, F5, F6, F7, F8, F9	🔴	🔴	🟠	🟠	🟢
		4.3.2	2. Development of models for **State of Health (SoH) estimates of transmission system components** conditions, e.g. SoH related to components' wear, oil level in transformer oil pits, SF6 level in switchgear and probabilities of failure. Investigation of parameters which impact the lifespan of HV transmission system components.	F6, F7, F9	🔴	🔴	🟠	🟠	🟢
		4.3.3	3. **Model-based detection of component failures** with sensors, conditions monitoring; robotics for hostile environments in HV systems; live maintenance (drones). Improved maintenance of HV-system components related to environmental (e.g., tree growth rate, wind) and operational (e.g., hazard rate) effects on assets' lifetime (Holistic approaches).	F6, F7	🔴	🔴	🟠	🟠	🟢
		4.3.4	4. **Remote LV/MV maintenance operations** by digital communications and monitoring equipment	F6, F7	🔴	🔴	🟠	🟢	🟢
		4.3.5	5. **HV and MV-asset management considering resiliency** against rare, severe-impact events due to natural catastrophes, terrorism, cyber-attacks using standardisation for diagnostic methodologies (for validating measuring chain, for safety of [live] operation).	F6, F7	🔴	🔴	🟠	🟢	🟢
		4.3.6	6. **Training of maintenance operators** for their adaptation to digital environments (i.e. human-machine interfaces) and new robotic solutions. Optimise maintenance-related costs (accuracy, redundancy, etc.) of the ICT infrastructure for collecting and processing data (both for on-line monitoring of components and data storage)	F7	🟠	🟠	🟠	🟢	🟢
		4.3.7	7. **Optimized lifespan of storage systems** and the failure modes, including stochastic cycling profiles, CAPEX, OPEX, efficiency.	F7, F8, F9, F10	🔴	🟠	🟠	🟢	🟢
		4.3.8	8. Smart sensors and online monitoring and diagnostic systems for the **optimal maintenance of hydropower and pumped-storage units**.	F6, F10	🟠	🟠	🟠	🟢	🟢
		4.3.9	9. **Improved lifetime of thermal generation** with fast cycling ability and fuel flexibility.	F6, F7, F9, F10	🟠	🟠	🟢	🟢	🟢
	4.4	4.4.1	1. Grid stability **support by DER** (distributed generation, storage and flexible demand) and by **microgrids and nanogrids** connected at the distribution networks to the stability and control of the bulk transmission network.	F1, F5, F7, F10, F11, F12	🔴	🔴	🟠	🟢	🟢



🔴 Research (TRL 3-5)

🟠 Demonstration (TRL 6-8)

🟢 Deployment (TRL 9)

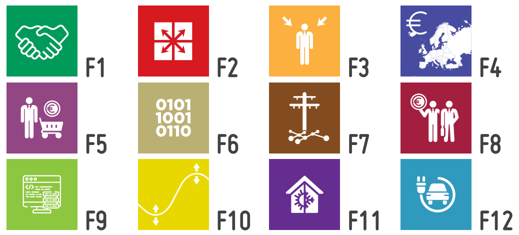
RA	RSA	Task No	Tasks – ETIP SNET R&I ROADMAP 2020-2030	Involved FUNCTIONALITIES	24	26	28	30	30+
		4.4.2	2. Control concepts for providing **synthetic inertia from power electronic converters** and additional damping of oscillations, for instance by conventional rotating machine concepts like the VFT (Variable Frequency Transformer)	F5, F7, F10	Demonstration	Demonstration	Demonstration	Deployment	Deployment
		4.4.3	3. Stability and control of AC, DC and Hybrid **Microgrids in islanded mode of operation**.	F1, F3, F7, F10	Demonstration	Demonstration	Deployment	Deployment	Deployment
		4.4.4	4. Models and tools for **converter driven stability** including fast interaction (dynamic interactions of the control systems of power electronic-based systems, e.g. DGs, HVDC, and FACTS with fast-response components of the power system, such as the transmission network, or other power electronic-based devices) and slow interaction (dynamic interactions with slow-response components, such as the electromechanical dynamics of synchronous generators phenomena.	F7, F9, F10	Research	Research	Demonstration	Deployment	Deployment
		4.4.5	5. Models and techniques (incl. artificial analysis) for rotor-angle, voltage and frequency **stability of large scale transmission systems with high penetration of Variable RES**.	F6, F7, F9, F10	Demonstration	Demonstration	Demonstration	Demonstration	Deployment
		4.4.6	6. Development and validation of **equivalent models of aggregated network and system components** consisting of multiple technologies and potential energy carriers in different environments for energy system stability.	F2, F7, F8, F9, F10, F11	Demonstration	Demonstration	Demonstration	Deployment	Deployment
		4.4.7	7. Methods and tools to analyse **large-scale inter-area oscillations**. Dynamic stability in grids with multiple control systems	F7, F9	Research	Research	Demonstration	Demonstration	Demonstration

