ETIP SNET

ETIP SNET R&I IMPLEMENTATION PLAN

2021–2024

ETIP SNET

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2021-2024

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Disclaimer

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Acronyms

AMM	Advanced Meter Management
AMI	Advanced Metering Infrastructure
AC	Alternating current
API	Application Program Interface
AI	Artificial Intelligence
BRP	Balance Responsible Party
BSP	Balancing Service Providers
CAPEX	Capital Expenditures
CHP	Combined Heat and Power
CIM	Common Information Model
DSR	Demand-Side Response
DC	Direct Current
DSO/TSO	Distribution/Transmission System Operators
EV	Electric Vehicle
EMF	Electromagnetic Fields
EMS	Energy Management Systems
ETSI	European Telecommunications Standards Institute
LEC	Energy Community / Citizen Energy Community / Local Energy Community
FACTS/FACDS	Flexible AC Transmission / Distribution System
HVDC	High Voltage Direct Current
GtH	Gas-to-Heat
GtP	Gas-to-Power
GtP&H	Gas-to-Power and Heat
GDPR	General Data Protection Regulation
G2V	Grid-to-Vehicle

HV	High Voltage
IT	Information Technology
IEEE	Institute of Electrical and Electronic Engineers
IEC	International Electrotechnical Commission
IoT	Internet of Things
LCOE	Levelized Cost Of Electricity
LtP	Liquid-to-Power
LFC	Load Frequency Control
LV	Low Voltage
M2M	Machine-to-Machine
ML	Machine Learning
MV	Medium Voltage
MEC	Multi-Access Edge Computing
NZEB	Near Zero Energy Building
NTC	Net Transfer Capacity
OLTC	On Load Tap Changer
OPEX	Operational Expenditures
ORC	Organic Rankine Cycle
OT	Overhead Transmission
PMU	Phasor Measurement Unit
PST	Phase Shifting Transformer
PCC	Point of Common Coupling
PE	Power Electronics
PQ	Power Quality
PtG	Power-to-Gas
PtH	Power-to-Heat

PtG&H	Power-to-Gas and Heat
PtL	Power-to-Liquid
PtW	Power-to-Water
RES	Renewable Energy Sources
SME	Small and Medium-sized Enterprise
SoH	State-of-Health
TYNDP	Ten Years Network Development Plan
TOTEX	TOTal EXpenditures
TSO	Transmission System Operators
V2G	Vehicle-to-Grid
VPP	Virtual Power Plant
WtP	Water-to-Power
WAMS	Wide Area Measurement System

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Executive Summary

Context

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

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

The EU "Green Deal" and related European national requirements set precise targets by 2030 including:

- Decarbonisation of the building stock, transport, industry, and energy systems.
- Involvement of consumers and citizen communities in energy systems.
- Digitalisation as an enabler of the environmental transition and participative energy markets.
- Ambitious reductions in transport emissions.
- Reliability, adaptability and resilience of the integrated energy systems.

While the ETIP SNET VISION 2050 provides a detailed description of this future with a set of goals to reach by 2050, **the ETIP SNET R&I Roadmap 2020-2030 describes the path towards this future.** However, this path is not linear for each of the goals defined for 2050. Some of the tasks will need to be deployed and implemented before others (prerequisites). Others will only need to be prepared or demonstrated by 2030 so that their deployment can be done between 2030 and 2040 or later, but obviously before 2050.

To meet the EU "Green Deal" and related European national requirements targets listed above, the R&I Roadmap 2020-2030 translates these requirements into 5 fundamental elements of an integrated energy system – called hereafter **BUILDING BLOCKS** – that are composed of 12 different impacts suited to achieve a specific purpose - called hereafter **FUNCTIONALITIES**.[1] To realise the 5 BUILDING BLOCKS and turn the associated 12 FUNCTIONALITIES into reality by 2030, **6 Research Areas** have been identified. These Research Areas were further divided in **24 TOPICS** (Research Sub-Areas), complemented by **Research and Demonstration activities**, referred to hereafter as **TASKS**.

Each task has dedicated maturity levels (expressed in Technology Readiness Level – **TRL**) to be reached by certain dates between 2020 and 2030. The tasks were developed in several iterations starting from a set of more than 400 tasks, from the previous ETIP SNET R&I Roadmap 2017-2026. ETIP SNET Stakeholders were strongly involved in the concatenation of these tasks, bringing them down to 261 tasks. This list was further concentrated in 120 tasks, as presented in this ETIP SNET R&I implementation plan 2021-2024.[2]

ETIP SNET recognises that in order to reach deployment,[3] research and above all demonstrations of these tasks are needed not only locally, but also at country, cross-country and pan-European level. It is well recognised that some of the tasks are local and national. The different aspects of tasks need to be researched and demonstrated in different types of environments, such as large-, medium- and small-sized cities, communities, rural areas, mountain-areas, and islands. The tasks may be cross-border, regional or even pan-European.

Each TOPIC can serve as input, not only to "Horizon Europe" for work programmes and co-funded projects at European level, but also to the transnational, national and regional projects (and preceding national roadmaps, R&I Implementation Plans, work programmes and calls) among and within European countries.

1 The five ETIP SNET VISION 2050 BUILDING BLOCKS and the 12 FUNCTIONALITIES of the ETIP SNET R&I Roadmap 2020-2030 are described in detail in Chapter I.

2 The 261 "stakeholder tasks" are available at: https://www.etip-snet.eu/wp-content/uploads/2020/05/ETIPSNETStakeholderTasks202001.pdf

3 Deployment and Innovation are meant in the same way in this ETIP SNET R&I Roadmap 2020-2030. They represent the phase after Research and Demonstration.

The Implementation Plan also indicates if – in this time horizon – the TOPIC is recommended to be at **Research** or at **Demonstration** level. Each TOPIC is described in terms of:

- CHALLENGE
- SCOPE
- SHORT-TERM AND LONG-TERM IMPACTS
- THE LIST OF TASKS THAT WILL BE INVESTIGATED IN R&I PROJECTS SORTED
- OUTCOMES OF R&I PROJECTS
- PARTICIPATING STAKEHOLDERS
- TRL AND RELATED BUDGETS

For further explanations of the ELABORATION PROCESS OF THE ETIP SNET R&I IMPLEMENTATION PLAN (IP) 2021-2024, see Chapter I.

Synthesis of TOPICS and budgets for 2021-2024

Applying a top-down stakeholder approach combined with the bottom-up methodology:

> The Research and Demonstration tasks together require an estimated budget of approximately €955 million for the period 2021-2024 from the estimated total budgets of around €4,000 million over the 10-year period 2020-2030.

The budgets for the first Implementation Plan (IP) Period 2021-2024 and the total for the whole Roadmap 2020-2030 was defined by the ETIP SNET stakeholders in a consultative process. The split of the total budgets was then based on the budget methodology where each task has an associated expected budget based on the number of functionalities to which it contributes and the maturity level the task should reach in each IP Period. These principles allow to calculate budgets in any aggregated way and per IP Period. (See Annex 1 for the methodology applied to the budget of the ETIP SNET R&I Implementation Plan 2021-2024.)

Table 1[4] shows how expected total budget of €955 million for the period 2021-2024 are divided among Research Areas and their contributions to each of the five building blocks.[5]

Table 2 below shows the ETIP SNET stakeholder-defined budgets in millions of Euros for each TOPIC for the period 2021-2024.

4 The following table shows the expected budget for each Research area and each BUILDING BLOCK for the ETIP SNET R&I Implementation Plan 2021-2024, visualized by background colour intensity:
- black background in table cells: highest budgets in the period 2021-2024.
- white background in table cells: lowest budgets in period 2021-2024.
- The first row of the table deals with the R&I efforts associated to Research Area 1 ("1. CONSUMER, PROSUMER and CITIZEN ENERGY COMMUNITY). The underlying tasks associated contribute in different intensities (budget, number of tasks, number of FUNCTIONALITIES) to the five building blocks.
- These individual tasks of each Research Area and how they contribute to the Building blocks can be found in the ETIP SNET R&I Roadmap 2020-2030, Annex II and in the SCOPE sections of each TOPIC, described in detail in this ETIP SNET R&I Implementation Plan 2021-2024.

5 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.

Table 1: IP Period 2021–2024 with expected budgets (budgets in millions of Euros)

		ETIP SNET Buidling Blocks (ETIP SNET Vision 2050)					
	Budgets ETIP SNET R&I Implementation Plan 2021–2024 for 5 building blocks and 6 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
ETIP SNET Research Areas	1. CONSUMER, PROSUMER and CITIZEN ENERGY COMMUNITY	15	15	10	8	29	77
	2. SYSTEM ECONOMICS	18	18	6	19	25	86
	3. DIGITALISATION	56	26	47	82	28	241
	4. PLANNING – HOLISTIC ARCHITECTURES and ASSETS	29	18	13	71	56	187
	5. FLEXIBILITY ENABLERS and SYSTEM FLEXIBILITY	30	13	12	47	61	163
	6. SYSTEM OPERATION	30	21	20	69	62	201
	Totals	179	111	108	296	261	955

Table 2: Expected budgets for each of the TOPICs for the IP Period 2021-2024.

Research Areas (RA)	TOPIC No.	TOPIC	Budget 2021-2024 (Millions of Euros)
1. CONSUMER, PROSUMER and CITIZEN ENERGY COMMUNITY	1.1	Social campaigns and social studies (related to societal acceptance and environmental sustainability of energy infrastructures)	15
	1.2	Adaptive consumer/user behaviour including energy communities (interaction, incentives by dynamic tariffs)	29
	1.3	Consumer and prosumer device control	33
2. SYSTEM ECONOMICS	2.1	Business models (including Aggregators)	22
	2.2	Market design and governance (Retail, Wholesale; Cross-border; Ancillary services; Flexibility markets)	64
3. DIGITALISATION	3.1	Protocols, standardisation and interoperability (IEC, CIM, Information models)	
	3.2	Data Communication (ICT) (Data acquisition, Smart Meter, Sensors (monitoring), AMR, AMM, smart devices)	61
	3.3	Data and Information Management (Platforms, Big Data, SW, IoT)	35
	3.4	Cybersecurity (vulnerabilities, failures, risks) and privacy	66
	3.5	End-to-end architecture (integrating market, automation, control, data acquisition, digital twin, end-users)	24
4. PLANNING – HOLISTIC ARCHITECTURES and ASSETS	4.1	Integrated Energy system Architectures (design including new materials and hybrid AC/DC grids)	55
	4.2	Long-term planning (System development)	72
	4.3	Asset management and maintenance (maintenance operation, failure detection, asset lifecycles, lifespan and costs, ageing)	48
	4.4	System Stability analysis	29
5. FLEXIBILITY ENABLERS and SYSTEM FLEXIBILITY	5.1	Demand flexibility (household and industry related)	38
	5.2	Generation flexibility (flexible thermal, RES such as Hydro, PV and wind generators)	28
	5.3	Storage flexibility & Energy Conversion flexibility (PtG&H, PtG, GtP, PtL, LtP; PtW; WtP)	53
	5.4	Network flexibility (FACTS, FACDS, smart transformers and HVDC)	40
	5.5	Transport flexibility (V2G/EV; railway, trams, trolleybus)	24

Research Areas (RA)	TOPIC No.	TOPIC	Budget 2021-2024 (Millions of Euros)
6. SYSTEM OPERATION	6.1	Supervisory control and State estimation	26
	6.2	Short-term control (Primary, Voltage, Frequency)	20
	6.3	Medium- and long-term control (Forecasting (Load, RES), secondary & tertiary control: LFC, operational planning: scheduling/optimization of active/reactive power, voltage control)	37
	6.4	Preventive control/restoration (Contingencies, Topology (including Switching) optimisation, Protection, Resilience)	54
	6.5	Control Center technologies (EMS, platforms, Operator training, Coordination among Control Centers)	64
Total expected budget for the ETIP SNET R&I Implementation Plan 2021-2024			**955**

I.
Introduction

Policy drivers for the energy transition

With the **European "Green Deal"** released in December 2019, the European Union has taken another considerable step towards the ambition of a climate neutral Europe by 2050. Making this goal a reality will require to achieve some key milestones such as:

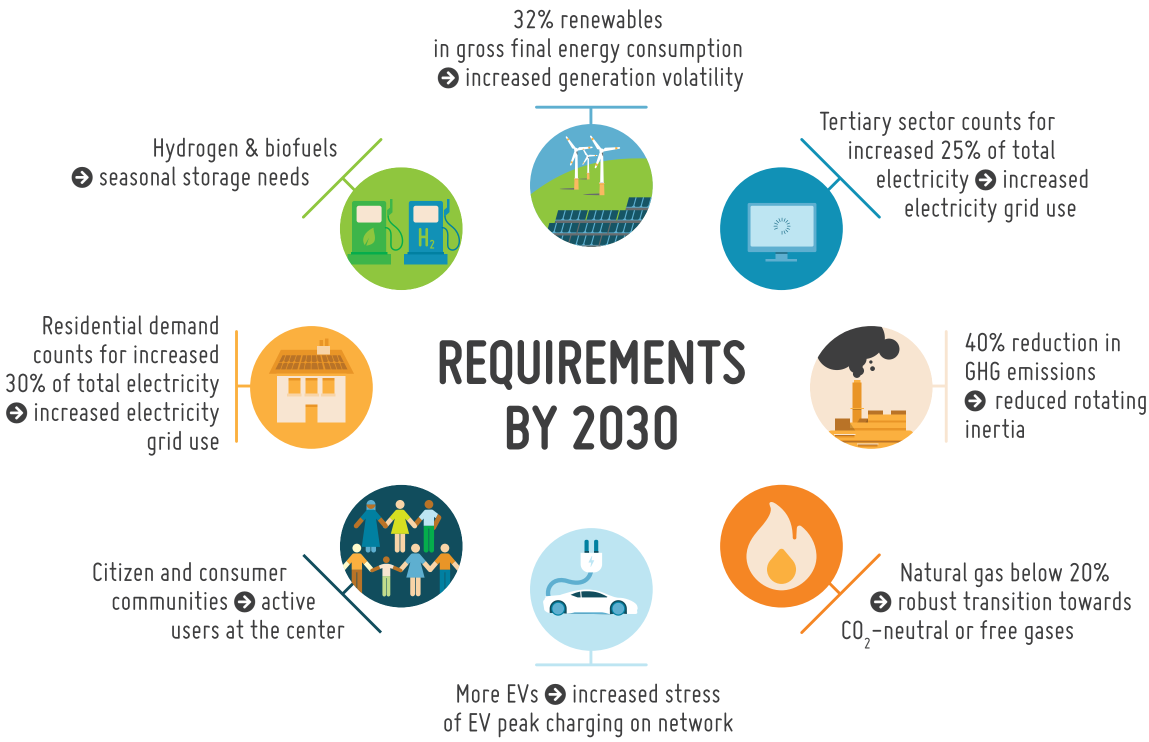
- Decarbonising the building stock, transport, industry, and energy systems.
- Involving consumers and citizen communities in the energy systems
- Digitalisation as an enabler of the environmental transition and of participative energy markets
- Reducing transport emissions.
- Increasing reliability, adaptability and resilience of the integrated energy systems.

Some **clear targets are set for the time horizon 2030** that will require the involvement of all stakeholders of the energy system (end-users; electricity, gas, heat and cooling providers; other market participants; grid operators; governments and regulators). Reaching those targets also requires a shift in technologies and infrastructures, as well as a change of laws and governance processes, and their implementation by regulators at EU and national levels.

The key indicators and their targets by 2030 are synthesised here:

- Greenhouse gas emissions are reduced by 40% compared to 1990; and renewable energy reaches at least 32% of gross final energy consumption.
- Electricity becomes the dominant energy carrier and its shares in the final energy demand grow steadily from 22% in 2015 to 29% in 2030; the share of renewables in gross electricity generation reaches 57% in 2030.
- The flexibility of energy systems is increased (both demand side and generation, including storage (such as with batteries, by use of (CO2-neutral or free) gases and liquids) so that the needed system services for the present and forthcoming system state (with more RES, more flexible demand, more storage) can be provided.
- The share of transport electricity use (except from trains, tramways) in total electricity consumption is still limited in 2030, however, simultaneous charging of EVs may lead to operational challenges, power quality and power system stability issues for electricity distribution grids (temporal overloads and too low voltages). Smart Charging prevents such operational challenges.
- Residential electricity use accounts for 30% of total electricity end use: this implies an increase in use of electricity for heating and cooling (via heat pumps) considering only a minor efficiency improvement due to the slow renovation rate of buildings and their insulation.
- Industrial electricity uses shift towards carbon neutral heat supply. Electrification, hydrogen or the use of green fuels will depend on the heat demand profiles and temperature needs. Electrification is one option.
- Tertiary sector (services) electricity uses reach up to 25% of total electricity end use with strong energy efficiency improvements.
- Household consumers (citizens) become "active consumers" thanks to new regulations and governance processes facilitating self-consumption, sustainable bio-energy, and Citizen Energy Communities.
- Distributed renewable energy sources are stimulated and integrated to buildings and the local environment.
- The share of nuclear energy in gross inland consumption (14% in 2015) remains stable.
- The share of natural gas (excluding non-energy uses) remains stable at approx. 20% .

Figure 1: Key indicators for Europe to be achieved by 2030



A shared vision and plan for the future European energy system

ETIP SNET – the European Technology & Innovation Platform (ETIP) for Smart Networks for Energy Transition (SNET) – was propelled by the European Commission to gather all stakeholders of the energy sector in view of guiding the Research, Development & Innovation activities required to support Europe's energy transition.

ETIP SNET VISION 2050

In 2018, as a result of a wide collaborative process, ETIP SNET published its **VISION 2050** describing a shared view of the energy sector on the requested features of the future European energy system in order to meet the above-mentioned ambitions.

This vision relies on the key assumption that the extensive electrification in (nearly) all sectors of the energy system, combined with large energy efficiency improvements and CO_2 reductions in all sectors, will allow Europe to reach a carbon-neutral energy system by 2050, based on:

- The massive deployment of renewables for electricity and heating & cooling generation,
- The deployment of Smart Grids technologies (Digitalisation and Smart control of flexible generation and demand, sustainable buildings),
- The combination of the above with sector coupling of all energy carriers via storage and conversion technologies (for extensive use of carbon neutral gases and green fuels and possibly hydrogen in industry, transport and buildings),
- A widely adopted circular approach of the energy systems, with high recycling rates.

The VISION 2050 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:

Table 3: The five BUILDING BLOCKS of the ETIP SNET Vision 2050 and their association to the FUNCTIONALITIES of the ETIP SNET Roadmap 2020-2030

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

Each of the five building blocks has a set of defined FUNCTIONALITIES as shown in Table 3 and defined in the ETIP SNET R&I Roadmap 2020-2030.