F1 F2 F3 F4
F5 F6 F7 F8
F9 F10 F11 F12

Research (TRL 3-5)
Demonstration (TRL 6-8)
Deployment (TRL 9)

RA	RSA	Task No	Tasks – ETIP SNET R&I ROADMAP 2020-2030	Involved FUNCTIONALITIES	24	26	28	30	30+
5	5.1	5.1.1	1. **Optimal utilization of DSR** (Demand Side Response) **by TSOs and DSOs** and their coordination, respecting demand requirements, and required data.	F1, F2, F6, F8, F10, F11, F12	Demonstration	Demonstration	Demonstration	Demonstration	Deployment
		5.1.2	2. **Direct load control** in close collaboration with telecom operators	F2, F3, F4, F5, F6, F10, F11, F12	Demonstration	Demonstration	Demonstration	Deployment	Deployment
		5.1.3	3. Incorporation of **Active Demand in DSO planning and operation**, to serve the needs of the connected end user and aggregators and to defer grid investments. Prediction of the amount of shifted energy or modified consumption in Distribution Networks considering data availability and information exchange models.	F1, F2, F5, F6, F8, F10, F11, F12	Research	Research	Demonstration	Deployment	Deployment
		5.1.4	4. Models for demand flexibility provided by integrated **energy-intensive industries** (e.g. steel production) and **bulk energy storage** (P2G, CAES, LAES, etc.).	F1, F2, F9, F10, F11	Research	Research	Demonstration	Deployment	Deployment
	5.2	5.2.1	1. **Contribution of WTs (Windturbines) and PVs to system flexibility.** Development of efficient controls for wind turbines and PV MPPT (Maximum Power Point Tracking) to take into account flexibility, reserve sharing, etc.	F9, F10	Research	Research	Demonstration	Demonstration	Deployment
		5.2.2	2. Increase **operational flexibility of hydropower and pumped storage plants**, while reducing the negative effects on highly reduced lifetime and security risks from sudden outage.	F9, F10	Demonstration	Demonstration	Deployment	Deployment	Deployment
		5.2.3	3. Increase the **flexibility of thermal generation**, i.e. their speed of ramping up and down, start-up/shut down capabilities and minimum loads. Increase efficiency and lower GHG and CO2-emissions without compromising ability for waste heat recovery (ORC, etc).	F2, F7, F8, F9, F10, F11	Research	Research	Demonstration	Deployment	Deployment
		5.2.4	4. Increase **fuel flexibility of thermal power plants** for using (mixing and switching) different sources of CO2-neutral fuels (hydrogen, biomass and biofuels).	F2, F7, F10, F11, F12	Research	Research	Demonstration	Demonstration	Deployment

RA	RSA	Task No	Tasks – ETIP SNET R&I ROADMAP 2020-2030	Involved FUNCTIONALITIES	24	26	28	30	30+
		5.2.5	5. Develop and test solutions for integrated **flexible small and medium scale thermal generation** of electricity, heating and cooling, storage, develop impact studies and demonstration (including environmental, user and societal and economic impacts).	F2, F6, F7, F8, F10, F11, F12	Research	Research	Demonstration	Demonstration	Deployment
		5.2.6	6. Development of highly efficient, integrated **cogeneration units** of varying size with **decoupled use of heat & power**, powered by hydrogen, biomass and biofuels.	F1, F2, F7, F10, F11	Research	Research	Research	Demonstration	Demonstration
		5.2.7	7. Develop **European hydro energy system model** based on hydro power data set. Develop European wide reservoir and river inflow data set based on up to date climate simulations.	F7, F9, F10	Demonstration	Demonstration	Demonstration	Deployment	Deployment
	5.3	5.3.1	1. Studies for **storage flexibilities in operation of electrical grids** (including Microgrids). Storage sizing and siting (also hybrid technologies) depending on applications and their characteristics (CAPEX, OPEX, cycling, lifetime, efficiency, interconnection with other energy carriers, environmental and social aspects (LCA))	F5, F6, F7, F8, F9, F10, F11, F12	Research	Research	Demonstration	Demonstration	Deployment
		5.3.2	2. Integration of **energy storage systems with conventional power generators**, such as cogeneration, hydropower, thermal plants to increase their flexibility and improve operation (incl. effectiveness and load hours of combined heat and power).	F5, F6, F7, F10	Research	Research	Demonstration	Demonstration	Demonstration