ETIP SNET R&I Roadmap 2020-2030

Based on this VISION 2050, the ETIP SNET developed in 2019 an **R&I Roadmap 2020-2030 in order to define pragmatic steps and achievable intermediary goals by 2030 in the transition towards the 2050 ambitions.**

The ETIP SNET R&I Roadmap 2020-2030 defines **12 FUNCTIONALITIES** that the energy system will have to ensure by 2030, as listed in Table 4. They are based on climate-science and integrated energy-system science insights. Some of them have been translated, via the European Clean Energy Legislation, into corresponding legal requirements for society. The implementation of these FUNCTIONALITIES in the energy system 2030 is urgently needed and requires more research, small-scale pilots and large-scale demonstrations and finally, deployment of products and services to enable their replicated, scaled-up implementation.

Table 4: The 12 FUNCTIONALITIES to be implemented by 2030.

FUNCTIONALITY (Full name)	Short FUNCTIONALITY[29]
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
F4 Pan-European wholesale markets	F4 Wholesale
F5 Integrating local markets (enabling citizen involvement)	F5 Retail
F6 Integrating digitalisation services (including data privacy, cybersecurity)	F6 Digitalisation
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
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 R&I Roadmap 2020-2030 then specifies **6 Research Areas** and related sub areas (or TOPICS), in which Research & Innovation activities must be conducted in order to enable turning those FUNCTIONALITIES into reality. They are synthesised in Table 5.

Table 5: Research Areas and Sub Areas

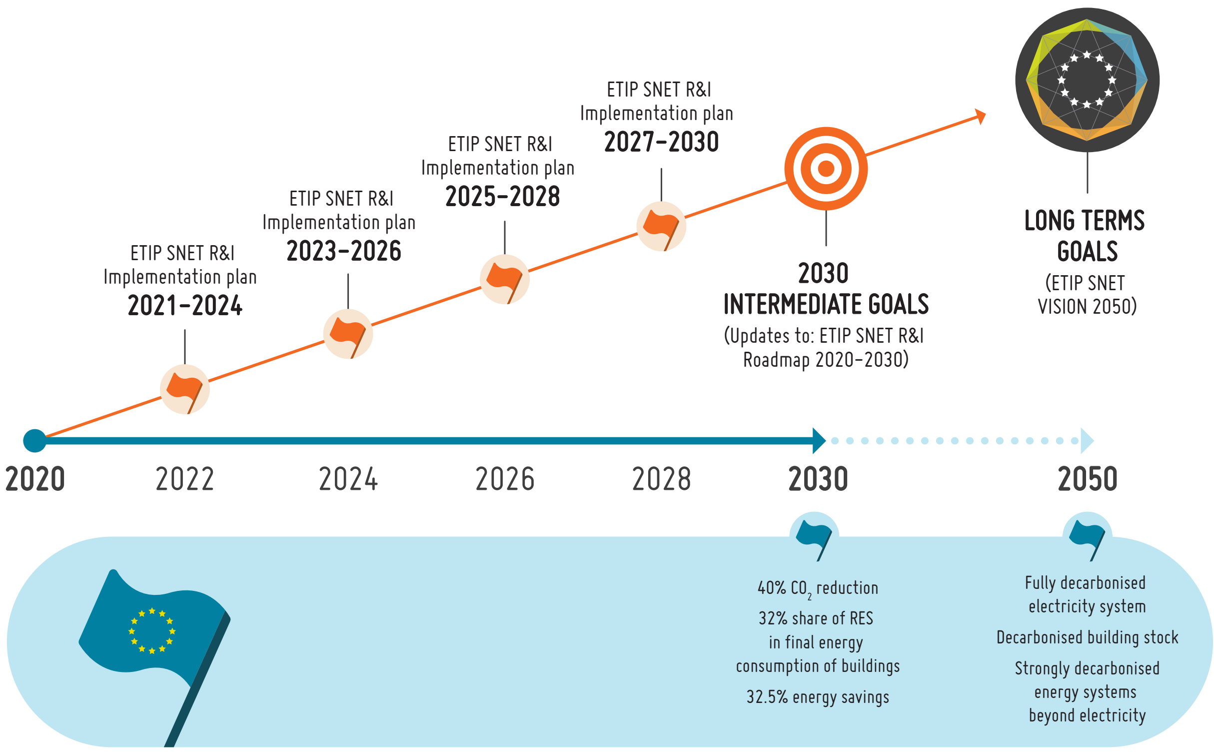
Research Areas (RA)	TOPIC No.	Research Sub Areas or TOPICS
1. CONSUMER, PROSUMER and CITIZEN ENERGY COMMUNITY	1.1	Social campaigns and social studies (related to societal acceptance and environmental sustainability of energy infrastructures)
	1.2	Adaptive consumer/user behaviour including energy communities (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 Communication (ICT) (Data acquisition, Smart Meter, Sensors (monitoring), AMR, AMM, smart devices)
	3.3	Data and Information Management (Platforms, Big Data, SW, IoT)
	3.4	Cybersecurity (vulnerabilities, failures, risks) and privacy
	3.5	End-to-end architecture (integrating market, automation, control, data acquisition, digital twin, end-users)
4. PLANNING – HOLISTIC ARCHITECTURES and ASSETS	4.1	Integrated Energy system Architectures (design including new materials and hybrid AC/DC grids)
	4.2	Long-term planning (System development)
	4.3	Asset management and maintenance (maintenance operation, failure detection, asset lifecycles, lifespan and costs, ageing)
	4.4	System Stability analysis
5. FLEXIBILITY ENABLERS and SYSTEM FLEXIBILITY	5.1	Demand flexibility (household and industry related)
	5.2	Generation flexibility (flexible thermal, RES such as Hydro, PV and wind generators)
	5.3	Storage flexibility & Energy Conversion flexibility (PtG&H, PtG, GtP, PtL, LtP; PtW; WtP)
	5.4	Network flexibility (FACTS, FACDS, smart transformers and HVDC)
	5.5	Transport flexibility (V2G/EV; railway, trams, trolleybus)

Research Areas (RA)	TOPIC No.	Research Sub Areas or TOPICS
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)

ETIP SNET R&I Implementation Plan 2021-2024

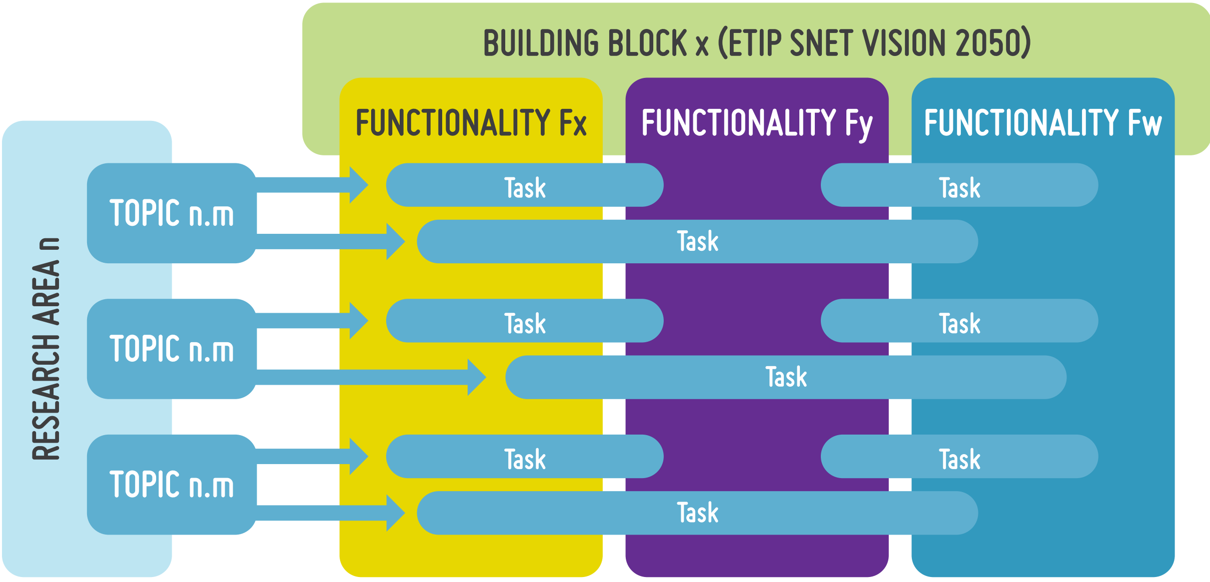
This ETIP SNET R&I Implementation Plan 2021-2024 details the Research and Demonstration activities that must be performed in order of priority. This Implementation Plan will be followed by three other R&I Implementation Plans that will cover the subsequent time periods until 2030.

Figure 2: ETIP SNET key steps from today to 2030 for achieving the 2050 goals.



Some tasks need to be deployed and implemented before others (as prerequisites), while some other tasks only need to be prepared or demonstrated by 2030, so that their deployment can be done between 2030 and 2040 or later. The ETIP SNET R&I Implementation Plan 2021-2024 therefore describes the required R&I tasks to be achieved by 2024 in relation to the 12 FUNCTIONALITIES (and the Building blocks) and to the 6 Research-Areas and related sub-areas (TOPICS) specified in the Roadmap. These task descriptions intend to serve as a basis for the (co-funded) R&I projects to be launched in the coming four years which may typically choose one or more of the tasks defined for each TOPIC.

Table 6: Example of the link between research areas, topics and tasks with functionalities and associated building blocks



Diversity in European landscapes requires implementation from local to transnational levels

The TOPICS detailed in the next sections are intended to serve as inputs not only to “Horizon Europe” for work programs and co-funded projects at European level, but also to the transnational, national and regional projects (and preceding national roadmaps, R&I Implementation Plans, work programmes and calls) among and within European countries.

Each TOPIC has a defined set of associated tasks with an associated R&I Journey[6], as defined in the ETIP SNET Roadmap 2020-2030. ETIP SNET recognises that in order to reach deployment[7], research and above all demonstrations of these tasks are needed not only locally, but also at country, cross-country and pan-European level. It is well recognised that some of the tasks are local and national:

6 The R&I Journey expresses the desired TRL-maturity which each task will have at a given year during the roadmap period 2020-2030. Typically, an R&I Journey starts with Research (TRL 3-5), then continues with Demonstration (TRL 6-8) and ends up with deployment (TRL 9).

7 Deployment and Innovation are meant in the same way in the ETIP SNET R&I Roadmap 2020-2030. It is the phase after Research and after Demonstration.

- due to different characteristics of weather (temperature, clouds, sunshine, wind, rain) during each day and seasons of the year
- due to different energy potentials
- due to different consumer and prosumer mixes and needs

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

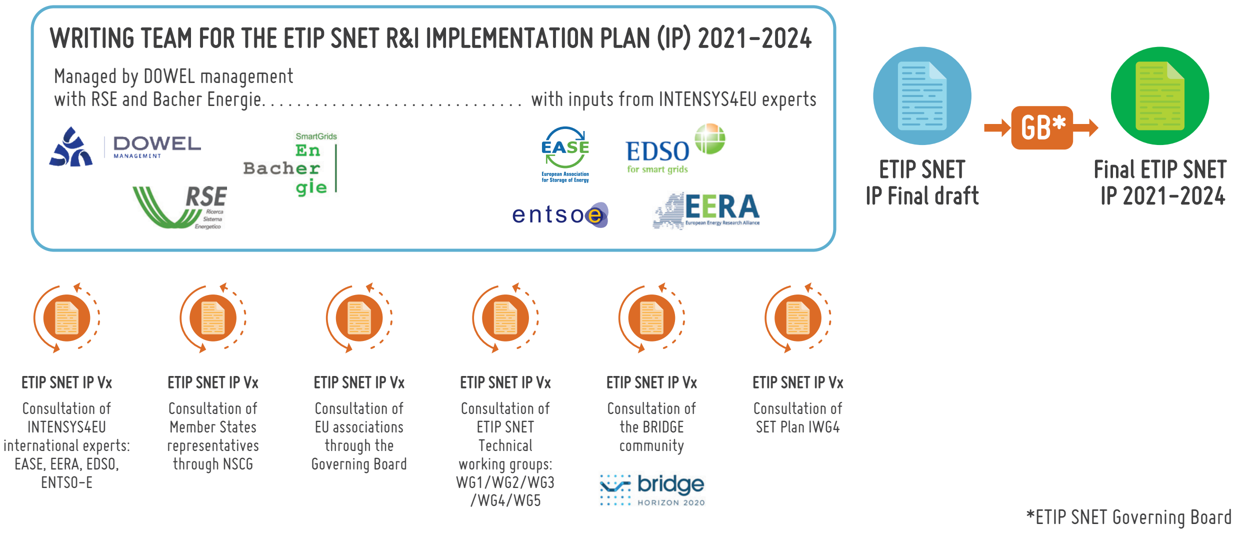
- the (EU-) internal electricity market
- harmonisation and standardisation of the IT
- flexibility markets
- sector coupling initiatives
- industrial applications

Challenges, such as balancing of variable RES, differ from one environment (such as northern Europe with more off-shore wind capacity and high bio-energy potentials) to another (such as southern Europe with higher PV yield). Across all solutions, however, are principles (such as interoperability, grid-operator cooperation, system flexibility solutions, smart charging, hierarchical control) that urgently require common solutions and knowledge sharing across Europe. These aspects need also to be balanced when selecting and funding R&I projects.

Collaborative process to build the ETIP SNET R&I IMPLEMENTATION PLAN 2021-2024

The elaboration of this document was coordinated by the ETIP SNET Core team (BACHER, DOWEL, RSE) in close cooperation with the ETIP SNET energy system stakeholders: INTENSYS4EU internal experts, EU associations, ETIP SNET technical Working Groups (WG1, WG2, WG3, WG4, WG5), BRIDGE initiative leaders and the SET Plan IWG4, Member States' representatives, through several consultation rounds in 2019 and early 2020. The ETIP SNET Governing Board (GB) was regularly informed about the progress made and validated the new structure adopted.

Figure 3: A collaborative process to build the ETIP SNET R&I Implementation Plan 2021-2024



Structure of this report

Chapter II describes each of the TOPICS to be undertaken during 2021-2024 and provdes for each TOPIC the following structure:

CHALLENGE: why is this TOPIC needed, what is lacking today and what is needed.

SCOPE: why is this TOPIC relevant and what key OUTCOMES will be produced.

SHORT-TERM AND LONG-TERM IMPACTS: the achievement of the OUTCOME has on the European Energy system and affected or involved stakeholders:

- Short-term impacts in this ETIP SNET R&I Implementation Plan 2021-2024 typically refer to the period until 2024.
- Long-term impacts in this ETIP SNET R&I Implementation Plan 2021-2024 refers to the time until 2030 or later.

LIST OF TASKS: to be investigated in R&I projects sorted in descending budget per task from the whole ETIP SNET R&I Roadmap 2020-2030, grouped by TOPIC. The background colour of the first column includes the desired task-TRL-maturity by the year 2024 where **Red indicates Research (TRL 3-5)**, **Orange indicates Demonstration (TRL 6-8)** and **Green indicates Deployment (TRL 9)**.

- Column 1 indicates the relative number of the task within each TOPIC.
- Column 2 indicates the priority of each task:
  - Priority "R" means that this is a Research (TRL 3-5) task that must be done in the IP period 2021-2024, because in the follow-up IP period, its maturity level will be "Demonstration".
  - Priority "D" means that this is a Demonstration (TRL 6-8) task that must be done in the IP period 2021-2024, because in the follow-up IP period, its maturity level will be "Deployment".
  - Priority "4 or 5 BB" means that this is a task that will be done in the IP period 2021-2024, because its FUNCTIONALITIES contribute to four or even five BUILDING BLOCKS (of a total of five building blocks).
  - Priority "3 BB" means that this is a task that will be done in the IP period 2021-2024, because its FUNCTIONALITIES contribute to three BUILDING BLOCKS (of a total of five building blocks)
  - Priority "€" means that this is a task that will be done in the IP period 2021-2024, because its budget is among the top task-related budgets of this IP-Period 2021-2024.
  - Column 3 describes the task.
  - Column 4 describes the expected FUNCTIONALITIES towards which the task contributes.

OUTCOMES of R&I projects on this TOPIC of planned activities: a tangible result or tangible effect of projects dealing with the TOPIC.

Outcomes defined in this ETIP SNET R&I Implementation Plan 2021-2024 refer to key results and effects to be achieved in R&I projects beginning in the period 2021-2024.

PARTICIPATING STAKEHOLDERS: a group of persons who are involved with in organizations, society, etc. and therefore have responsibilities towards it and a strong interest in its success.

TRL (Technology Readiness Level) and related BUDGETS: a measure for estimating the maturity of technologies during the execution of the R&I projects from basic **research (TRL 1 upward)** via **demonstration of technology (TRL 6 upward)** to **deployment (TRL 9)** of technology; and financial figures in millions of Euros to show what budget is needed to achieve the OUTCOMES in terms of **D(emonstration)** and **R (esearch)**.

- The TRLs defined in this ETIP SNET R&I Implementation Plan 2021-2024 refer to the goal TRL to be reached in the year 2024. Progress implies increasingly higher TRLs.
- The budget in this ETIP SNET R&I Implementation Plan 2021-2024 refers to projects defined for and beginning in the period 2021-2024.

Chapter III gives insights on the budget for the R&I Implementation Plan 2021-2024 and provides a synthetic view on how budgets and research and & demonstration tasks are distributed among the different research topics, and how they contribute to the 12 FUNCTIONALITIES (and by that to the BUILDING BLOCKS) defined in the Roadmap.

Chapter IV gives a synthesis on the ETIP SNET R&I Implementation plan.

Chapter V indicates the next steps to prepare the next R&I Implementation plan.

II.
ETIP SNET Topics during 2021-2024

R&I Stakeholder groups contributing to the TOPICS

Different types and groups of stakeholders will participate in R&I projects during 2021-2024:

Table 7: R&I Stakeholder groups contributing to the TOPIC

Stakeholder Groups	Explanation
Research & Academia	research centres, universities, think-tanks, consultants and other services.
Consumers	residential, professional and industrial consumers, as well as cities acting as consumers in projects.
Citizen Energy Communities	associations, cooperatives, partnerships, non-profit organisations or other legal entities which are effectively controlled by local shareholders or members, generally value- rather than profit-driven, involved in distributed generation and in performing activities of a distribution system operator, supplier or aggregator at local level, including across borders.
Energy Suppliers	power generators (thermal, retailers, energy service companies) acting in the competitive energy market.
Aggregators	market participants that combine multiple customer loads or generated electricity for sale, for purchase or auction in any organised energy market.
Market operators	power exchanges, brokers and traders on the energy markets.
Regulated (Grid) Operators	TSOs (Transmission System Operators), TNO (Transmission Network Operators), SO (System Operators) and DSOs (Distribution System Operators) as defined by the Electricity Directive.
Power technology providers	manufacturers of hardware and all types of monitoring, protection and control solutions for power transmission, distribution and generation.
Storage technology providers	all storage technologies, including batteries from EVs with associated smart charging and V2G, hot water tanks, storage for carbon neutral or free gases and liquids, car manufacturers, and manufacturers of charging infrastructure.