Research (TRL 3-5)

Demonstration (TRL 6-8)

Deployment (TRL 9)

RA	RSA	Task No	Tasks – ETIP SNET R&I ROADMAP 2020-2030	Involved FUNCTIONALITIES	24	26	28	30	30+
		5.3.3	3. Flexibility potential from **aggregated heating (and cooling) storage at household / building / industrial level** to provide system services (balancing). Power-to-heat technologies, like heat pumps, heat boilers, etc.	F2, F9, F10, F11, F12	Research	Research	Research	Demonstration	Deployment
		5.3.4	4. Large-scale **power-to-gas applications**: Dynamics of coupled, integrated energy systems when producing large quantities of methane (power-to-gas) to be injected into the gas system (pipelines and underground storages).	F2, F5, F8, F10, F11, F12	Research	Research	Demonstration	Demonstration	Demonstration
		5.3.5	5. **Stand-alone (islands) buildings, living quarters and small and medium sized businesses and industries**, supplied by renewable generation, sector-coupling and storage components (P2hydrogen, P2G, P2H, P2fuels (involving carbon capture), P2chemicals and vice versa; flex control of P2H conversions.	F2, F3, F5, F6, F8, F9, F10, F11, F12	Research	Research	Demonstration	Demonstration	Deployment
	5.4	5.4.1	1. Increasing **flexibility in transmission and distribution networks** by flexible, power electronics **grid technologies**, such as FACTS, PSTs and HVDC links, smart transformers (power electronics OLTCs), open soft points, FACDS, fault current limiters, etc.	F1, F2, F4, F5, F6, F7, F8, F9, F10	Research	Research	Demonstration	Demonstration	Deployment
		5.4.2	2. Flexibilities provided by **distribution network reconfiguration**	F1, F2, F6, F7, F9, F10	Research	Research	Demonstration	Demonstration	Deployment
		5.4.3	3. Standardised **HVDC multi-terminal networks to coordinate power flows** among different regions and to connect off- and onshore Wind Power plants	F1, F7, F9, F10	Research	Research	Research	Demonstration	Deployment
			4. **Dynamic Line Rating** (DLR) solutions in capacity calculations of transmission and distribution grids .	F6, F7, F8	Research	Research	Demonstration	Deployment	Deployment
	5.5	5.5.1	1. Centralized and distributed algorithms for **efficient management of EV charging**, supporting business-to-customers and business-to-business relationships and ensuring easy and secure payments for customers (incl. roaming services).	F2, F5, F7, F8, F10, F11, F12	Research	Research	Demonstration	Demonstration	Deployment

RA	RSA	Task No	Tasks – ETIP SNET R&I ROADMAP 2020-2030	Involved FUNCTIONALITIES	24	26	28	30	30+
		5.5.2	2. Energy management in **transport electricity networks** (railway, metro, tramway, trolleybus, etc) to provide ancillary services to DSOs via storage facilities in the substations of the PCC (point of common coupling)	F1, F2, F5, F7, F10, F11, F12	🔴	🔴	🟠	🟢	🟢
		5.5.3	3. Flexibility services offered by transport electrification, especially **Electric Vehicles with Grid to Vehicle G2V and Vehicle to Grid V2G** capabilities on distribution grid operation, especially for load flattening, system balancing and voltage support.	F2, F5, F7, F10, F11, F12	🔴	🟠	🟢	🟢	🟢
6	6.1	6.1.1	1. **Steady State and Dynamic State Estimation of transmission systems using intelligent monitoring devices**, like PMUs, intelligent sensors and data processing. (Distributed observability of the transmission system)	F1, F2, F4, F5, F6, F7, F9, F10, F11, F12	🔴	🟠	🟠	🟠	🟢
		6.1.2	2. Increased **Observability and State Estimation of distribution systems** (MV and LV) using smart meter consumer data. Advanced forecasting and data flow between DSOs and TSOs	F1, F3, F5, F6, F7, F9, F10, F11, F12	🔴	🟠	🟠	🟢	🟢
		6.1.3	3. **Real-time observability of RES** (algorithms and tools) and **improved forecasts** for operational planning purposes	F9, F10, F11, F12	🟠	🟠	🟠	🟠	🟢
	6.2	6.2.1	1. Optimal **Load Frequency Control** considering requirements for telecommunication infrastructures, latencies and reliabilities	F6, F7, F9, F10	🟠	🟠	🟢	🟢	🟢
			2. Contribution of **RES to primary voltage and frequency control** of power grids with emphasis on weak grids (including islands). Provision of primary reserves by kinetic energy of WT rotors, synthetic inertia by PE interfaced DER, PE based reactive power control, etc.	F5, F7, F10	🟠	🟠	🟢	🟢	🟢

🔴 Research (TRL 3-5)

🟠 Demonstration (TRL 6-8)

🟢 Deployment (TRL 9)

RA	RSA	Task No	Tasks – ETIP SNET R&I ROADMAP 2020-2030	Involved FUNCTIONALITIES	24	26	28	30	30+
			3. **Primary voltage and frequency control of distribution grids** (interconnected or islanded) with **very low or no inertia** by Power Electronics interfaced DER, local storage and load, VPPs, etc.	F7, F9, F10, F11, F12	🔴	🔴	🟠	🟢	🟢
	6.3	6.3.1	1. Advanced **RES forecasting** considering weather forecasts, local ad-hoc models, historical data and on-line measurements.	F5, F6, F7, F9, F10, F11	🔴	🔴	🟠	🟢	🟢
		6.3.2	2. **Hydropower forecasting** based on weather, precipitation models and live sensors.	F1, F9, F10	🟠	🟠	🟠	🟠	🟢
		6.3.3	3. Solving **location-based grid constraints** with the use of short-term forecasting of generation and load and exploiting customer behaviour and flexible loads, including EV charging.	F3, F6, F7, F9, F10, F11, F12	🟠	🟠	🟠	🟢	🟢
		6.3.4	4. **Optimal scheduling** of generation units (unit commitment, economic dispatch), reserve allocation and optimal power flow in **highly uncertain conditions**.	F4, F6, F7, F9, F10	🟠	🟠	🟠	🟢	🟢
		6.3.5	5. Optimal **distribution network configuration** taking into account increased monitoring capabilities at distribution level, automatic LV and MV System Topology identification and day-ahead forecasting.	F7, F9	🟠	🟠	🟠	🟢	🟢
		6.3.6	6. Massive use of control **technologies in secondary substations** and the resulting coordination needs for system operators.	F7, F10	🔴	🔴	🟠	🟢	🟢
	6.4	6.4.1	1. Protection of **distribution networks with low fault currents** due to high penetration of PE interfaced DER	F7, F9	🔴	🔴	🔴	🟠	🟢
		6.4.2	2. **DC grid protection, protection relays and breakers**, multi-vendor solution with the consideration of interoperability, standardization	F7, F9	🔴	🔴	🟠	🟢	🟢
		6.4.3	3. Distribution network operational measures, like **topology optimisation** and DER operational planning for **increasing network resilience** against natural disasters, terrorism and cyber-attacks.	F3, F6, F7, F9, F10, F11, F12	🔴	🔴	🟠	🟠	🟢