Stakeholder Groups	Explanation
ICT providers	software and telecommunication vendors
Regulators, Certification authorities	as defined by the Electricity Directive, and Certification authorities are needed to certify standards
Heating and cooling operators, gas and water system operators, conversion plants manufacturers	Additional categories are identified. They cover stakeholders that do not fall in any of the above-defined categories such as Heating and cooling operators, gas and water system operators, conversion plants manufacturers.

Detailed description of the 24 TOPICS

RA 1: CONSUMER, PROSUMER and CITIZEN ENERGY COMMUNITY

TOPIC 1.1: Social campaigns and social studies (related to societal acceptance and environmental sustainability of energy infrastructure)

CHALLENGE

The target of at least 32% of renewable energy in gross final energy consumption in 2030 relies on measures to facilitate the participation of citizens in the energy transition. In the process of acceptance of the integration of variable Renewable Energy Sources (vRES), social and environmental aspects must be considered at all levels.

The transition of societal needs from today's energy system towards the future energy system need to be analysed: social studies and communication campaigns are needed to raise awareness with citizens, to build common knowledge and to involve them in the decisions process since the very beginning. In parallel, the current energy infrastructures do not consider yet environmental sustainability such as related to human and animal exposure to EMF and 5G effects. R&I efforts are needed to reduce negative environmental effects from, for example, hydropower plants, windmills, and HV infrastructure.

The integration of vRES needs communication campaigns to increase public awareness, acceptance and engagement regarding the building of energy communities and the process of construction of energy infrastructures; the reduction of impacts of the energy infrastructure on the environment and on wildlife; and efforts to put the end-user (customer) at the centre of the energy system.

SCOPE

The TOPIC will include, as a basis for subsequent work, social studies fostering societal acceptance and environmental sustainability of energy infrastructure.

The TOPIC will include, as a basis of further works, social studies fostering societal acceptance and environmental sustainability of energy infrastructure.

Social acceptance and environmental sustanaibility are key elements to foster the integration of variable Renewable Energy Sources (vRES). Some examples are:

- the overhead line of 132 kV design and construction connecting southern Cyprus to the mountains of Cyprus replacing an older line that has long passed its useful life. The study initiated in 1991 and to this day the line remains incomplete due to public reaction in an area affecting 3 mountain communities. About 80% of the line is complete but in between the two constructed sections there is approximately 20% of the line still pending, and currently operating using the old insecure link running through inhabited areas.
- the delay in the construction of a 400 kV HV line in southern Greece, necessary to transfer the energy produced by a new natural gas 417 MW thermal station, one of the largest in the country enough to supply 400,000 households. The operation of this modern unit would benefit the Greek economy about €40 million annually (€110k daily) thanks to the excellent efficiency rate of the unit and would have important positive environmental effects by avoiding the operation of older, polluting thermal units. The completion of just a few kilometres of the line construction was delayed for several months due to local reactions. The financial losses caused by the delayed operation more than doubled considering that assets of the €400 mln investment were stranded and the compensations requested by the project contractor.

Social studies will be conducted to promote stakeholder engagement and acceptance through the involvement of final users. Specific methodologies will be developed to identify the best practices between the different energy communities, to implement participative decision-making process and support public debates. Studies will also analyse how to minimise the environmental effects of energy infrastructures and harmonise environmental authorisation at EU level. Key indicators will be identified to measure both the degree of social acceptance and environmental impacts. Specific demonstrations will be developed to enhance the microgrid-by-design concept to strengthen Citizen Energy Communities for increased grid stability and reduced energy poverty.

SHORT-TERM IMPACT:

- Reduce the number of infrastructure projects / assets that cannot be realised for public acceptance reasons.
- Adopt technical solutions to bring higher socio-economical return for society in general, and that not linked to specific social groups.

LONG-TERM IMPACT:

- From the beginning of any infrastructure project / asset, implement social acceptance interaction to minimise the number of infrastructure projects / assets that cannot be realised for public acceptance reasons.
- Reduce time for the realisation of the society-accepted technical infrastructures.

The following tasks[8] will be investigated in R&I projects:

Task No	PRIORITY[9]	Tasks	Functionalities
1	€	1. Methods and tools for effective stakeholder engagement to increase **public acceptance of new energy infrastructures**, including transmission lines (overhead lines and underground cables), sub-stations, storage facilities, generation stations (thermal and RES, like hydro and wind), gas pipelines and conversion stations (links to Social Science and Humanities).	F1, F2, F3, F5, F6, F7, F8, F10
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
3		3. Studies to reduce or remove the **environmental impacts of energy infrastructures (visual and audible)** such as for hydropower plants (hydro-peaking effects, better sediment management, fish migration and fish protection, water quality), noise of transformers and transmission lines, more attractive designs for transmission-line towers, changed visibility by undergrounding.	F2, F3, F5, F6, F7

8 The background colour of Column 1 includes the desired task-TRL-maturity by the year 2024 where Red indicates Research (TRL 3-5), Orange indicates Demonstration (TRL 6-8) and Green indicates Deployment (TRL 9). Column 4 describes the expected FUNCTIONALITIES towards which the task contributes.

9 Column 2 indicates the priority of each task: Priority "R" means that this is a Research (TRL 3-5) task that must be done in the IP period 2021-2024, because in the follow-up IP period, its maturity level will be "Demonstration", Priority "D" means that this is a Demonstration (TRL 6-8) task that must be done in the IP period 2021-2024, because in the follow-up IP period, its maturity level will be "Deployment" Priority "4 or 5 BB" means that this is a task that will be done in the IP period 2021-2024, because its FUNCTIONALITIES contribute to four or even five BUILDING BLOCKS (of a total of five building blocks). Priority "3 BB" is a task to be done in the IP period 2021-2024, because its FUNCTIONALITIES contribute to three BUILDING BLOCKS. Priority "€" means that this is a task to be done in the IP period 2021-2024, because its budget is among the top task-related budgets of this IP Period 2021-2024. **The percentages of the total €955 million budget of the IP period 2021-2024, which is spent by each of the priorities are: Priority "R"= 21%, Priority "D"= 2%, Priority "4 or 5 BB" = 6%, Priority "3 BB"= 11% and Priority "€"=25%.**

OUTCOMES OF R&I PROJECTS WORKING ON THIS TOPIC:

KNOWLEDGE

- Best practices from the very beginning on how to minimise environmental effects of energy infrastructures and how to promote stakeholder engagement and acceptance (for each situation / kind of project or asset).
- Documentation in support of public debates.
- Streamlined environmental authorisation process, harmonised at EU level.
- Harmonisation of authorisation procedures for cross-border projects.
- List of KPIs to measure societal acceptance and environmental sustainability of energy infrastructure.
- Consolidated assessment methods integrating stakeholder values and concerns as validated in pilot projects.
- Validated approaches and methodologies to increase public acceptance through the involvement of final users in the rationale for grid investments.
- Consolidated procedures for full and satisfactory stakeholder engagement developed and implemented in large real-size projects.
- Validated strategies to implement participative decision-making processes in the authorisation and permitting procedures.
- Increase cooperation between public institutions and energy communities and cooperatives.

DEMONSTRATIONS

- Enhance the microgrid-by-design concept to strengthen Citizen Energy Communities for increased grid stability and reduced energy poverty.

PARTICIPATING STAKEHOLDERS:

Research & Academia	Consumers	Citizen Energy Communities	Regulated (Grid) operators	Power technology providers

TRL and related BUDGETS:

1 Research related tasks (TRL 3-5) with a budget of €3.6 million
2 Demonstration related tasks (TRL 6-8) with a budget of €11.4 million

RA 1: CONSUMER, PROSUMER and CITIZEN ENERGY COMMUNITY

TOPIC 1.2: Adaptive consumer/user behaviour incl. energy communities (Interaction, incentives by dynamic tariffs)

CHALLENGE

In 2030, local and regional demonstrations of Active Demand Response will be implemented relying on the evolution of relations between consumers, prosumers and the energy system. This change of behaviour is needed to strengthen interactions between citizen energy communities and the energy system. In the process of active consumer participation, all means of measuring electricity and other energy consumptions, user participation and motivations must be explored and evaluated.

The present relationship of the consumer and prosumer with the energy system does not address the integration needs to change society characterised by a progressive increase of environmental and sustainability consciousness that triggers behavioural changes, such as the current lack of general consideration for 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. In terms of hardware and software answers, there is a general lack of solutions that enable consumers, prosumers and communities to make informed decisions as easily as possible to create their own comfort, sustainability and security needs, considering budgetary restrictions, market-based prices and regulated tariffs.

The relationship evolution of the consumer and prosumers needs to rely on tools and knowledge for the active participation of prosumers in electricity markets, for the consumer satisfaction by energy services, and for the complete behaviour motivations of the customers to contribute to the functioning of integrated energy systems.

SCOPE

This TOPIC will include, as a basis for further works, comprehensive guidelines to define the level of interactions between the consumer, prosumer, energy communities and energy system as well as clear incentives by dynamic prices, regulated tariffs and other market incentives.

Interactions between consumers, prosumers and energy communities will be clearly specified to foster participation in electricity markets. Tools will be developed for putting the end-user in direct contact with supplier, distributor and other involved market stakeholders in order to increase consumer satisfaction. Dedicated demonstrations will show real-time optimisation of Distributed Energy Resources and increase the understanding of consumer behaviour providing direct action on demanding asset in real-time through dynamic energy management mechanisms.

SHORT-TERM IMPACT:

- Intensify behavioural motivations for end-users to become prosumers.

LONG-TERM IMPACT:

- Adapt consumer / user behaviour including energy communities for a sustainable, resilient, secure and affordable energy system.

The following tasks[8] will be investigated in R&I projects:

Task No	PRIORITY[9]	Tasks	Functionalities
1	3 BB	1. Methods and Tools to support **consumer and prosumer adaptation of their energy behaviour**, including online 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

Task No	PRIORITY[9]	Tasks	Functionalities
2		2. Methods and tools including campaigns to support the **industry's consumption adaptation** in order to support the system.	F3, F4, F10, F11

OUTCOME OF R&I PROJECTS WORKING ON THIS TOPIC

KNOWLEDGE

- Guidelines for the participation of prosumers and energy communities in electricity markets.
- Guidelines for the implementation of incentives by dynamic prices, regulated tariffs and other market incentives.
- Regulatory framework.
- Regulatory models.
- Participation of consumers and prosumers in demand response campaigns through aggregators and retailers.

ALGORITHMS, SOFTWARE, MODELS AND TOOLS

- Applications devices for putting the end-user in direct contact with supplier, distributor and other involved market stakeholders.
- Software to provide services to increase consumer satisfaction based on IoT.

DEMONSTRATIONS

- Real-time optimization of Distributed Energy Resources.
- Increase understanding of consumer's behaviour by matching consumption profiles to specific loads providing and automatized identification of the demanding assets being able to act on them in real-time through dynamic energy management mechanisms.

PARTICIPATING STAKEHOLDERS:

Research & Academia	Consumers	Citizen Energy Communities	Energy Suppliers	Aggregators	Market operators	Regulated (Grid) operators

TRL and related BUDGETS:

2 Demonstration related tasks (TRL 6-8) with a budget of €29 million

RA 1: CONSUMER, PROSUMER and CITIZEN ENERGY COMMUNITY

TOPIC 1.3: Consumer and Prosumer Device Control

CHALLENGE

In 2030 households actively participate in real-time, automated demand response (electricity, heating and cooling) with connected appliances and equipment. A shift is needed in the relation of the consumer and prosumer with the energy system mainly via technological devices. All control devices to empower the consumer must be considered.

The present consumer and prosumer device control tools do not consider enough, in the relationship towards energy system technologies, the experience from digital adopters, the user centredness of technologies, the prosumer device control, market tools. There is a general lack of solutions enabling the consumers to be actors in the energy system (roles and integration of consumer owned DER, smart metering); including local industrial actors with flexibility potential (such as load shifting and Power-to-heat/cooling solutions) to provide a more resilient, clean and self-sufficient energy community system; addressing the market opportunities offered by new digital technologies (peer-to-peer energy markets, flexibility and ancillary services markets).

Consumers and prosumers need to have access to technologies and tools to empower them with regards to the energy system in a user-friendly environment. There is a need to develop solutions including storage (such as by batteries, containers for carbon neutral or free gases and liquids), micro CHP, heat pumps, EV with smart charging, smart appliances, incentives, dynamic tariffs. Being active means also the need to connect to flexibility potential with e-mobility smart sector integration, second life EV battery systems; and to consider new digital technologies such as prosumer device control which can be used by energy communities.

SCOPE

The TOPIC will include, as a basis for further works, comprehensive documentation on the use of control devices, measurement and visualisation by consumer and prosumer to adapt their behaviour in terms of demand response.

Specific guidelines will be specified for the use of smart appliances for measurement and control devices such as smart plugs and voltage clamps, for visualization such as in-home displays, etc. Suitable IT tools will be developed to foster peer to peer interactions, improvement of cooperative energy services; optimisation of energy consumption portfolio; flexibilization of local industrial bodies behaviour. Dedicated demonstration will be set to develop and test standardized devices enabling visualisation and control of electricity consumption/generation and storage (such as by batteries, hot water tanks, containers for CO2-neutral or free gases and liquids).

SHORT-TERM IMPACT:

- Enhanced complex relation of the consumer and prosumer (be it an individual, a community, a commercial user, an industry) with the energy system by development of technologies.

LONG-TERM IMPACT:

- Full appropriation of device control by consumer and prosumer.

The following tasks[8] will be investigated in R&I projects:

Task No	PRIORITY[9]	Tasks	Functionalities
1	€	1. **Wireless technologies for direct control** of prosumers' electricity consumption/generation using low-cost technologies (smart phones).	F3, F5, F6, F10, F11
2	D	2. In-home **ICT technologies for smart appliances** (for example smart load controllers) for direct control of consumer demand, incl. visualization via in-home displays.	F3, F5, F6, F10, F11, F12

OUTCOMES OF R&I PROJECTS WORKING ON THIS TOPIC:

KNOWLEDGE

- Application guidelines for use of smart appliances, for measurement and control devices such as smart plugs and voltage clamps, for visualization such as in-home displays, web portals and smartphone apps; for interacting with the devices in an easy, intuitive way.

ALGORITHMS, SOFTWARE, MODELS AND TOOLS

- Robust and low-cost application of digital technology for peer to peer interactions (blockchain).
- Software tools for enhanced cooperative energy services increasing community's resilience and self-sufficiency.
- Automated demand management tools to optimise energy consumption portfolio of different assets at home and building level.
- Software tools to automatically calculate flexibility of different assets and trigger demand response campaigns.
- Remuneration software tools, based on energy retail and market prices.
- Tools to foster flexibilization of local industrial bodies behaviour to contribute with integrated prosumer energy systems.

DEMONSTRATION

- Developed and tested standardized devices enabling visualization and control (via protocols) of electricity consumption/generation and storage (such as by batteries, hot water tanks, containers for CO2-neutral or free gases and liquids).

PARTICIPATING STAKEHOLDERS:

Research & Academia	Consumers	Citizen Energy Communities	Aggregators	Market operators	Storage technology providers

ICT providers	Regulators, Certification authorities	Heating and cooling operators, gas and water system operators

TRL and related BUDGETS:

2 Demonstration related tasks (TRL 6-8) with a budget of €33 million

RA 2: SYSTEM ECONOMICS

TOPIC 2.1: Business models (including Aggregators)

CHALLENGE

The value chain of energy production and supply is changing with the entrance of new actors and elements. The existing structure does not fit with the new demands based of decentralised generation, electric devices and appliances, or storage requirements realised by batteries, hot water tanks, low-cost containers for CO2-neutral or free gases and liquids), where both customers and end-users are playing a fundamental role.

Business models for the different (traditional and new) stakeholders are not yet available. They must be simulated and analysed. Today's market rules for the transition towards the future energy system are not yet sufficient to enable more effective markets and to enhance the transition to a de-carbonized energy system and economy.

For example, in most of the European Countries, renewable, demand and storage resources (except pumped-storage hydropower plants) are not allowed to participate in the balancing services market.

For example, in most of the European Countries, renewable, demand and storage resources (except pumped-storage hydropower plants) are not allowed to participate in the balancing services market.

In many countries in Europe flexibility trading in the true meaning of the function, is still in its infancy. Moreover, smart charging of EVs is not included in market rules and the connected grid is still not smart enough to utilise this huge potential.

The changes in the value chain of energy production and supply, due to the entrance of new actors, technology and elements, needs to be managed, to fit the existing structure to the new demands. Standardized templates and tools to develop CBA in the smart grids' projects need to be developed and extensively used, together with the definition of new regulatory frames, ensuring equitable and fair participation and competition possibilities to all the stakeholders.

SCOPE

This TOPIC addresses the development and analysis of business models, for the different actors in the energy system playground, namely prosumers, aggregators, DSOs, storage operators (such as of batteries, heating/cooling storage, including EV recharge, EV smart charging) and heating/cooling operators.

Business models will be developed and analysed for all the different stakeholders of the energy value chain; particular focus will be devoted to actors in LV/MV systems (such as DSO, aggregators and retailers, prosumers), to storage operators and to electric mobility actors, all providing ancillary services to the network, to operators in the energy efficiency sector, to operators in the heating/cooling sector.

SHORT-TERM IMPACT:

- Support of policy makers in the definition of suitable regulatory measures related to future business during the energy transition (market rules, incentives, prices).

LONG-TERM IMPACT:

- Robust regulatory measures implemented in EU and national laws and acts to maximise welfare by profitable businesses during the energy transition.

The following tasks[8] will be investigated in R&I projects:

Task No	PRIORITY[9]	Tasks	Functionalities
1	4 or 5 BB	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	3 BB	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
3	R	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
4	3 BB	4. Business models for **storage in electrical transportation networks** (such as tramways, trains, buses).	F4, F5, F6, F8, F9, F10, F11, F12
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

OUTCOMES OF R&I PROJECTS WORKING ON THIS TOPIC:

KNOWLEDGE

- Environmental impact analysis performed according to relevant standards.
- Sustainability analysis performed as broadening and complementary to environmental impact analysis.
- Best practices to identify roles and responsibilities in the evolving and environmental-friendly power system.
- Preliminary evaluation of an evolutionary Systems of Systems (SoS) approach for the power system (standard interfaces, interface layers, system verification and validation) with embedded models and tools.
- Documentation about validated methodologies and tools to perform full sustainability analysis considering all social, economic, and environmental aspects.
- Guidelines and best practices to properly include also the indirect impacts of an investment (as well of the no-investment option) in the decision-making process.
- Standard methodologies for circular economy analysis of power system developments.
- Business model definition and analysis, for the different actors of the energy system.
- Mapped and analysed roles of the energy system stakeholders in the energy transition.
- Business case for the heating/cooling sector integrated with the electricity sector.
- Business case for leveraging cold production and power-to-cool systems, as an added value from phase-change materials, HVAC systems and chillers.
- Improvement of Business models for Demand Response Schemes.

PARTICIPATING STAKEHOLDERS:

- Research & Academia
- Citizen Energy Communities
- Energy Suppliers
- Aggregators
- Market operators
- Regulated (Grid) operators
- Power technology providers
- ICT providers
- Heating and cooling operators, gas and water system operators

TRL and related BUDGETS:

5 Research related tasks (TRL 3-5) with a budget of €22 million

TOPIC 2.2: Market Design and Governance (Retail, Wholesale; Cross-border; Ancillary services; Flexibility markets)

CHALLENGE

Increased shares of variable renewable energy, combined with the rise in distributed generation, are profoundly impacting on electricity markets, the demand for system flexibility and the business models of traditional utilities and distribution companies. This requires a rethinking of the way power sector markets are designed and operated as well as a timely and efficient adaptation of traditional market and operational mechanisms

The integration of European intra-day and balancing markets is not yet ready to be accelerated with a swift implementation of the network codes and increased dialogues and cooperation across national borders. Demand does not yet have equal market access as supply resources.

They lack access to markets (forward, day-ahead, intra-day and balancing markets) to offer their services, provided they fulfil the criteria needed for these sometimes very specific markets. The roles and responsibilities of all market parties are not yet clearly defined for a flexibility market design and for smooth functioning and security of supply.

Prior to full-scale application of new markets real-life piloting is needed. This requires regulatory sandboxes where innovative solutions can be tested ahead of widespread deployment. Roles clarification through R&I might be useful for the definition of local flexibility markets, as there may not always be enough market players to constitute a market, as well as for a common description of flexibility products .

Prosumers are not yet supported by stable, transparent and enabling regulatory frameworks. They cannot carry responsibilities e.g. for balancing according to their means; moreover, they do not yet bear network costs reflecting the services they receive from the public infrastructure, unable to ensure a fair allocation of costs between all consumer groups.

An integrated EU energy market needs to be a priority, to ensure secure and affordable energy supplies to European citizens and businesses: therefore, common energy market rules, communication standards and protocols and cross-border infrastructure need to be designed and established. Fair competition must be guaranteed to all the stakeholder in the energy supply chain, together with provisions to attract investment in the resources, like energy storage such as by batteries, hot water tanks, containers for CO_2-neutral or free gases and liquids, that can compensate for variable energy production. The markets must provide the right incentives for consumers to become more active and to contribute to keeping the electricity system stable, as well as allowing ancillary services being fairly remunerated providing essential data, together with the possibility of integration of different network.

SCOPE

This TOPIC addresses the design of energy markets at all time scales and at all geographical scales, 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).

Detailed analyses and studies will be conducted of new services which could arise in conjunction with the new aspects introduced by the Clean Energy for All Europeans Package. Standard pan-European ICT platforms will be defined to allow the interaction of the different actors in the process of acquisition of both local and cross-border ancillary services. Customers segmentation and clustering will be carefully analysed, in order to fully unlock the peer-to-peer transactions for energy and flexibilities.

Providing a reference implementation and architecture will facilitate the digitalization process for all operators. A standard solution will dramatically facilitate the implementation of innovative services for customer involvement.

The market design will be developed allowing flexible coordination between TSO and DSO, considering physical grid constraints, ancillary services and uncertainties, at the same time addressing the social welfare for the customers and energy communities. Market design will be extended beyond the electricity sector, and contribute to integration of heating/cooling, thermal storage and batteries, including those of Electric vehicles.

Targeting unhindered electricity market access of coupled sectors and technologies will benefit the liquidity of markets. With about half of EU final energy demand consumed by heating and cooling, and with increased electrification of this sector, the potential market integration in terms of MWh and MW is considerable. In EU households, heating and hot water account for 2.2 PWh/a. In industry, 2.3 PWh/a is used for space and industrial process heating.

Extensive demonstration activities are deemed necessary, especially for higher TRL. Among the issues to be covered, it is worth to include cooperation strategies for TSOs/DSOs to support cross-border AD-based service provisions, innovative market rules and mechanisms for provision of ancillary services by RES, CO2-neutral thermal generation, virtual power plants and storage systems, integration and proper valorisation of ancillary services provided by EVs and their smart charging, system services brought by gas, heating/cooling and water network operators.

SHORT-TERM IMPACT:

- Enabled new market roles, market participants and energy communities
- Enabled flexibility markets by from increasingly more variable RES, storage and conversion using hybridization of technologies and better forecasting tools
- Enabled residential DR (Demand Response)
- Freedom of choice for prosumers (selecting its own preferred energy suppliers, flexibility providers, aggregators)

LONG-TERM IMPACT:

- Enabled new market roles, market participants and energy communities
- Enabled flexibility markets by from increasingly more variable RES, storage and conversion using hybridization of technologies and better forecasting tools
- Enabled residential DR (Demand Response)
- Freedom of choice for prosumers (selecting its own preferred energy suppliers, flexibility providers, aggregators)

The following tasks[8] will be investigated in R&I projects:

Task No	PRIORITY[9]	Tasks	Functionalities
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
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
3	4 or 5 BB	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
4	4 or 5 BB	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
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
6	R	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
7	3 BB	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
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
9		9. Market design for system services (balancing) by **water cycle management operators**.	F2, F8, F10, F11

OUTCOMES OF R&I PROJECTS WORKING ON THIS TOPIC

KNOWLEDGE

- Compatible and clearly defined data-exchange interfaces.
- Regulatory framework.
- Most useful level of customers' clustering (individual, full tailoring of services, load/flexibility type-based segmentation, according to size and segmentation schemes to cluster customers/load)
- Value of peer-to-peer transactions for energy and flexibilities fully unlocked.
- Definition of the deployment process for the trans-national ENTSO-E platforms, by analysing in detail the effect of coexistence of such platforms with the present national procurement mechanisms of ancillary services. Possible distortive mechanisms and needs for harmonization are analysed.
- Detailed analyses and studies of other new services which could arise in conjunction with the new aspects introduced by the Clean Energy for All Europeans Package: in particular, new opportunities for flexible loads or combinations of loads and storage (such as distributed batteries, hot water tanks, storage for CO2-neutral or free gases and liquids), which should further mark the "central role" of the consumer in the new services market, and possible self-dispatch areas for local communities.
- Definition of standard pan-European ICT platforms to allow the interaction of the different actors in the process of acquisition of ancillary services (end-users/BSPs, market operators, TSOs, DSOs, aggregators and BRPs) in an integrated and optimized environment.

SOFTWARE, TOOLS, ALGORITHMS, MODELS

- Innovative market design and associated tools/algorithms based on new energy system requirements addressing the social welfare for the customers and energy communities
- New tools and algorithms for market and network analysis.
- Innovative and interoperable market tools and platform that integrate market signals.
- Forecasting and estimation AI (Artificial Intelligence)- and Data analytics-based logic for the smart aggregation of DER (Distributed Energy Resource) with the best added value and profit for the involved actors.
- Models of non-discriminatory decentralised market systems.
- Main architecture for the flexibility markets integrating local and European-wide markets in an efficient way and enabling multilateral flexibility where several operators (TSOs and DSOs) may be present at the same time.
- ICT requirements and standards to collect, deliver and utilize data, including data from different energy sector, to enable efficient flexibility markets.
- Methods and tools that can be used when the main architecture for the flexibility market is in place.
- Promote reliable Guarantees of Origins trading markets along Europe using trustworthy technologies (such as Blockchain).

DEMONSTRATIONS

- Power flow control devices and storage (such as batteries) **that offer increased flexibility**.
- Cooperation strategies for connected DSOs to support cross-border AD-based service provisions.
- System services brought by gas network operators.
- Ancillary services provided by Evs.
- Retail (peer-to-peer) markets with power balancing and coordinated LV/MV technical grid control.
- Market rules and mechanisms for provision of ancillary services by RES, CO2-neutral thermal generation and virtual power plants Storage and multi-service (stacking concept) fully integrated in the electricity market.
- Market architecture for EU-wide sector coupling deployed.
- Multi-energy markets considering flexibility resources developed and validated.

- Removal of the remaining obstacles to the deployment of FFR and Synthetic Inertia enlarging the test area all over Europe. This should help elaborate new common specifications to be included into the ENTSO-E grid codes. At the same time, transient effects are more thoroughly studied, thus optimising the control systems design, with the aim of providing such services.
- Optimal modalities for integrating services from DER in-distribution networks and defined best TSO-DSO coordination models.
- Tested modalities to create pan-European ICT platforms to allow the interaction of the different actors in the process of acquisition of ancillary services (end-users/BSPs, market operators, TSOs, DSOs, aggregators and BRPs).
- Integration into the ENTSO-E codes of common specifications for the new "fast" frequency services (FFR and synthetic inertia).
- Implementation of standard TSO-DSO interaction mechanisms, boosting the most efficient procurement modalities and proposing reforms for the ancillary services markets in order to better fit with such mechanisms. Results of experimentations of new mathematical procedure fit for fast elaboration of very large optimization models and of investigation on the best ICT technologies to ensure exchange of information between TSO and DSO (in conjunction with those systems which ensure observability of the distribution networks).
- Integration of the above aspects with trans-national ENTSO-E platforms while pursuing the full harmonization of the different aspects managed at local level. Seamless integration at both horizontal (between countries) and vertical level (between transmission and distribution).
- Preliminary investigations and demonstrations about interactions between different energy carriers (electricity, gas, hydrogen) as a further possible source of services for the future, whenever economically justified.

PARTICIPATING STAKEHOLDERS:

- Research & Academia
- Consumers
- Citizen Energy Communities
- Energy Suppliers
- Aggregators
- Market operators
- Regulated (Grid) operators
- Regulators, Certification authorities
- Heating and cooling operators, gas and water system operators

TRL and related BUDGETS:

7 Research related tasks (TRL 3-5) with a budget of €45.6 million
2 Demonstration related tasks (TRL 6-8) with a budget of €18.4 million

TOPIC 3.1: Protocols, standardisation and interoperability (IEC, CIM, Information models)

CHALLENGE

Standardisation comprises the establishment of minimum performances for digital equipment and defines a set of rules (e.g. protocols and data models) governing how computer programs, hardware components, etc. interact and exchange information and data for the purposes of the integrated energy system. Standardization helps devices and systems to interact, using adequate language codes, and to become marketable (ensuring a common base for performances and communication rules) and provide a foundation for certification systems, promoting international trade of uniform high-quality products, thus supporting transfer of expertise from traditional energy systems. Interoperability is needed for integrated energy systems so that products or systems can cooperate with other products or systems to share resources.

The present standardisation and interoperability of digital technologies are not yet able to be the overarching enablers for the functioning of a decarbonized energy system. Stable common modular approaches and standards ensuring the needed data and information flow along the energy system value chain are not yet established and their development represents a key challenge. Equipment and systems used in different European countries and regions and made by different equipment producers are not yet fully interoperable. Providing flexibility within the system accommodating disruptive innovations and addressing the different configurations and layers of the SGAM frameworks requires standards and semantics to be interpreted and managed by Artificial Intelligence, to leverage the potential of these advanced applications.

R&I is needed for the adequate functioning of fully digitalised solutions implemented by network operators, flexibility providers, storage (such as batteries, hot water tanks, cooling systems, storage for CO2-neutral or free gases and liquids), DER, RES, PV, EV with Smart Charging and V2G services and market operators. There is an urgent need for recommendations regarding communications protocols within the energy network, e.g., the IEC 61850 standard series, IEC 61970 (CIM) standard series, IEC 61968 (CIM) standard series, IEC 62324 (CIM), IEC 61400-24 standard series, ISO/IEC 9594 standard series, ITU-T X500 standard series. There is a strong need for standardisation of encrypted and authenticated market processes considering on different timescales for improved reliability (blockchain) to enhance DSO and TSO information exchange with DER, enabled for third party owned PV and storage from different manufacturers and using different technologies. There is also a strong need for standardisation on physical and cyber security.

SCOPE

The TOPIC will include, as a basis for further work, comprehensive studies about standardised interfaces of energy operators and users, bulk and aggregated renewable power plants and flexible loads, electric vehicles charging infrastructures and of energy IoT devices. R&I is needed to establish guidelines on interoperability and cyber protection of the grids and assets and their interfaces, and to consider the digital applications enabling markets and user participation. Gaps must be identified to unlock technology applications in view of facilitating data exchange among players of the energy sector (System Operators, market parties and end users). ETSI activities around Common Information Model will be explored.

Widely recognised international standards from energy sector committees will be developed to ensure interoperability of IoT devices. Dedicated demonstrations will be set to implement standardised interfaces among all energy operators and the bulk and aggregated renewable power plants, the electric vehicles charging infrastructures, the final users and their smart home and smart building appliances. Demonstrations will also consider the standardisation and interoperability for advanced market platforms: for example the energy data hubs and tele-control platforms interconnecting Balancing Service Providers-TSO-DSO-SGU (Significant Grid User) infrastructures, the new market platforms with energy management systems etc. Communication and security standards will be developed in the European Network Codes, while interoperability will be ensured between TSO-owned digital assets integrated with public telecommunication services. CIM will be applied for cross-border and cross-sector data exchanges, evaluating the benefits of semantic interoperability.

SHORT-TERM IMPACT:

- Enabled efficient functioning of energy markets at local and European levels, in view of delivering the adequate quality of services.
- Higher degree of interoperability among players and (cyber) security at an EU level, enabling new Digital Use Cases and Services supporting the energy transition.
- Increased availability of validating laboratory environments of the Quality of Service (QoS) for communication and security protocols for energy applications.
- More Open-Source advanced market platforms.

LONG-TERM IMPACT:

- System-wide implementation of standardized and interoperable energy services and business models.
- Fostered participation of new players (SMEs) in the energy markets by easy use of standards and interoperability.
- Fully interoperable energy data hubs and tele-control platforms interconnecting Balancing Service Providers-TSO-DSO-SGU (Significant Grid User) infrastructures based on communication and security international standards validated in pilot projects.
- Full application of communication and security standards in the implementation of European Network Codes.
- Full interoperability between new market platforms with energy management systems.

The following tasks[8] will be investigated in R&I projects:

Task No	PRIORITY[9]	Tasks	Functionalities
1	R	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
2	R	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	R	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
4	R	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

OUTCOMES OF R&I PROJECTS WORKING ON THIS TOPIC:

KNOWLEDGE

- Standardised interfaces of energy operators and users such as semantic data models for all energy application domains; standardised interfaces of bulk and aggregated renewable power plants and flexible loads participating to enhanced grid services; standardised interfaces of electric vehicles charging infrastructures used as flexible loads (V1G) and storage systems (VtG); standardised interfaces of energy IoT devices, standard virtualised platforms for energy edge and cloud computing.
- Consolidated procedures and best practices for digital assets' management.
- Guidelines on interoperability and their interfaces, to work with other products or systems, at present or in the future, along the entire value chain of the energy system (for interfaces, standards, protocols).
- Standardised hardware, ICT and software modules and their integrated management principles for the interoperability and protection of the grids and assets.
- Link the digitalisation issues with the energy system operation (such as 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.
- Consider the digital applications enabling markets and user participation thereby enabling three layers:
    - **Communication Infrastructure Layer:** enabling smart energy networks by shared, standardised communication-based data processing and communication (standard architectures, protocols, common information model – CIM) by using cyber-secure service-oriented software infrastructures, and interoperable sector coupling.
    - **Services Layer:** providing adaptive, interoperable, intuitive, multidevice and secure functionalities and tools for the different actors and stakeholders involved in the energy systems according to their role.
    - **Business Layer:** Enabling interaction of the energy system sector with other business sectors (Health, Mobility, Information) by solutions that support open APIs and open solutions on open platforms, trust-raising technologies and adequate service management, education and adaptation of legislation for massive application of smart technologies.
- Leverage the existing recommendations[3] develop standards, criteria for interoperability, open interfaces and protocols at a EU level, identify gaps that could block technology applications in view of facilitating data exchange among players of the energy sector (System Operators, market parties and end users).
- Explore the new ETSI activities around Common Information Model. Add semantics in the standards such that they can be understood, such that data models and meaning can be converted by AI.
- Investigate CIM extensions addressing the needs of emerging data types like flexibility market data, private data (personal, commercially sensitive).

SOFTWARE, TOOLS, ALGORITHMS, MODELS

- Develop and apply standard interfaces required by the digitalisation of energy distributed platforms to ensure device interoperability, to enable platform integration and to maintain up-to-date cyber security capabilities.
- Develop applications and deploy technologies that conform to widely recognised international standards from energy sector committees (standardisation organisations from the information technology and telecommunication sectors such as IEC and IEEE) due to the convergence of information and operational technologies and the need to integrate IoT devices, wireless network technologies and cloud-based services into energy platforms.

DEMONSTRATION

- Standardised interfaces of energy operators and users such as on semantic data models for all energy application domains.
- Standardised interfaces of bulk and aggregated renewable power plants and flexible loads participating to enhanced grid services.
- Standardised interfaces of electric vehicles charging infrastructures used as flexible loads (GtV, Grid to Vehicle) and storage systems (V2G, Vehicle to Grid).
- Standardised interfaces of energy IoT (Internet of Things) devices.
- Standardised interoperability platforms for energy edge and cloud computing.
- Standardized interfaces for smart home and smart building appliances, to enable demand side flexibility.
- Explore beyond electricity related standards, emerging in areas such as e-mobility.
- Validation in laboratory environments of the Quality of Service (QoS) of communication and security protocols for energy applications.
- Advanced market platforms.
- Interoperable energy data hubs and tele-control platforms interconnecting Balancing Service Providers-TSO-DSO-SGU (Significant Grid User) infrastructures based on communication and security international standards validated in pilot projects.
- Application of communication and security standards in the implementation of European Network Codes.
- Interoperability between new market platforms with energy management systems.
- Digital infrastructure as part of TSO core infrastructures.
- TSO-owned digital assets integrated with public telecommunication services.
- IoT sensors and digitalized devices that can improve TSO processes already tested in operational environments.
- Diffused sensors and digitalized devices fully integrated within the electrical infrastructure thus creating a true physical-cyber system.
- Wide scale demonstrators of TSO's improved processes owing to the integration of new sensors and digital assets.
- CIM application for cross-border and cross-sector data exchanges.
- Explore and demonstrate benefits of semantic interoperability, for example based on SAREF (Smart Appliances REFerence).