RA	RSA	Task No	Tasks – ETIP SNET R&I ROADMAP 2020-2030	Involved FUNCTIONALITIES	24	26	28	30	30+
		6.4.4	4. **Bottom up restoration** by DER support and storage including intentional islanding techniques via Microgrids and Web-of Cells approaches. Synchronization of DER and storage reconnection.	F1, F2, F4, F5, F6, F7, F8, F9, F10, F11, F12	🟠	🟠	🟠	🟢	🟢
		6.4.5	5. **Self-healing techniques** at distribution level by automatic fault clearing procedures in automatic power system restoration	F7	🟠	🟢	🟢	🟢	🟢
		6.4.6	6. Efficient **Load Shedding techniques** and tools considering reactive power and voltage control	F1, F7, F9, F11	🔴	🔴	🟠	🟢	🟢
		6.4.7	7. **Security support by various multi-energy carriers** in the distribution electricity network (e.g. electric pumps in the district heating and cooling networks, or in the drinking and wastewater networks, as well as electric compressors and control equipment in the gas network).	F1, F2, F6, F9, F10, F11, F12	🟠	🟠	🟠	🟢	🟢
		6.4.8	8. **Pan-EU or multi-regional system restoration** based on coordination of tie lines and/or black start units, whilst considering system condition, system constraints, available resources and regulatory rules. Minimize negative impacts of switching actions from one Transmission System to the neighbouring ones.	F1, F4, F5, F6, F7, F8, F9, F10	🔴	🟠	🟠	🟢	🟢
	6.5	6.5.1	1. **Wide Area Monitoring and Control Architecture for Transmission Systems**: High-performance and high-speed communication infrastructure combined with sensing technologies, automation and control methods, also for critical situations.	F1, F6, F7	🔴	🔴	🟠	🟠	🟢

F1 F2 F3 F4
F5 F6 F7 F8
F9 F10 F11 F12

🔴 Research (TRL 3-5)

🟠 Demonstration (TRL 6-8)

🟢 Deployment (TRL 9)

RA	RSA	Task No	Tasks – ETIP SNET R&I ROADMAP 2020-2030	Involved FUNCTIONALITIES	24	26	28	30	30+
		6.5.2	2. **Energy Management platforms for TSOs** (with the associated monitoring and control systems) able to **interact with local markets** and with embedded functionalities such as self-healing capabilities for fault management.	F1, F5, F6, F7, F8, F10	🔴	🟠	🟢	🟢	🟢
		6.5.3	3. **Energy Management Platforms for DSOs** allowing **active participation of customers in energy market** and in the grid operation optimization, **interoperability** with other actors (retailers, aggregators, TSOs) for grid status and data and smart metering data processing. Advanced functionalities for forecasting, protection and optimization in preventive and corrective way.	F1, F2, F5, F6, F7, F8, F10, F11, F12	🔴	🟠	🟠	🟢	🟢
		6.5.4	4. **Control center architectures for distributed network control** (e.g. Web-of-Cells and Microgrids) considering new sensors (e.g. fault detectors, voltage and current sensors in generation, storage, buildings, EVs, industry, etc) and also MV levels with limited bandwidths.	F1, F2, F5, F7, F8, F9, F10, F11, F12	🟠	🟠	🟠	🟠	🟢
		6.5.5	5. Anti-islanding protection, control of **intentional islanding**. Technical, economic and regulatory dimensions of interaction with local DER for islanding.	F5, F7, F8, F9, F10	🔴	🔴	🟠	🟢	🟢
		6.5.6	6. Advanced **Training simulators for DSOs and TSOs** (e.g. **using Digital Twins**) in order to adapt to new Network Energy Management platforms (including multi-energy carrier systems).	F2, F3, F5, F6, F7, F8, F9, F10, F12	🟠	🟠	🟢	🟢	🟢
		6.5.7	7. **Advanced MMI (Man-Machine-Interface)** for Energy Management System control rooms at all voltage levels, provision of suitable indicators for resilience / vulnerability and other criteria to help network operators to make decisions for preventive and corrective actions.	F1, F2, F5, F6, F7, F9, F10, F11, F12	🔴	🟠	🟢	🟢	🟢

Annex III: Methodology for FUNCTIONALITIES

The following structures have been used in the Chapter "FUNCTIONALITIES 2030" of this ETIP SNET R&I Roadmap.

Main Title "BUILDING BLOCK OF THE VISION 2050"

WHY does the Integrated Energy System need the FUNCTIONALITY? This indicates the legislative context, its evolution, justifying the need of having the FUNCTIONALITY.

WHAT FUNCTIONALITIES are needed to achieve the Objective, what R&I needs to be done for enabling a successful real-world realisation of the FUNCTIONALITIES by the year 2030? The ETIP SNET Vision 2050 Building Blocks are repeated in bold in the text. For each FUNCTIONALITY, ETIP SNET describes the expected characteristics by the year 2030.