PARTICIPATING STAKEHOLDERS:

Research & Academia	Regulated (Grid) operators	Power technology providers	Storage technology providers	ICT providers	Regulators, Certification authorities

TRL and related BUDGETS:

4 Research related tasks (TRL 3-5) with a budget of €61 million

RA 3: DIGITALISATION

TOPIC 3.2: Data Communication (ICT) (Data acquisition, Smart Meter, Sensors (monitoring), AMR, AMM, smart devices)

CHALLENGE

Sensors are electronic devices used to measure physical quantities in networks, in view of the monitoring, control and protection. Smart meters are sensors that record generation and consumption of electric energy and other energy grid-related quantities. The information is communicated from prosumers to dedicated market stakeholders and to the regulated grid operators for monitoring and billing. Communication is typically done in the form of two-way signals between the meter/sensor and the data collection system through wireless, or fixed wired connections. Data communication infrastructures and channels need to link smart meters, allowing market entities to charge different prices for consumption, for production and for grid use according to the state of the integrated energy system.

Wide area monitoring systems are nowadays used in electricity transmission networks. The distribution networks are lack observability, with special reference to the lower voltage levels. In the particular case of the integrated energy system, sensors, data collection systems, metering and control are far beyond the requirements for the full integration of system flexibilities and consideration of physical, thermal and security constraints in the grids through smart and flexible devices and for enabling resilience in scenarios including internet denial-of-service events. Broadband data exchange with all communication systems (and with particular reference to the potential of 5G) are needed. The available technologies for smart metering are not yet used on the widest possible scales and the related market and flexibility services are therefore not yet fully enabled.

Smart metering allows much more than metering of electricity consumed and produced. It represents the observability in detail of the networks including the low voltage parts that normally are quite unknown from the point of view of operation and planning. The functional benefits are far-reaching. For the prosumer, apart from the obvious advantages of more accurate billing, easier procedures to place in service of new connection, easier ways to modify contracted power and improvement of service communications (with DSO), it is and will be fundamental for allowing close to real time market and flexibility options local markets, in these cases through retailers and aggregators. Benefits of massive smart metering implementation are very important for the electricity european market.

There is a need to develop and validate adequate sensors for the optimal performances of a fully integrated energy system, starting from smart metering and ranging across the key physical quantities necessary for system monitoring, automation and control. There is also an urgent need to investigate distributed and/or, meshed communication infrastructure for a system-wide monitoring and control across the entire integrated energy system., using all types, technologies and solutions for telecommunication (with special reference to 5G). Costs analyses of the ICT infrastructure for collecting and processing data to feed the data mining algorithms for system control at all times (from system stability to conditional and risk-based maintenance) need to be carried out.

SCOPE

The TOPIC will include a proof of concept of new technologies and algorithms (AI/ML) and systems interfaces and systems integration mechanisms to enable joint processing of data from different sources and repositories.

IoT devices will be developed for system operation and for conditional and risk-based maintenance, enabling advanced solutions for the increasing complexity of system development and operations. Demonstrations will be implemented and include advanced features for the integrated Energy system such as for ICT infrastructure leveraging 5G, by use of the smart meters and the communication structure for AMM, by use of Smart meters for accessing its data directly by multiple actors, while preserving GDPR and contractual clauses. The resilience of infrastructure and operation management systems will be investigated including resilient digital (communication) components, thereby considering data communication needs to handle anomalies. The adaptation of grid operation concepts to the new communication and digital environment using secure and broadband data exchange will be demonstrated as well as the provision of proof of concept of innovative human machine interfaces for system operation, and of AI technologies to estimate indicators and completion of information to operate the system. The development of tools and architectures to manage, large amount of data (also in real time) for mass data communication and processing (Blockchain, Exchange Platforms) including the Integration of sensors and actuators will be validated. Cost-effective data gateways for RES integration, reliability of "sub-meters" to be usable for different business processes and billing and enhancement of resilience of the ICT architecture (electrical black-out) to ensure the continuity of grid operation services will be included in the demonstrations.

SHORT-TERM IMPACT:

- ICT is more and more security integrated into upgraded energy systems, particularly in distribution systems.

LONG-TERM IMPACT:

- Seamless integration of all types of variable resources into the system adequately managed through digitalisation along the entire value chain.

The following tasks[8] will be investigated in R&I projects:

Task No	PRIORITY[9]	Tasks	Functionalities
1	€	1. Communication infrastructures to support **demand aggregation and control**. M2M or Artificial Intelligence to Artificial Intelligence, 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
2	€	2. ICT infrastructure for **monitoring and control of distributed generation**, e.g. PV systems, including standards and protocols.	F2, F6, F7, F10
3	R	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
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

OUTCOMES OF R&I PROJECTS WORKING ON THIS TOPIC

KNOWLEDGE

- Proof of concept of new technologies and algorithms (AI/ML) to increase the data accuracy to be used in system operation and market processes.
- Systems interfaces and systems integration mechanisms enabling joint processing of data from different sources and repositories.

SOFTWARE, TOOLS, ALGORITHMS, MODELS

- Data mining algorithms for conditional and risk-based maintenance.
- Innovative data processing architectures and methods that enable advanced solutions for the increasing complexity of system development and operations.
- Big data analysis functions of real-time data streaming for system operation.
- ICT architectures for mass data communication and processing (Blockchain, Exchange Platforms).

DEMONSTRATION

- ICT infrastructure equipment.
- Use of the smart meters and the communication structure for AMM.
- Use Smart meters for accessing its data directly by multiple actors, while preserving GDPR and contractual clauses.
- Resilient infrastructure and operations management systems, including resilient digital (communication) components.
- Data communication needs to handle anomalies.
- Grid operation concepts adapted to the new communication and digital environment.
- Multiple actors accessing directly Smart meter data for various types of services, while preserving GDPR and contractual clauses between each part.
- Secure and broadband data exchange with all communication systems that are compatible with each other in all interfaces.
- Concepts for communication and ICT based monitoring and control (such as load control).
- Addressing the benefits of the successful existing telecommunications architectures, such as PRIME.
- Proof of concept of innovative human machine interfaces for system operation, for example for decision support.
- Validated tools and architectures to manage, also in real-time, large amount of data from relevant data sources deployed in the power system.
- Consolidated big data analytics systems able to operate on real-time data streams.
- Test results and proof of concept of AI technologies applied to estimation of indicators and completion of information necessary to operate the system (control systems and interfaces for market participant applications, demand pattern recognition).
- Integration of sensors and actuators.
- Demand for cost-effective data gateways for RES integration.
- Implementation of the successful existing telecommunications architectures, such as PRIME.
- Develop solutions for accessing Smart meter data directly by multiple actors (not mediated through DSO or third party), in order to unleash data innovative business models while keeping data privacy and rights according to the contract with each actor.
- Reliability of 'sub-meters' (meters beyond normal, certified meters) to be usable for different business processes and billing.
- Enhanced resilience of the ICT architecture in case of electrical black-out to ensure the continuity of grid operation services.

PARTICIPATING STAKEHOLDERS:

- Research & Academia
- Consumers
- Energy Suppliers
- Aggregators
- Market operators
- Regulated (Grid) operators
- Power technology providers
- Storage technology providers
- ICT providers

TRL and related BUDGETS:

3 Research related tasks (TRL 3-5) with a budget of €23.7 million
1 Demonstration related tasks (TRL 6-8) with a budget of €11.3 million

TOPIC 3.3: Data and Information Management (Platforms, Big Data, Software , IoT)

CHALLENGE

Data and information management platforms need to connect to the cloud and remotely access energy-system and user-related devices (sensors, controllers, etc.). Due to the expected masses of such devices, IoT platforms must provide seamless integration of various hardware through interfaces, communication protocols, network topologies, as well as data storage, processing and data mining.

At present, there is a lack for integrating new, not yet proven IoT technology in society-critical TSO and DSO activities, for merging and managing big data coming from different sources (e.g. by applying standards, interoperability) and for ensuring the proper integration of different platforms into the energy technical and value chain.

There is a strong need to manage big data from different sources which include planning tools, management tools, market platforms, smart-meters, social medias, etc. (infrastructures or tools). This management includes needs to apply data analytics, applications of artificial intelligence, digital twins, etc. TSO and DSO need to understand the implications of applying massive IoT in their activities including both benefits and risks. R&I must contribute to use IoT in TSO and DSO planning, asset management and operational activities and interfaces to market activities.

SCOPE

The TOPIC will provide a consolidated ICT vision and strategy for common data acquisition processes for TSO-TSO, TSO-DSO, TSO-BSP (Balancing Service Provider) and TSO-SGU (Significant Grid User) data exchange; identify business opportunities, capturing aggregation and analysis of the operational data collected by distributed systems; identify digital issues and market opportunities related to big data and IoT and the energy system; and leverage the potential of IoT, **digital technologies and solution and advanced data management for all users**.

There is probably no need for a common data acquisition strategy, however the interoperability of data and architectures has to be ensured. Data sets need to be identfied. The main goal is to ensure that the flexibility is used at local level to solve local requirements (congestion) but also at pan European level through flexibility platforms for balancing purposes and for having more liquidity in the market.

Software, algorithms and tools will be developed for the security of data collection and digital applications across the energy sectors; for data flexibility management (data mining, control, aggregation, trading, integration into system planning, etc.); for data communication; for platform integration in the energy system; for providing an easy access to data for all citizens and stakeholders; for exploring the benefits, etc of data hubs in the system operation and for cross-border and cross-sector data exchanges.

Specific demonstrations will be implemented to validate: advanced features for the integrated Energy system; best practices to scale up individual TSOs flexibility platforms; case studies dealing with common Data hub and Grid hub architectures; implementation of a framework of data exchange between Data Hubs, Grid hubs and other platforms; the operation of a pan-European data hub interconnecting all TSOs and across market players (customers, generators, DSOs, etc.); the massive Big data, IoT, IIoT and interface technologies, enabling full functioning of the system and for enhanced grid operation and planning; platforms and architectures for cross-sector data exchange; cross-border exchange of private data and the wide use of ontologies. To validate efficient data and information management mechanisms for platforms integration in the energy system, from consumer related platforms to system operation platforms including community platforms, provenance platforms, and access platforms.

SHORT-TERM Impact:

- Lower cost-based, monitoring and control of a massive number of devices relevant for the integrated energy system.

LONG-TERM Impact:

- Fully and efficiently managed complexity of IoT data coming from a variety of streamlined, partially disorganised sources.

The following tasks[8] will be investigated in R&I projects:

Task No	PRIORITY[9]	Tasks	Functionalities
1	€	1. **Big data management** from different sources: smart-meters, smart-sensors, social media for their use in planning tools, management tools, market platforms, data-driven tools supported by data analytics, artificial intelligence, and the development of digital twins.	F1, F5, F6, F8, F10
2	€	2. Investigate the use of **IoT technologies** in TSO and DSO planning, asset management, operational and market activities.	F6, F7, F8

OUTCOMES OF R&I PROJECTS WORKING ON THIS TOPIC

KNOWLEDGE

- Consolidated ICT vision and strategy for common data acquisition processes for TSO-TSO, TSO-DSO, TSO-BSP (Balancing Service Provider) and TSO-SGU (Significant Grid User) data exchange corresponding to the expected targets for future market design, system development and operation.
- Identification of scope and relevant business opportunities, capturing aggregation and analysis of the operational data collected by distributed systems.
- Identified possibilities, digital issues and market opportunities related to big data and IoT and the energy system.
- The digital infrastructure which enables the operation and control of the physical energy system.
- Leveraging the potential of IoT, digital technologies and solution and advanced data management for all users.

SOFTWARE, ALGORITHMS, TOOLS, MODELS

- Methods and algorithms for secure and comprehensive data collection across all energy sectors and for providing a more transparent and timely data access for decision making to all market participants (by exploiting new technologies such as IoT, Big data and AI).
- Security features of digital applications enabling markets and user participation.
- Measures for safeguarding energy systems by planning cyber threats that have the potential to cause considerable damage both on structures and on operation.
- Designed and developed flexibility related toolkits, such as data mining, control, aggregation, trading, integration into system planning and planning for all and integrated sectors, considering the protection of the user (consumer rights, privacy, cyber protection).
- Tools and (ICT) networks for data communication, exchange and analytics.
- Design of efficient data and information management mechanisms for platforms integration in the energy system, from consumer related platforms to system operation platforms.
- Easy access to data for all citizens and stakeholders – interoperability of systems, APIs, single access point to different data.

- Explore the benefits, efficiency, operational aspects and data and information management of data-hubs in the system operation.
- Platforms and architectures for cross-border and cross-sector data exchanges.

DEMONSTRATION

- Best practices to scale up individual TSOs flexibility platforms.
- Case studies and pilot projects dealing with common Data hub and Grid hub architectures.
- Experimental validation of implemented ICT solutions for enhanced data access and data collection from multiple sources, with different data types and with large bit rates.
- Implementation of the framework of data exchange between Data Hubs, Grid hubs and other platforms ensuring wide access to customers and data sharing among market participants as well as privacy.
- A pan-European data hub interconnecting all TSOs as well as data hubs across market players (customers, generators, DSOs, etc.) is operational.
- Tested and validated prototypes of the connection of at least 4-6 data hubs across Europe
- Massively applied Big data, IoT, IioT and interface technologies, enabling full functioning of the system.
- Cross-sector data exchange – for example with health, building, transports sectors.
- Cross-border exchange of private data.
- Efficient data and information management mechanisms for platforms integration in the energy system, from consumer related platforms to system operation platforms.
- Massive integration of IioT (Industrial IoT) and IoT devices for enhanced grid operation and planning.
- Platforms and architectures for cross-border and cross-sector data exchanges.
- Wide use of ontologies, such as SAREF, to allow semantic interoperability (both within the energy domain (cross-zones, cross-domains) and with other sectors (health, home, building, transports).
- Integration of community platforms, provenance platforms, access platforms, system operation platforms, flexibility platforms, exploring its Data and Information Management aspects.

PARTICIPATING STAKEHOLDERS:

- Research & Academia
- Consumers
- Citizen Energy Communities
- Aggregators
- Market operators
- Regulated (Grid) operators
- Power technology providers
- ICT providers
- Heating and cooling operators, gas and water system operators

TRL and related BUDGETS:

2 Research related tasks (TRL 3-5) with a budget of €66 million

TOPIC 3.4: Cybersecurity (vulnerabilities, failures, risks) and privacy

CHALLENGE

It is paramount important to define main cyber threats and implement applicable cybersecurity frameworks in the European energy system. For this to happen, energy-focused risks and associated regulatory needs with cost impact must be deeply understood.

Today, there is a lack of an integrated solution for physical and cyber requirements for the integrated energy and communication networks between grid operators, market participants including small prosumers which also require full privacy. There is a lack of cybersecure application of digitised solutions which can support the coordination needs for system operators, the increased use decentralised energy resources. Energy systems include assets with long lifetimes which must be upgraded to interact with cybersecure communication layers. This may expose the system to new threats as it moves towards increased digitalisation of operation. There is a lack of solutions which consider risks and vulnerabilities by use of public ICT and wireless infrastructures for energy systems monitoring and control.

Grid operators need to get physical and cyber security protections to avoid fraudulent or destructive access or injection of e.g. fault data through their physical installations. Grid infrastructures and their ICT must be protected against cyber-attacks, terrorism and extreme weather conditions. There is a strong need for more automatic, but cybersecure control of decentralized resources. The parallel use of IoT-upgraded and legacy SCADA systems must consider risks and vulnerabilities control. Risks and vulnerabilities by using public ICT and wireless infrastructures for smart grid purposes must be understood. Grid operators must be enabled to keep running the grid operation in case of natural catastrophes, terrorism and cyber-attacks. In normal operation, failure modes of ICT including different kinds of sensors must be supported by intrusion prevention and detection systems. Not only electricity systems, but also the whole integrated energy system with other energy carriers and sectors must be transformed to be fully cybersecure.

SCOPE

The TOPIC will provide support tools (such as recommendations, guidelines, certifications) to improve practices in cybersecurity (vulnerabilities, failures, risks) and data privacy management.

Tools must be developed for future Security Operation Centres (SOCs) allowing cyber threats detection and response, with anticipative and proactive strategies. Data analytics and deep learning should benefit from the development of new tools for predictive and automated maintenance of TSO’s grid assets, and the automation of their data validation processes. Tools will be developed to ensure full consistency between data privacy compliance and cyber-physical security practices.

Demonstrations will be done related to dedicated strategies for enhanced cyber security and resilience at DSO and TSO level, including TSO/DSO security data sharing; related to authentication processes for multiple usages, from market mechanisms to system protections and with the involvement of various prosumers, data/service platforms complying with data privacy requirements on one side, and physical-cyber security & resilience of systems on the other. The relevance and impacts of integrating technologies such as blockchain, AI, automation or data analytics for security and maintenance purposes will be assessed in detail and be demonstrated for system development, operation and asset management.

SHORT-TERM Impact:

- Preventing damages for energy system related businesses by a lack of focus on cyber security.
- Minimising the direct economic cost of cyber-attacks to the business, including for theft of corporate information, disruption to trading or having to repair affected systems all resulting in financial loss.

LONG-TERM Impact:

- By design, fully cyber-secure ICT systems enabling fully integrated energy systems.

The following tasks[8] will be investigated in R&I projects:

Task No	PRIORITY[9]	Tasks	Functionalities
1	R	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, Cybersecurity strategies for TSOs and DSOs.	F1, F6, F7, F8, F9
2		2. Data protection for **management of distributed energy resources**, including decentralized storage.	F3, F5, F6, F8, F10
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
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

OUTCOMES OF R&I PROJECTS WORKING ON THIS TOPIC

KNOWLEDGE

- White paper on situation analysis, threats.
- White papers on preventive and curative measures.
- Guidelines on detecting physical and cyber security issues, potential fraudulent or destructive access to ICT systems.
- GDPR implementation guideline recommendations for the secure and privacy.
- Guidelines for preventing fraudulent intrusion into the integrated energy system.
- Recommendations for mechanisms for effective counter attacks.
- Architecture choice for protection of TSO systems at multiple contact points with lower intrinsic protection levels systems (buffer intermediate layer).
- Cyber security certification schemes for the energy sector.
- A European Cyber Security Network Code.
- Sharing of information about past, current and foreseen threats and attacks between actors, in particular grid operators and other operators of essential services.

SOFTWARE, ALGORITHMS, TOOLS, MODELS

- Advanced intrusion detection and prevention systems for energy infrastructures using security-related big data and deep learning methods.
- Advanced technologies and tools for the implementation of a proactive and anticipatory security strategy supporting threat hunting in integrated and federated Security Operation Centres (SOCs). New technologies for future SOCs are related to security monitoring, threat detection and response.
- Methodologies for automation of grid maintenance (for example through robotics), advanced human-machine interfaces, and of data validation processes automation by applying emerging technologies.
- An integrated framework of interoperable systems, fed by multiple data sources and with automatized learning and updating processes, implemented in day-by-day TSO processes able to represent near real-time power system status and maintenance and working conditions of the grid assets.
- Encryption and Cybersecurity algorithms for all related data.
- Integrating in a fully consistent way privacy, cyber-physical security and GDPR requirements.

DEMONSTRATION (WITH PARTICIPATING GRID STAKEHOLDERS)

- Implementation of measures to minimize TSO and DSO risks, vulnerabilities and priority strategies and measures against cyber-attacks, terrorism, weather, and migration for:
    - substation and ICT system security and design
    - the HV, MV, LV grid infrastructures
    - used legacy SCADA systems together with IOT
    - automatic control of decentralized storage (such as batteries, hot water tanks)
- Platforms for TSO and DSO.
- Solutions and processes allowing the sharing of cybersecurity-related information (past, current and foreseen threats and attacks) between grid operators / operators of essential services.
- Validation of Security Operation Centres (SOC) as a Service, Security as a Service and Software Defined Security in energy digital platforms.
- Validation of the secure application of IoT technologies through the public internet, addressing cyber risks and sensitive data protection.
- Experimental application of blockchain technology for the identification and authentication of energy IoT devices, authentication of origin in spare part management, trading certificate infrastructures, electric vehicle token-based payment systems, protection relay configuration and micro grid management.
- Validation of cyber incident management environments in real Pan-European SOCs.
- Practical application of cyber security certification schemes to PAN-European energy infrastructures.
- Demonstrating and evaluating the application of advanced information technologies (such as probabilistic assessment, quantitative risk analysis, digital twins, augmented reality) in system development, operation and asset management.
- Experimental validation of the application of Artificial Intelligence (AI) for ensuring operational data quality and demand patterns recognition for data access and information acquisition to maintenance operators.
- Consolidated information and automation technologies applied to system development, operation and asset management in large demonstration projects.
- Experimental results of the application of augmented reality in power system operation, infrastructure inspection and maintenance.

DEMONSTRATION (WITH PARTICIPATING PROSUMERS OF VARIOUS SIZES AND TYPES)

- Platforms which fully consider privacy and GDPR of prosumer data.
- Redundant backup and restoration systems in case of natural catastrophes, terrorism and cyber-attacks.
- Secure, encryption algorithms-based data exchange.

PARTICIPATING STAKEHOLDERS:

- Research & Academia
- Energy Suppliers
- Aggregators
- Market operators
- Regulated (Grid) Operators
- Power technology providers
- Storage technology providers
- ICT providers
- Heating and cooling operators, gas and water system operators

TRL and related BUDGETS:

4 Research related tasks (TRL 3-5) with a budget of €24 million

TOPIC 3.5: End-to-End Architecture (integrating market, automation, control, data acquisition, digital twin, end-users)

CHALLENGE

Digital twins transform the way companies perform predictive maintenance of technologies and assets in the energy systems. Embedded sensors feed performance data into a digital twin in real time, making it possible not only to identify and address malfunctions before they happen but to tailor market services to better meet unique prosumer needs. Digital twins may be able to control and steer automated processes of the integrated energy system with less or even without human intervention. Integrated end-to-end architecture of digital twins will enable the integrated energy system to evolve on its own, for example by making predictions more accurate and enabling coordinated control of the massive number of devices.

The present solution do not yet providing a single unified architecture for Telecommunication and Control for various IEC and CIM standards. There is a lack of bringing together grid data storage and computing on new architectural schemes. MV and LV remote monitoring and control architectures are not yet fully automated in an integrated way. There is a lack of multi-agent systems for the management of LV/MV networks with large amounts of RES. Cyber physical systems concepts and tools from other industrial sectors are not yet applied and adapted to energy systems.

There is a need to increase the level of robustness of the future LV/MV grids and systems infrastructures by creation of digital twins of interoperating grid and communication networks among other to resolve performance problems and recovery from abnormal events. An enhanced architecture design for data exchange at the different system voltage levels, in different time frames with enhanced TSO/DSO communication interfaces is needed. There is urgency to demonstrate LV and MV telecommunication and control architectures including information models and their conformance to IEC 61850, IEC 61970, IEC 61968, IEC 62324, and CIM standards to support integration. Advanced ICT-based approaches for both grid data storage and computing on new architectural schemes must be demonstrated. There is a need to analyse middleware layers (with multi-agent systems) as a possible alternative for the management of LV/MV networks hosting large shares of renewables (including storage such as batteries, hot water tanks, for CO2-neutral or free gases and liquids). New concepts for distributed online analytical data streaming and processing must be investigated. There is a need for pre-integrated architectures, open source frameworks and tools from other industrial sectors which also apply cyber physical systems concepts, methods and tools to energy systems.

SCOPE

The TOPIC will include principles for integrated communication design and architectures allowing data exchange between distribution and transmission levels. Sharable support tools (software, guidelines, trainings) will be developed for the upskilling of competences in view of improving the robustness, cybersecurity and resilience of systems. Risk management tools will be developed to assess and mitigate hazards on cyber-power systems.

Specific demonstrators will address operational end-to-end architectures and digital twins of interoperating grid and communication networks. Demonstration activities will also target the real-life market implementation of different types of flexibilities (loads, DER, storage like batteries, hot water tanks, cooling systems, for CO2-neutral or free gases and liquids) down to the household level. Tools for an integrated approach to cyber risk management and cyber resilience will also be demonstrated. TSOs must demonstrate new practices in digital assets' management, leading to clear improvements in their operational processes, and increased participation of customers.

By digital management of assets, utilities can postpone or avoid new investments making better use of existing assets. They can better organize predictive maintenance increasing the reliability of operation and drastically reducing costs. Predictive maintenance can reduce maintenance related costs up to 50% and extend asset life by up to 60%.

SHORT-TERM IMPACT:

- Fostered active System Management.
- Fostered real time monitoring.
- Facilitated participation from players of the energy sector.
- Facilitated involvement and increased confidence of the end-user.
- Higher flexibility investments for business in electricity sector to other energy vectors and their networks and businesses.
- allowing new service portfolio for the whole energy system beyond electricity.

LONG-TERM IMPACT:

- Seamless integration of all types of variable resources into the system adequately managed through market mechanisms and adequate tools and business processes.
- Fully standardized flexibility products and services.
- Fully deployed market architecture for EU-wide sector coupling.

The following tasks[8] will be investigated in R&I projects:

Task No	PRIORITY[9]	Tasks	Functionalities
1	R	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
2	R	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
3	€	3. Application of **advanced ICT-based approaches** (IoT, edge computing, cloud computing, cyber-security, blockchain, etc) **for data storage** and computing on new (Hardware & Software) **architectural schemes**.	F1, F2, F6, F9

OUTCOMES OF R&I PROJECTS WORKING ON THIS TOPIC

KNOWLEDGE

- Principles for an integrated communication design.
- Communication handbooks and open-source tools to increase the level of robustness of the future LV/MV grids and systems infrastructures, communication needs and their operation by smartness, by infrastructure, by storage, by RES, by stand-by-generation and associated storage, in order to face extreme events due to climate change (high temperatures and floods) and due to natural hazards like earthquakes, and including environmental footprint and the social acceptance of new equipment and role of consumers.
- Enhanced architecture design for data exchange at the different system voltage levels, in different time frames with enhanced TSO/DSO communication interfaces (includes feedback on the design of the architecture from the implemented system prototypes).
- TSO training programs addressing IT/OT on Cyber-Physical Systems and Cyber Security.

SOFTWARE, TOOLS, ALGORITHMS, MODELS

- Consolidated risk management tools of cyber-power systems.
- Advanced modelling and simulation tools for assessing the effects of cyber kill chains to multi-energy tele-control infrastructures.

DEMONSTRATION

- Resilient and safe system operation through end-to-end architectures, including early fault detection and determination of the status of the system (components).
- ICT and digitalization of distribution (and transmission) networks: Demonstration of a digital twin of interoperating grid and communication networks to resolve performance problems and recovery from abnormal events.
- Welfare-maximised, peer-to-peer transactions for energy and flexibilities (households and SMEs).
- Storage (such as batteries, hot water tanks, cooling systems, for CO2-neutral or free gases) and multi-services, integrated in the electricity market (stacking concept)
- Multi-energy markets considering flexibility resources.
- Small-scale projects optimizing energy balancing with Digitalisation between households and SME.
- PtX solutions enabling DER entities – connected to distribution grids – to become more and more active.
- Validation of simulation environments for assessing cyber-power resilience scenarios. Such environments include energy control communications, security monitoring, attack processes and power simulators.
- Pilot projects demonstrating the resilience of the National/European cyber-physical power system
- Validated methodologies to integrate cyber risk management into a comprehensive risk management environment for the security of cyber-power systems.
- Testing and validation of power system resilience to cyber threats of electrical tele control platforms integrating BSP (Balancing Service Providers)-TSO-DSO-SGU (Significant Grid Users) infrastructures as tested and validated in pilot projects.
- Testing and validation of the system resilience to cyber threats of multi-energy vector tele control infrastructures.
- Digital infrastructure as part of TSO core infrastructures.
- TSO-owned digital assets integrated with public telecommunication services.
- IoT sensors and digitalized devices that can improve TSO processes already tested in operational environments.
- Consolidated procedures and best practices for digital assets' management.
- Diffused sensors and digitalised devices fully integrated within the electrical infrastructure thus creating a true physical-cyber system.
- Wide scale demonstrators of TSO's improved processes owing to the integration of new sensors and digital assets.
- Integration of 5G communication infrastructure to communicate with the energy assets (smart meters, substations, RES) in a secure, fast and reliable way.
- Enhancement of customer premises infrastructure assets (smart meters, smart sensors, smart building controllers) to enable the customer participate in the smart grid as an active actor. Special emphasis could be given to the development of enhanced Smart metering devices, that are becoming ubiquitous in Europe but currently only provide off-line services linked to billing, profiling and forecasting. The Smart meter could evolve into a more sophisticated device that would unveil new FUNCTIONALITIES and become the gateway for the customer premise to participate in the smart grid.

PARTICIPATING STAKEHOLDERS:

Research & Academia	Consumers	Citizen Energy Communities	Energy Suppliers	Aggregators	Market operators
Regulated (Grid) Operators	Power technology providers	Storage technology providers	ICT providers	Regulators, Certification authorities	Heating and cooling operators, gas and water system operators

TRL and related BUDGETS:

2 Research related tasks (TRL 3-5) with a budget of €35.3 million
1 Demonstration related tasks (TRL 6-8) with a budget of €19.7 million

RA 4: PLANNING — HOLISTIC ARCHITECTURES and ASSETS

TOPIC 4.1: Integrated Energy system Architectures (design including new materials and hybrid AC/DC grids)

CHALLENGE

To enable the integration of renewable energy sources at the penetration rate considered in the fully decarbonised scenarios and to satisfy the energy demand with renewable sources also during winter the electricity system cannot evolve in isolation. Integrated Energy Systems overcoming the silos among energy vectors need to be developed. New architectures encompassing the entire energy system will be needed addressing and optimising the synergies among all energy vectors (i.e. electricity, gas, heating/cooling, mobility, Hydrogen etc.). Specific technologies to enable the implementation of the architectures will be needed, enhancing the system performances, increasing its sustainability and leveraging subsidiarity and circularity.

Today, energy system architectures are not yet based on coherent and convergent approaches, which facilitate all processes necessary for a reliable, economic and environmentally friendly operation of smart integrated energy systems.

Approaches, tools and technologies are needed to plan, analyse and operate the integrated energy system under all scenarios: from scenario setting based on reliable and transparent hypotheses, parameters and relations, to integrated and complete planning tools, addressing holistically an energy system where all vectors interact and foster one another and the development and validation of technologies and solutions that help increasing system performances, environmental friendliness (increased efficiency, reduced footprint, circularity), thus leveraging subsidiarity (for example through energy communities/web of cells).

SCOPE

This TOPIC addresses the selection and design of optimal system architectures and key innovative technologies of the integrated energy system covering the different energy vectors, thus overcoming the silos approach and meeting the requirements of efficiency, sustainability and subsidiarity.

The research activities included in this topic will start from definition and evolution of unified architectures for the integrated energy system, considering better and more advanced planning techniques (probabilistic approaches, dynamic optimisation, integration of Cost Benefits Analysis with Life Cycle Assessment of investments and components). Key components, solutions and technologies to improve system efficiency and sustainability will be developed, assessed, validated and demonstrated such as smart transformers, energy routers, web of cells, interoperable HVDC converters (“plug-and-play”), HVDC grids with multi-terminal and protection, digital equipment for metering, adaptation of conventional equipment to the digital operation (merging units) etc. Innovative materials will also be developed and tested to increase performances and sustainability such as alternative gases to SF6 for HV and UHV systems, esters to replace mineral oil in power transformers, composite core conductors, superconductors for fault limiters and links.

SHORT-TERM IMPACT:

- Improved system performance by increasing stability, predictability and controllability based on higher observability.
- Enhanced system controllability and stability, thus enabling the integration of higher shares of non-synchronous renewable generation.
- Increased resilience in case of natural disasters.
- More secure frequency (balancing) and voltage control in the future power system.
- Better use of network capacities.
- Demonstrated innovative solutions to counteract the decrease of short circuit current and increased voltage/frequency interactions resulting from the increased penetration of PE-connected generation.
- Deployed power electronics based “synthetic inertia” services with positive impact on stability, assessed at system level.
- Deployed holistic architectures which include hybrid AC/DC systems, smart transformers, energy routers and web of cells.
- Applied techniques to detect cascading mechanisms possibly triggered by multiple contingencies or interarea oscillations.
- Proven wide area defence systems aimed to limit the extension and consequences of disturbances, also resorting to islanding, reconnection and grid formation capabilities by power electronics connected generators.

LONG-TERM IMPACT:

- Fully integrated energy system services: full DER integration, regionally beyond 100% demand.
- Tested and proven mature technological solutions for the provision of large-scale controllability and flexibility on both TSO and DSO voltage levels.
- Grid resilience by design.
- Minimized stranded assets and infrastructure with cost savings.
- Assessed impact of network controllability (achieved by methods and tools for optimal and coordinated use of flexibility resources) on the global social welfare and ancillary services sharing.

The following tasks[8] will be investigated in R&I projects:

Task No	PRIORITY[9]	Tasks	Functionalities
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
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
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
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
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
6		6. **Optimally located, sized and coordinated** hydro, gas and chemical thermal and chemical **storage for seasonal needs**.	F1, F2, F9, F10, F11, F12
7	4 or 5 BB	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
8	R	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
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

OUTCOMES OF R&I PROJECTS WORKING ON THIS TOPIC

KNOWLEDGE

- Scenarios, architectures, impact studies (including regulation, legislation and environmental aspects, user and societal and economic impacts), technologies and solutions to enhance the energy system flexibilities (including storage) through coupling of electricity with other energy vectors such as gas (synergies of gas network operation in support to electricity flexibility, cost reduction of Power-to-Gas), heat/cooling (for example in the presence of district heating networks), liquids, including transformation processes PtX, and XtP.
- Identification of potentials, barriers and roles of grid operators in the integration of energy sectors through studies and prototype tools to enable an efficient and reliable integration
- Best practices to reduce environmental impacts of grid infrastructures.
- Critical analyses of state-of-art on alternative gases to SF6 for HV and UHV systems and on mineral oil in power transformers.
- Consolidated SF6 replacement alternatives to retrofit existing grid assets.
- Agreed and shared criteria and metrics for life cycle assessment of investments.
- Viable solutions for circular economy of grid infrastructures.
- Methodologies for integrating Costs Benefits Analysis with Life Cycle Assessment.
- Improved CBA (Cost-Benefit-Analysis) as well as CBCA (Cross Border Cost Allocation) for international investments; quantitative analyses and evaluations of potential advantages against costs of including new approaches and technologies as well as coherently integrating environmental aspects (life-cycle assessment, air quality, visual and noise constraints) into the grid planning procedures.
- Better and more advanced planning techniques: from the integration of probabilistic techniques starting from the results of past research projects and integrating these aspects with dynamic programming (one-shot optimization for target years 2030-2040-2050 in order to consider at the same time the short, middle- and long-term perspective).
- Improved technical-economic evaluation of new investments (cost-benefit analysis) by putting in quantitative terms aspects that are now considered qualitatively only, making such methodology capable of more accurate and/or comparable assessments.
- Analyses of new planning modalities capable to appraise the potential of deploying new local storage facilities and/or exploiting local flexibility as an alternative to build new lines
- Further developments of all the points outlined as Milestones 2024 up to reaching “industrial” levels which can be integrated into TSOs standard procedures and, most notably, in ENTSO-E TYNDP standard assessment methodologies.
- Results from experimentations in real planning procedures of some innovative techniques that have proven efficient and robust in pilot projects.
- Unified architectures for the integrated energy system.
- Methodologies for the dimensioning and location of the different forms and technologies of energy storage (such as batteries, hot water tanks, cooling systems storage, storage for CO2-neutral or free gases).
- Plans for the reliable and sustainable transition from the traditional to the smart power systems.
- Grid codes conforming to the smart power system behaviour.

SOFTWARE, TOOLS, ALGORITHMS, MODELS

- Open source co-simulation tools for planning the integrated energy systems at the different geographical scales and time frames.
- Applicable, complete solutions for smart power systems including prosumer-based local distribution structures and markets.
- Software, algorithms, for increased system observability and control, using demonstrated operational strategies in presence of variable energy sources.
- Advanced algorithms for implementing decision support applications to grid control centres and solutions of implementing automatic control and balancing of the grid.