Tasks typically take an R&I-Journeyss (First Research, usually followed by Demonstration, followed by Deployment) in the time frame between 2020 and 2030.

For each task (for list of tasks, see Annex II), an R&I-Journeys is defined to realise the FUNCTIONALITY by the year 2030. This is shown in tables displaying indicators for each research area (RA) and research sub-area (RSA) with a color code indicating the **RD** (**Research / Demonstration**)-maturity needed for each timeline (24: 2021-2024; 26: 2023-2026; 28: 2025-2028; 30: 2027-2030; 30+: beyond 2030).

Each R&I-maturity uses a specific color code and display:

- Red / Research: Indicates that the associated tasks are assumed to be at the Research level in the year indicated by the associated column header (i.e. not yet at demonstration or deployment level),
- Orange / Demonstration: Indicates that the tasks are assumed to be at Demonstration level (i.e. beyond Research level, but not yet at Deployment level) at the latest in the year indicated by the associated column header.

The number of **R**/**D** tasks is materialised by the area size of a circle: the larger the circle area, the higher is the number of tasks whose goals shall be solved by the respective year and **R**- or **D**-maturity. An empty cell means means that no Research and no Demonstration task was identified for the FUNCTIONALITY by the respective year.

Deployment: It is implied that in the time period after the Demonstration maturity has been reached, the task shall reach the Deployment level. Budgets for Deployment are not taken into consideration in this ETIP SNET R&I Roadmap 2020-2030.

Annex IV: Summary of tasks contributions to individual functionalities for ETIP SNET R&I Roadmap 2020-2030

In the following Table 18,

- the size of red-colored circle areas is proportional to the number of Research tasks with significant contributions to one or more FUNCTIONALITIES defined in the ETIP SNET R&I Roadmap 2020-2030
- the size of visible orange-colored areas is proportional to the number of Demonstration tasks, each with significant contributions to one or more of the 12 FUNCTIONALITIES ETIP SNET R&I Roadmap 2020-2030.

Demonstration tasks may also include supporting Research. This table does not explicitly mention Deployment tasks and goals during the period 2020-2030. However, they are implied to happen in the IP-periods after the tasks have fully reached Demonstration level.

In addition to the number of R(esearch)-Tasks and D(emonstration)-Tasks, the following table shows the expected budget for each RSA and each FUNCTIONALITY for the ETIP SNET R&I Roadmap 2020- 2030, visualised by background colour intensity:

- black background in table cells: highest budgets among all RSA and FUNCTIONALITIES of the period 2020-2030.
- white background in table cells: lowest budgets among all TOPICs and FUNCTIONALITIES of the period 2020-2030.

The first row of the table deals with the tasks associated to RSA 1.1 (“Social campaigns and social studies (related to societal acceptance and environmental sustainability of energy infrastructures)”). These tasks contribute in different intensities to the 12 FUNCTIONALITIES.

- Tasks related to RSA 1.1 contribute to all FUNCTIONALITIES except for F4 and F9 where there are no circles for Research tasks (red) and no circles for Demonstration tasks (orange).
- Most demonstration activities within tasks related to RSA 1.1 serve the achievement of FUNCTIONALITY F3, F5 and F6 (largest orange circles).
- The highest budget shares within tasks related to TOPIC 1.1 are dedicated to FUNCTIONALITY F3, F5 and F7 (darkest grey colour of the cells within RSA 1.1). The individual tasks of RSA 1.1 and all other TOPICS can be found in this ETIP SNET R&I Roadmap 2020-2030, Annex II.

Table 18: RM Period 2020-2030 with number of Research (red) and Demonstration (orange) Tasks and expected budgets (number of Research and Demonstration Tasks is proportional to visible red and orange areas; total budget: the higher the budget, the darker the background)