DEMONSTRATIONS

- Energy router: Developing innovative and intelligent solutions to enable energy transfer (routing) between various AC and DC networks, also considering energy storage means, in order to increase flexibility, renewable sources (RES) integration and resilience of energy communities.
- Development of mature Smart transformers, energy routers, web of cells related technologies.
- Long-term reliability tests validating HTLS solutions and development of international standards (HTLS conductors with composite core).
- Full characterization of HVDC insulators and progresses in HVDC links components' standardization towards interoperability.
- Business cases and demonstrators for superconductivity-based links and SFCL (Superconducting Fault Current Limiter).
- Field testing results on HVDC circuit breakers in operation.
- Long-term reliability tests to validate fibre reinforced polymer towers and development of international standards.
- Field testing results on low power instrument transformers with digital output.
- demonstration of on-site calibration and adjustment of conventional instrument transformers for new wide-area applications (metering, PMUs, PQ measurement) in digital environments (for example stand-alone merging units).
- Power system broad adoption of HTLS composite conductors.
- Fully interoperable HVDC converters ("plug and play") to allow multi-vendor HVDC networks.
- HVDC grids with multi-terminal and protection equipment in operation.
- Grid commissioning of superconducting links.
- Experimental validation of advanced modalities allowing integrated TSO-DSO planning.
- Esters for transformers insulation.
- SF6-free solutions.

PARTICIPATING STAKEHOLDERS:

Research & Academia	Regulated (Grid) Operators	Power technology providers	Storage technology providers	ICT providers	Regulators, Certification authorities	Heating and cooling operators, gas and water system operators

TRL and related BUDGETS:

6 Research related tasks (TRL 3-5) with a budget of €34.5 million
3 Demonstration related tasks (TRL 6-8) with a budget of €37.5 million

TOPIC 4.2: Long-Term Planning (System Development)

CHALLENGE

Planning the energy system towards a deep integration of renewables, while leveraging all flexibility sources will be a key driver in the process of the decarbonisation. Planning is multifaceted and implies policy strategies, regulatory frameworks, probabilistic analyses considering the variable RES and DER. Planning leverages demand response, storage (such as by batteries or hydro reservoirs) and the interface with other energy and transport/mobility networks and spans through the evolution of known methodologies, considering energy as well as power needs, and the duration and availability of DSR and storage assets.

Although planning methodologies are rapidly evolving to take into consideration the different types of resources (RES, DER) and the possible flexibilities (generation, network, demand, storage such as batteries), the approach from the energy vectors point of view still remains essentially deterministic and each energy carrier is dealt with separately, thus missing potential synergies. Combined and fully integrated planning of electricity-gas-heating/cooling and mobility are not yet available for the stakeholders.

LONG-TERM planning towards a decarbonised integrated energy system requires the upgrading and smartening of planning procedures to include flexible systems coupling of electricity with other energy vectors such as gas (synergies of gas network operation in support to electricity flexibility, cost reduction of Power-to-Gas), heating and cooling (in the presence of district heating networks), liquids, including transformation processes PtX, XtP. There is a need to apply probabilistic approaches in the planning of the integrated energy systems, considering the stochastic behaviour of demand, RES generation, longer-term climate change effects. The process needs to consider new technologies in the transmission and distribution networks (hybrid AC/DC systems at energy community/buildings level, microgrids, energy cells and combinations of AC and DC solutions at local level) using eco-design and lifecycle assessment approaches.

SCOPE

This TOPIC addresses the evolution of long-term planning methodologies and tools for the design of the future decarbonised integrated energy system. This evolution will be multi-fold, based on probabilistic approaches and will start from scenarios considering environmental, societal and economic aspects of multi-vectors integrated systems.

The research activities included in this topic will leverage scenario analysis developed in an integrated way spanning across the energy systems, in particular heat and transport, considering environmental, social and economic aspects and the impacts on the grid of high RES share penetration, electrification of heat and transport sectors, evolution of load profiles and hybridization of systems. Planning tools will be developed for modern system requirements (increased variability, flexibility needs, grid constraints, environmental sustainability, climate change issues), and will include improved CBA (Cost-Benefit-Analysis) as well as CBCA (Cross Border Cost Allocation) for international investments. The tools will be developed so as to coherently integrate environmental aspects (life-cycle assessment, air quality, visual and noise constraints) into the grid planning procedures.

Any full life cycle cost and environmental impact optimization of assets starts at the planning stage, where the careful selection of the most adequate materials, components and production methods, - also in consideration of “green” criteria such as expected maintenance frequency, degree of inherent resilience, asset life duration and feasibility of reuse of materials at life end; will allow to opt for the most sustainable technical solutions. Benefits should be assessed on the basis of full life cycle costs and environmental impacts.

SHORT-TERM IMPACT:

- Learning from validation of advanced planning techniques adapted to the energy system transition.
- Faster, easier appraisal of the potential of exploiting local flexibility or deploying new local storage facilities and/or as an alternative to build new lines.
- Scaled-up experimentation results in real planning procedures of innovative techniques that have proven efficient and robust in pilot projects.

LONG-TERM IMPACT:

- Validated tools and platforms enabling effective sector coupling as tested in large demonstration projects.
- Maximal efficiency of costs for upgrading grids while fully guaranteeing security, reliability, market-compatibility and resilience of grid planning and operation.
- Consolidated methodology to evaluate the impacts on OPEX and CAPEX connected to the integration of flexibility from storage and other energy sectors.

The following tasks[8] will be investigated in R&I projects:

Task No	PRIORITY[9]	Tasks	Functionalities
1	3 BB	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
2	R	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
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
4	R	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).	F1, F7, F9, F10, F11

5	3 BB	5. **Probabilistic planning including DER stochasticity.** 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
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
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

OUTCOMES OF R&I PROJECTS WORKING ON THIS TOPIC

KNOWLEDGE

- Enhanced network planning methodologies to allow a cheaper, less environmentally invasive (and thus more acceptable) system refurbishment policy.
- Identification of the potential, the barriers and the role of grid operators in the integration of energy sectors, considering the cost of coupling of complementary energy systems (electricity, natural gas system, green molecules (hydrogen), liquid fuels, district heating and cooling, electromobility).
- TSO-DSO combined and integrated system planning tools to better dispatch DER entities connected to distribution grids.
- Improved CBA (Cost-Benefit-Analysis) as well as CBCA (Cross Border Cost Allocation) for international investments; quantitative analyses and evaluations of potential advantages against costs of including new approaches and technologies as well as coherently integrating environmental aspects (life-cycle assessment, air quality, visual and noise constraints) into the grid planning procedures.
- Develop methodologies to foster flexibility-related energy efficiency investments in residential and tertiary buildings.

SOFTWARE, TOOLS, ALGORITHMS, MODELS

- Toolset (or tool chain) that enables the creation of scenarios of the entire energy system (beyond 2040 and up to 2050) considering the dynamics of endogenous electricity demand in response to changes arising from low-carbon policies, the incorporation of non-mature/high potential innovative technologies, enabling a sensitivity analysis (depending on the maturity level).
- Scenarios developed in an integrated way within all of the energy systems, in particular heat and transport, considering environmental, social and economic aspects and the impacts on the grid of high RES share penetration, electrification of heat and transport sectors, evolution of load profiles and hybridisation of systems.
- Planning tools for modern system requirements (increased variability, flexibility needs, grid constraints, environmental sustainability, climate change issues).
- Tools for integration of probabilistic techniques starting from the results of past research projects considering at the same time the short, middle- and long-term perspective.
- Improved, combined technical-economic evaluation tools for new investments (cost-benefit analysis, grid investment cost deferral) by addressing quantitative terms aspects that are now considered qualitatively only, making such methodology capable of more accurate and/or comparable assessments.

PARTICIPATING STAKEHOLDERS:

- Research & Academia
- Market operators
- Regulated (Grid) Operators
- Power technology providers
- Storage technology providers
- ICT providers
- Regulators, Certification authorities
- Heating and cooling operators, gas and water system operators

TRL and related BUDGETS:

4 Research related tasks (TRL 3-5) with a budget of €23.2 million
3 Demonstration related tasks (TRL 6-8) with a budget of €24.8 million

RA 4: PLANNING — HOLISTIC ARCHITECTURES and ASSETS

TOPIC 4.3: Asset management and maintenance (maintenance operation, failure detection, asset lifecycles, lifespan and costs, ageing)

CHALLENGE

The power system will be progressively operating under increasing constraints: managing and balancing the system under the extreme variability linked with the integration of renewables will imply higher frequencies of equipment load cycling, temporary overloads, working conditions closer to the design limits. Moreover climate changes impose increasing mechanical, electrical, thermal, environmental stresses to all system components. Asset management approaches must evolve to ensure the level of reliability of the system.

Asset management is one of the most important chapters in the operation of the energy system. Identifying critical components deserve a specific attention in view of the overall system availability, balancing the necessity to minimise the OPEX and fulfilling the requirements of continuity and quality of supply is an important step towards a reliability or a risk-based operation. Selecting the most adequate monitoring and diagnostic quantities to be used in conjunction with well proven degradation and end-of-life mathematical models is the rationale on which to build the asset management policy: this must be complemented by sensors, monitoring systems, ICT, data, information and knowledge management tools (data analytics and big data). Critical assets must be managed based on risk and optimization, to reduce OPEX, while increasing network flexibility and ensuring adequate power quality. Finally, lifetime extension of existing power system components, based on improved monitoring and measurement of their health state and residual lifetime is key to optimise CAPEX.

There is a strong need to develop and validate tools which address the lifecycle management of energy system components. They must span from the study of performance degradation laws to components and systems diagnostics and monitoring. Maintenance approach and residual life evaluation must be addressed at the light of the threats deriving from the radical changes in operation cycles and environmental constraints.

SCOPE

The TOPIC addresses the advanced management of assets in the energy system along their entire lifecycle, from the commissioning to the end-of life covering the identification of the degradation phenomena and the indicators of the failure development, the sensors and methods for diagnostic and monitoring, the setting up of maintenance policies and end-of-life decision making at the light of the progressive advancement of data acquisition and management techniques.

The research activities included in this topic aim at cost-efficient and highly effective probabilistic risk-based approaches for increasing system reliability through enhanced equipment maintenance and lifetime extension of existing power components based on improved monitoring, measurements and models to determine their health and remaining lifetime. The topic will consider diffused asset monitoring enabled by distributed sensors (IoT technology) for a real-time view of the status of the grid, the identification of grid component anomalies through inspections with minimal human intervention, evidencing use cases for drones, robotics, AR applied to maintenance.

Deployment of IoT sensors, communication, data management & analysis and feedback to control systems encompasses a huge number of devices and systems, so high TRL R&I actions are definitely needed.

With the onset of observability solutions and IoT utilization, systems and components can be constantly monitored through intelligent systems capable of offering improved operational regimes and advanced sensing capabilities that can offer accurate usage of installed infrastructure. Together with the prespecified capabilities of installed equipment and systems by the manufacturers, maintenance decisions can be more accurate and in time to safeguard flawless operation of the system. This can be of real value to operators and R&I in this direction can offer a family of solutions that can improve operation and maintenance practices.

Acquisition, elaboration and interpretation of the huge amount of data available from system monitoring and inspection will also be considered leveraging data analytics based on AI, and machine learning.

SHORT-TERM IMPACT:

- Safer grid operation and reduction of accidents in maintenance, through the use of validated systems for diffused asset monitoring by distributed sensors (IoT technology) for a real–time view of the status of the grid.
- Extended lifetime of existing power system components based on improved monitoring and measurement of their health state and residual lifetime.
- Optimized costs up to 50% for asset maintenance activities while increasing the life-time of existing assets (up to 60%).
- Reduced OPEX, through the use of common asset models for interpretation of the huge amount of data available from system monitoring and inspection.
- Cost efficient solutions and policy guidelines to use drones for large campaigns (data acquisition of power lines with drones are fully competitive in terms of performance and costs).

LONG-TERM IMPACT:

- Full application of probabilistic asset management methodologies based on risk evaluation.
- Validated automatic detection software to assess electrical lines and grid components anomalies also supported by on-board dedicated Software with no human intervention.
- Maximised efficiency of system management costs, guaranteed levels of reliability and resilience, and adequate planning of the network modernisation investments.
- Validated robotic procedures and solutions to replace live line working activities.

The following tasks[8] will be investigated in R&I projects:

Task No	PRIORITY[9]	Tasks	Functionalities
1	3 BB	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), ICT infrastructures (sensors, communication infrastructures) and smart meters.	F4, F5, F6, F7, F8, F9
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

Task No	PRIORITY[9]	Tasks	Functionalities
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		4. **Remote LV/MV maintenance operation**s by digital communications and monitoring equipment	F6, F7
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
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
7	R	7. **Optimized lifespan of storage systems** and the failure modes, including stochastic cycling profiles, CAPEX, OPEX, efficiency.	F7, F8, F9, F10
8		8. Smart sensors and online monitoring and diagnostic systems for the **optimal maintenance of hydropower and pumped-storage units.**	F6, F10
9		9. **Improved lifetime of thermal generation** with fast cycling ability and fuel flexibility.	F6, F7, F9, F10

OUTCOMES OF R&I PROJECTS WORKING ON THIS TOPIC

KNOWLEDGE

- Cost-efficient and highly effective approaches for increasing system reliability through enhanced equipment maintenance and lifetime extension of existing power components based on improved monitoring, measurements and models to determine their health and remaining lifetime in the future.
- Best practices and guidelines for scaling-up and replication of coordinated asset management techniques.
- Cost efficient solutions and policy guidelines to use drones for large campaigns; data acquisition of power lines with drones are fully competitive in terms of performance and costs.

SOFTWARE, TOOLS, ALGORITHMS, MODELS

- New approaches for managing critical assets based on probabilistic risk assessment and optimization of maintenance planning.
- Common asset models for interpretation of the huge amount of data available from system monitoring and inspection.
- Techniques and tools to extract the maximum level of information and knowledge out of the data from the field, using advanced analytics, machine learning and Big Data technologies, to be applied using equipment ageing and failure models as well as system resilience evaluation tools.
- Solutions based on digital approaches (such as tablets, wearables, robotics, drones and other elements) to support asset management and intelligent management to increase system reliability, reduced the risk for workers, decrease OPEX.

DEMONSTRATION

- Validated advanced tools and systems to support decision-making processes in order to implement enhanced maintenance strategies (condition based / Predictive based) and policies (risk-based).
- Validated failure models based on the understanding of how working conditions impact the aging of critical network components, creating enhanced monitoring systems or performing ex-post analysis of assets that have been removed from the grid (Health Index Models).
- Validated system for diffused asset monitoring by distributed sensors (IoT technology) for a real–time view of the status of the grid.
- Software for detection of grid component anomalies and inspections with minimal human intervention.
- Use cases for robotics applied to maintenance available for TSOs service operation.
- Validation of automatic detection software to assess electrical lines and grid components anomalies also done by on-board dedicated SW with no human intervention.
- Validation of robotic procedures and solutions to replace some live line working activities.
- Full application of probabilistic asset management methodologies based on risk evaluation.

PARTICIPATING STAKEHOLDERS:

Research & Academia	Regulated (Grid) Operators	Power technology providers	Storage technology providers	ICT providers	Regulators, Certification authorities	Heating and cooling operators, gas and water system operators

TRL and related BUDGETS:

6 Research related tasks (TRL 3-5) with a budget of €17.9 million
3 Demonstration related tasks (TRL 6-8) with a budget of €11.1 million

TOPIC 4.4: System Stability Analysis

CHALLENGE

The stability of the electric system may be affected by strong variability situations: this can be caused by the deep integration of renewables, in situations where the intrinsic system inertia is reduced because of the extensive use of inverter-based generation.

The assessment of the electric system stability margins is an important driver for the network operators, especially on the transmission side; the wide development of distributed generation raises the need of advanced tools able to assess the power system stability at local level (i.e. distribution level and/or cell level), to be put in relation to that at pan-European level in presence of large perturbations.

There are urgent needs to develop and validate tools for system stability analysis at all voltage levels. They must be complemented with the setting up of technologies and solutions for synthetic inertia to compensate for this potential weakness.

In the presence of a large number of power electronics connected distributed generators, the number of directly coupled rotating machines in the system will unavoidably be reduced. The reduction in the amount of rotating mass, hence inertia, in the system could lead to a higher rate of change of frequency after a disturbance. This increased rate of change of frequency, may in turn result in a greater frequency excursion (the frequency nadir in the network increases following network disturbances, such as conventional generator outage, connection of large load). The amount of synthetic inertia needed is system specific, it should be high enough to avoid triggering of under-frequency protection devices.

SCOPE

The TOPIC addresses the design and planning of the integrated energy system with special attention to the issue of stability of the power system considering the integration of extensive penetration of variable renewables, in presence of extended inverter-based generation connected to the network.

The research and demonstration activities addressed in this TOPIC will start from the development and validation of tools and models to assess and enhance the level of power system stability, resilience and reliability in presence of high shares of vRES and include the demonstration of synthetic inertia as substitutes for rotating inertia by power electronics, storage (such as batteries, hot water tanks, cooling systems storage, storage for CO2-neutral or free gases), variable frequency, and other innovative technologies combined with software and algorithms.

SHORT-TERM IMPACT:

- Focused, location and situation dependent identification of the most relevant parameters and technologies to ensure the stability of power systems in front of large perturbations linked with vRES.

LONG-TERM IMPACT:

- Stable and reliable power systems with 100% and more vRES, using adequate technologies (like synthetic inertia) and design criteria (like advanced sector coupling).

The following tasks[8] will be investigated in R&I projects:

Task No	PRIORITY[9]	Tasks	Functionalities
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
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
3		3. Stability and control of AC, DC and Hybrid **Microgrids in islanded mode of operation**.	F1, F3, F7, F10
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
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
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
7		7. 7Methods and tools to analyse **large-scale inter-area oscillations**. Dynamic stability in grids with multiple control systems	F7, F9

OUTCOMES OF R&I PROJECTS WORKING ON THIS TOPIC

SOFTWARE, TOOLS, ALGORITHMS, MODELS

- Tools and models to assess and enhance the level of power system stability, resilience and reliability in presence of high shares of vRES.

DEMONSTRATION

- Synthetic inertia as substitutes for rotating inertia by power electronics, storage, variable frequency, and other innovative technologies combined with software and algorithms.

PARTICIPATING STAKEHOLDERS:

- Research & Academia
- Energy Suppliers
- Aggregators
- Regulated (Grid) Operators
- Power technology providers
- Storage technology providers
- ICT providers
- Regulators, Certification authorities

TRL and related BUDGETS:

3 Research related tasks (TRL 3-5) with a budget of €10.6 million
4 Demonstration related tasks (TRL 6-8) with a budget of €27.4 million

RA 5: FLEXIBILITY ENABLERS and SYSTEM FLEXIBILITY

TOPIC 5.1: Demand Flexibility (household and industry related)

CHALLENGE

The progressive decarbonisation of the energy system relies on the deep integration of variable renewable energy sources. A paradigm shift is needed in the management of the energy system in front of all uncertainties, to guarantee the stability and efficiency of the system at all time and geographical scales. All sources of flexibility must be employed along the entire value chain.