		Building Block (ETIP SNET VISION 2050) =>	The efficient organisation of energy systems			Markets as key enablers of the energy transition		Digitalisation enables new services for Integrated Energy Systems	Infrastructure for Integrated Energy Systems as key enablers of the energy transition			Efficient energy use			
Research Areas (RA)	No.	FUNCTIONALITIES => TOPIC ↓	F1 Cooperation	F2 Cross-Sector	F3 Subsidiarity	F4 Wholesale	F5 Retail	F6 Digitalisation	F7 Electricity Systems and Networks	F8 Business	F9 Simulation	F10 Flexibility	F11 Heating Cooling	F12 Transport	MIO EUR expected Budget
1. CONSUMER, PROSUMER and CITIZEN ENERGY COMMUNITY	RSA 1.1.	Social campaigns and social studies (related to societal acceptance and environmental sustainability of energy infrastructures)													54M€
	RSA 1.2.	Adaptive consumer/user behaviour including energy communities (interaction, incentives by dynamic tariffs)													98M€
	RSA 1.3.	Consumer and prosumer device control													63M€
2. SYSTEM ECONOMICS	RSA 2.1.	Business models (including Aggregators)													114M€
	RSA 2.2.	Market design and governance (Retail, Wholesale; Cross-border; Ancillary services; Flexibility markets)													316M€
3. DIGITALISATION	RSA 3.1.	Protocols, standardisation and interoperability (IEC, CIM, Information models)													337M€
	RSA 3.2.	Data Communication (ICT) (Data acquisition, Smart Meter, Sensors (monitoring), AMR, AMM, smart devices)													178M€
	RSA 3.3.	Data and Information Management (Platforms, Big Data, Software, IoT)													353M€
	RSA 3.4.	Cybersecurity (vulnerabilities, failures, risks) and privacy													129M€
	RSA 3.5.	End-to-end architecture (integrating market, automation, control, data acquisition, digital twin, end-users)													163M€
4. PLANNING - HOLISTIC ARCHITECTURES and ASSETS	RSA 4.1.	Integrated Energy System Architectures (design including new materials and hybrid AC/DC grids)													333M€
	RSA 4.2.	Long-term planning (System development)													195M€
	RSA 4.3.	Asset management and maintenance (maintenance operation, failure detection, asset lifecycles, lifespan and costs, ageing)													113M€
	RSA 4.4.	System Stability analysis													124M€

Research Areas (RA)	No.	Building Block (ETIP SNET VISION 2050) => / FUNCTIONALITIES => / TOPIC ↓	The efficient organisation of energy systems: F1 Cooperation	F2 Cross-Sector	F3 Subsidiarity	Markets as key enablers of the energy transition: F4 Wholesale	F5 Retail
5. FLEXIBILITY ENABLERS and SYSTEM FLEXIBILITY	RSA 5.1.	Demand flexibility (household and industry related)					
	RSA 5.2.	Generation flexibility (flexible thermal, RES such as Hydro, PV and wind generators)					
	RSA 5.3.	Storage flexibility & Energy Conversion flexibility (PtG&H, PtG, GtP, PtL, LtP; PtW; WtP)					
	RSA 5.4.	Network flexibility (FACTS, FACDS, smart transformers and HVDC)					
	RSA 5.5.	Transport flexibility (V2G/EV; railway, trams, trolleybus)					
6. SYSTEM OPERATION	RSA 6.1.	Supervisory control and State estimation					
	RSA 6.2.	Short-term control (Primary, Voltage, Frequency)					
	RSA 6.3.	Medium- and long-term control (Forecasting (Load, RES), secondary & tertiary control: LFC, operational planning: scheduling/optimization of active/reactive power, voltage control)					
	RSA 6.4.	Preventive control/restoration (Contingencies, Topology (including Switching) optimisation, Protection, Resilience)					
	RSA 6.5.	Control Center technologies (EMS, platforms, Operator training, Coordination among Control Centers)					
		Total Budget ETIP SNET R&I Roadmap 2020-2030	315M€	282M€	154M€	122M€	352M€

No.	Digitalisation enables new services for Integrated Energy Systems: F6 Digitalisation	Infrastructure for Integrated Energy Systems as key enablers of the energy transition: F7 Electricity Systems and Networks	F8 Business	F9 Simulation	Efficient energy use: F10 Flexibility	F11 Heating Cooling	F12 Transport	MIO EUR expected Budget
RSA 5.1.								99M€
RSA 5.2.								226M€
RSA 5.3.								210M€
RSA 5.4.								120M€
RSA 5.5.								71M€
RSA 6.1.								128M€
RSA 6.2.								50M€
RSA 6.3.								122M€
RSA 6.4.								193M€
RSA 6.5.								210M€
Total	457M€	515M€	387M€	351M€	525M€	301M€	238M€	4000M€

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