The present demand-related technologies, market models and integrated energy system policies do not provide sufficient features and incentives to the customer/prosumer, to engage in DSM and DR programs and market initiatives. There is also a lack of knowledge about customers behaviour and motivation to involve them in the energy markets.

Power systems need to be increasingly flexible to accommodate rising shares of distributed, non-controllable renewable generation. Demand side flexibility in this context refers to enabling final customers/prosumers to become active in the market but also to enable system operators to make best use of flexibility in order to ensure low-carbon, secure, reliable, resilient, accessible, cost-efficient, and market-based system operation at affordable costs. There is a need to assess, in a reliable way, the full potential of flexibility to be addressed in different context and to simulate the effects of different technical and economic measures.

SCOPE

The TOPIC will include, as a basis for further works, comprehensive studies of consumers on social behaviours and motivation patterns to adapt their consumption profile, aimed to assess customer and prosumer awareness of importance of demand response and design of stimulation packages.

Societal studies will be conducted to characterise and segment the different types of users (from households to the industry) and to identify the levers (behavioural, societal, economical, technical) to foster their participation into the flexibility arena. Suitable market mechanisms will be developed and analysed for the exploitation of services based on demand side flexibility, able to support both system adequacy and system security in an integrated and coordinated way. They will include suitable price signals and/or incentives for leveraging the wide-spread electrification of the economy, such as DSR and V2G.

Market models will be developed and validated, to drive more cost-effective demand-related investments in a coordinated approach including also other energy sectors and vectors, with market mechanisms to facilitate and integrate very large shares of variable RES generation in a cost effective way as sector coupling, while ensuring the flexibility that is needed to maintain system adequacy and security. Suitable and validated methodologies will be developed, for evaluating the full potential of optimal utilisation of available flexibilities including technical, economic and regulatory aspects, and consider the efficient planning and operation of the power grid using the full potential of demand side flexibility. The design of new architectures for the flexibility markets will integrate local and European-wide markets in an efficient way and enabling multilateral flexibility where several operators (TSOs and DSOs) may be present at the same time.

SHORT-TERM IMPACT:

- Accelerated availability of market based sustainable flexibility services for the grid.
- Increased market participation of a wide range of flexibility products, both short and LONG-TERM, through remuneration in multiple balancing / flexible markets.
- Improved market conditions of flexibility products at both supply and demand sides to ensure balancing and ancillary service provision in the markets.
- Transparent knowledge (catalogue) of flexibility products.
- Standardised ICT requirements to collect, deliver and utilize data, including data from different energy sector, to enable efficient flexibility markets.

LONG-TERM IMPACT:

- Increased flexibility investments for business in electricity sector to other energy vectors and their networks and businesses.
- PtX solutions enabling DER entities – connected to distribution grids – to become more and more active, allowing new service portfolio for the whole energy system beyond electricity.
- Fully standardised flexibility products and services.
- Welfare-maximised, fully unlocked peer-to-peer transactions for energy and flexibilities.
- Fully integrated (in the electricity market) storage and multi-service (stacking concept).
- Fully deployed market architecture for EU-wide sector coupling.
- Developed and validated multi-energy markets considering flexibility resources.

The following tasks[8] will be investigated in R&I projects:

Task No	PRIORITY[9]	Tasks	Functionalities
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
2	3 BB	2. **Direct load control** in close collaboration with telecom operators	F2, F3, F4, F5, F6, F10, F11, F12
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
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

OUTCOMES OF R&I PROJECTS WORKING ON THIS TOPIC

KNOWLEDGE

- Comprehensive studies of consumers social behaviours and motivation patterns to adapt their consumption profiles.
- Customer's awareness of importance of demand response and design of stimulation packages.
- Main requirements for the digital infrastructure that enables the DSR of the resources connected at DSO and TSO level to provide ancillary services as defined and validated experimentally. This includes among other models for the DSR from electric vehicles.
- Market mechanisms for the exploitation of services based on demand side flexibility able to support both system adequacy and system security in an integrated and coordinated way.
- Suitable price signals for leveraging the wide-spread electrification of the economy, e.g. DSR and VtG.
- Optimised solutions to limit the impacts on OPEX and CAPEX for the integration of demand side flexibility.
- Social studies clarifying best approaches in order i) to increase the involvement of local entities and citizens in the DSR, ii) to organise specific communication campaigns in the early stage of infrastructures planning, and iii) to evaluate the communication effects of information campaigns on the end-users behaviour in increasing demand side flexibility and awareness on such a topic.
- Models of customer/load behaviour, segmentation, and quantification of the degree of flexibility provided by distribution networks.
- Definition of market mechanisms that ensure both system adequacy and system security in an integrated and coordinated way.
- Optimised balancing procedures for the integration of demand side flexibility.
- Optimised impacts on OPEX and CAPEX for the integration of demand side flexibility.
- Efficient planning and operation of the power grid using the full potential of demand side flexibility.
- Methodology for evaluating full potential of optimal utilisation of available flexibilities including technical, economic and regulatory aspects.
- Viable energy flexibility business models.
- A market for flexibility that supports the economic based management of all the kinds of flexibility resources useful to guarantee the security, resilience and reliability of the power system. The new market avoids conflicts and helps optimizing the use of flexibility resources.

SOFTWARE, TOOLS, ALGORITHMS, MODELS

- Design of new architectures for the flexibility markets, integrating local and European-wide markets in an efficient way and enabling multilateral flexibility where several operators (TSOs and DSOs) may be present at the same time.
- Market models to drive more cost-effective investments in a coordinated approach including also other energy sectors and vectors, with market mechanisms to facilitate and integrate very large shares of variable RES generation in a cost effective way as sector coupling, while ensuring the flexibility that is needed to maintain system adequacy and security.
- Software development to evaluate the business models, evaluate benefits of DER-provided flexibility services via simulations across a wide range of distribution circuits, under multiple scenarios.
- Simulation of DER-provided flexibility for Distribution, under various scenarios, considering TOTEX approach.
- Network-constrained market simulation tools that allow the assessment and provision of recommendations about specific network management and market designs, taking into account uncertainties; that unlock the full flexibility potential; that coordinate flexibility usage by different parties (such as active power regulation for TSO balancing and DSO congestion management).

DEMONSTRATIONS

- Solutions for direct load control.
- Evaluation criteria, validation procedure and implementation guideline to assess the amount of shifted energy or modified consumption in AD schemes.
- Optimal TSO and DSO-related DSR utilisation by defined demand requirements and required data.
- Production DSS (decision support system) and implementation strategies for flexible scheduled operation as function of RES (such as the BAMBOO project and other SPIRE projects).
- Explore the potential (in economic and technical terms) of second-life batteries for small and medium prosumers.

PARTICIPATING STAKEHOLDERS:

- Research & Academia
- Consumers
- Energy Suppliers
- Aggregators
- Market operators
- Regulated (Grid) Operators
- Power technology providers
- ICT providers

TRL and related BUDGETS:

2 Research related tasks (TRL 3-5) with a budget of €9.5 million
2 Demonstration related tasks (TRL 6-8) with a budget of €18.5 million

RA 5: FLEXIBILITY ENABLERS and SYSTEM FLEXIBILITY

TOPIC 5.2: Generation flexibility (flexible thermal, RES (Hydro, PV and wind generators))

CHALLENGE

The progressive decarbonisation of the energy system relies on the deep integration of variable renewable energy sources. Thermal power generation will be more and more based on CO_2-neutral fuels, while –at the same time- guaranteeing a higher level of flexibility. This means faster up/down ramping, increased resilience and lower maintenance costs. Hydropower generation, already a major source of flexibility for the electricity system, will improve its capacity of supporting network balancing needs. Wind turbine and PV MPPT (Maximum Power Point Tracking) controls must consider flexibility and reserve sharing.

Thermal Power Generation, at all the network levels, lack an integrated coordination with non-programmable RES which needs to be rapid, reliable and efficient and which must guarantee the lowest possible emission level. Fuel flexibility is not realised to its full extend, i.e. the capacity to switch between renewable-based fuel as well as conventional ones, including different rates of mixtures, depending on the availability of carbon-neutral synthetic fuels like synthetic methanol or methane, hydrogen, ammonia, biomass derived from waste, etc. Seasonal storage capabilities of the gas network, via Power-to-gas technologies will also be developed and extensively used.

Flexible operation could impact negatively on the equipment and components life, with increased maintenance and repair costs; innovative solutions will, therefore, be developed to reduce out-of-service and failure rates. Power-to-Gas and Power-to-Liquid options are needed to allow increasing synergies between Power and Transport sectors.

SCOPE

The TOPIC addresses the solutions and tools to improve the flexibility of all types of generation technologies to cope with all the uncertainties and variabilities of the progressively integrated energy system.

Suitable tools will be developed to optimize the different flexibility resources, assessing their availability, the retrofitting technologies, the operating (and external) costs, both under a planning point of view and in a more short-term operational horizon. Improved combustion systems for CO_2-neutral fuels (including renewable "green" hydrogen/ natural gas mixtures) will be demonstrated, with particular attention to efficiency and reliability, as well as faster thermal generation ramping down and up and start-up/shut down. Energy storage systems such as batteries, hydro reservoirs, hot water tanks, cooling systems storage, storage for CO2-neutral or free gases, integrated with power generation plants, will be demonstrated via pilot experiences. New technologies and operational methodologies will be developed and demonstrated to increase hydropower and pumped hydro-storage plants flexibility.

SHORT-TERM IMPACT:

- Ensured knowledge that power generation –including for existing generation capacities – is ready to optimally use the gases generated under novel Power-to-Gas concepts, where alternative fuels are provided.
- Optimized operation of power generation through storage, for instance by bridging between stop and restart of a generator or by providing the needed time to achieve optimal ramp-up/-down, allowing fast load changes to be met.
- Optimized coupling of the gas, heat and electricity networks and adaptation to the flexibility challenge connected to the increased penetration of variable renewables in the system.

LONG-TERM IMPACT:

- Leveraged flexibility on the generation side to enhance the integration of variable renewables in the electricity system, but also for heating and cooling and carbon-neutral gas systems.
- Support the effective penetration of the novel Power-to-Gas concepts, where alternative "green" fuels are provided.

The following tasks[8] will be investigated in R&I projects:

Task No	PRIORITY[9]	Tasks	Functionalities
1		1. **Contribution of WTs (Wind Turbines) and PVs to system flexibility**. Development of efficient controls for wind turbines and PV MPPT (Maximum Power Point Tracking) to consider flexibility and reserve sharing.	F9, F10
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
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).	F2, F7, F8, F9, F10, F11
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
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
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
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

OUTCOMES OF R&I PROJECTS WORKING ON THIS TOPIC

KNOWLEDGE

- "Merit order" for the different flexibility resources and products to allow system operators to predict the availability of resources for the different products and timeframes, as well as to estimate the related costs.
- Best practices to optimize system flexibility costs, including the ones covered by customer bills and the external costs (environmental), always ensuring an excellent power supply quality.
- Techno-economic feasibility assessment of retrofitting existing assets for low-carbon flexible power generation, including the re-use of natural gas infrastructure for decarbonized gases such as hydrogen.
- Development of a safe hydrogen fuel starting methodology.
- New technology developments to enhance the flexibility of commercial RES (CSP, hybrid systems solar biomass, etc).
- Proof-of-concept of new disruptive technologies for flexible generation.
- CO2 as working fluid (cycles).
- Improved short-term (5-10 min) predictability of generation.

SOFTWARE, TOOLS, ALGORITHMS, MODELS

- Tools and methods for system planning, considering the new types of flexibility services, as in case of a low inertia network.
- Novel monitoring and control tools and advanced modelling tools for better operation management and decisional support.

DEMONSTRATIONS

- Improved combustion systems for different gas/fuels qualities, while maintaining efficient operation.
- Increase thermal power plants flexibility for using CO2-neutral fuels.
- Development of an optimised natural gas system operating with varying hydrogen concentrations.
- Optimised control and management of CHPs connected to district heating networks.
- Pilot demonstration of highly responsive and cost-effective energy storage (different types – chemical, electro-chemical, mechanical, thermal) integrated with power plants to show the potential for increased grid stability and flexibility.
- Faster thermal generation ramping down and up as well as start-up/shut down.
- New technology, inventions and methods giving increased operational flexibility to hydropower and pumped hydro-storage plants.
- Pilot demonstration for an integrated and flexible small and medium scale generation system
- Open source European wide reservoir and river inflow data set based on up to date climate simulations.
- Cost-efficient use of “green” gases and fluids for power and heat generation based on known thermal power generation.
- Increased flexibility from thermal generation, in terms of ramping up/down, minimum load, duty cycles, fast load-follow capabilities, start-up (cold and hot).
- Enhanced RES generation forecast techniques, tools and models supporting the integration of enhanced flexibility from thermal-based generation and to enable efficient flexibility market.
- Flexibility potential and capabilities by programmable RES (generation by biomass, small hydro, geothermal) as resulting from pilot projects activity.
- Consolidated methods enabling balancing services from RES generation, hybrid installations and VPPs.
- Suitable methods for dynamic capacity management and reserve allocation that support system operations with high share of RES integration.
- Improved power quality output from non-synchronous generators.
- A holistic approach to flexibility provision by RES generation demonstrated by pilot projects along with cost/benefit assessment of the flexibility provided by centralized and distributed environmentally friendly technologies.
- Demonstration and implementation by pilot projects of a flexibility market involving, with the same rules and in transparent way, conventional and new resources (programmable and stochastic RES, hybrid plants, VPP’s), operated by different types of actors, covering with different shares the required amounts of flexibility.
- Demonstration of a Europe-wide, cross border exchange of flexibility services, efficiently exploiting the existing differences in generation mix and weather conditions among different areas.

PARTICIPATING STAKEHOLDERS:

Research & Academia	Energy Suppliers	Regulated (Grid) Operators	Power technology providers	Storage technology providers	ICT providers	Heating and cooling operators, gas and water system operators

TRL and related BUDGETS:

5 Research related tasks (TRL 3-5) with a budget of €39.7 million
2 Demonstration related tasks (TRL 6-8) with a budget of €13.3 million

RA 5: FLEXIBILITY ENABLERS and SYSTEM FLEXIBILITY

TOPIC 5.3: Storage flexibility & Energy Conversion flexibility (PtG&H, PtG, GtP, PtL, LtP; PtW; WtP)

CHALLENGE

The progressive decarbonisation of the energy system relies on the deep integration of variable renewable energy sources. Storage such as batteries appear as the more accessible technological option to guarantee to RES generation the needed flexibility; on the other side, PtX technologies are emerging as a promising option, allowing as well the desired integration with other “energy-related” networks, i.e. the gas and the heating/cooling ones.

Storage systems and Energy conversion technologies are key factors in ensuring a high degree of flexibility to the energy system as a whole, as well as guaranteeing the deep de-carbonization requested. Storage still lacks a proper valorisation in many scenarios and context, thus limiting the unlocking of its full potential. PtX technologies need extensive R&I activities, followed by the suitable demonstration at different scales.

Storage systems including batteries will be developed to ensure flexibility and balancing services at all the network levels, at the same time contributing both to the optimal operation of power generation (conventional, fed by CO_2-neutral fuels, and Renewable) and to the DSM (Demand Side Management) at the level of final customers. PtX technologies (the most promising appears to be the Power-to-gas one) will increase their role and penetration into the energy system. Potential and limits of these technologies need to be carefully assessed, via simulation and demonstration activities; regulatory issues must also be investigated. There is a strong need to assess the costs/benefits ratio of PtX technologies and to understand their effective integration in real scenarios, taking into account realistic synergies with gas, heating/cooling and water networks.

SCOPE

The TOPIC addresses the contribution to flexibility of energy storage integration, together with the advanced conversion technologies, aimed to transform electricity into gas, liquids and water and vice versa.

Massive and effective storage penetration requires, on one side, a new regulatory framework and market design (including storage services remuneration), and the availability of comprehensive tools to assess cost/benefit balance and to evaluate the economics of each initiative (including bankability). Suitable tools and models, to determine optimal size, location and utilisation of storage and PtX technologies and plants, is a pre-condition to ensure their effective deployment.

Demonstration activities will be undertaken on LONG-TERM energy storage systems (from advanced pumping hydro to other alternative solutions as PtX), solutions for district heating and cooling as sector integration for flexible operation at different energy levels and carriers, solutions for industry and industrial clusters for integrated flexible generation, consumption and storage.

SHORT-TERM IMPACT:

- Estimated impact and developed scenarios of distributed and concentrated (and virtual) storage.
- Best practices for the optimal use of different storage systems, such as a large storage plants, or aggregation of distributed storage devices (industrial and residential storage), or hybrid storage systems able to provide a staking of multiple services and/or advanced specific services (such as Virtual Inertia for fast frequency response).

LONG-TERM IMPACT:

- Increased level of flexibility in transmission and distribution grid management to allow increased integration of RES while maintaining the security of supply at the pan-European level and reducing the need of grid reinforcement.

- Stable regulation framework for storage integration and valorisations Integration of new storage technologies for operating the grid.
- Optimised balancing procedures for the integration of energy storage and flexibility from sub-systems (such as DSO or Citizen Energy Communities) in a system of systems approach (3.2).
- Optimised impacts on OPEX and CAPEX for the integration of flexibility from distributed storage.
- Optimised balancing procedures for the integration of energy storage and flexibility from sub-systems (such as DSO or Citizen Energy Communities) in a system of systems approach.

The following tasks[8] will be investigated in R&I projects:

Task No	PRIORITY[9]	Tasks	Functionalities
1	3 BB	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
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
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, and heat boilers.	F2, F9, F10, F11, F12
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
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

OUTCOMES OF R&I PROJECTS WORKING ON THIS TOPIC

KNOWLEDGE

- Analysis of the storage (technology) CBA and economics (including bankability conditions and requirements).
- Technological and regulatory conditions for virtual storage implementation.
- Recommendations for a new regulatory framework and market design (including storage services remuneration) that enable recognition of the full value of storage, technologically neutral in order to allow the most cost-effective way solutions to emerge.
- Analysis of the challenges for gas networks of the PtG technologies penetration.
- Best practices for the optimal use of different storage systems, such as a large storage plants, or aggregation of distributed storage devices (industrial and residential storage), or hybrid storage systems able to provide a staking of multiple services and/or advanced specific services (for example, Virtual Inertia for fast frequency response).
- A complete set of rules, standards and guidelines for classification, test procedures, labelling, uniform test parameters and performance/diagnostic tests, including standardization of communication protocols for data exchange with storage systems.
- Finalized assessment on the quantitative contribution and potential benefits to the electric system of sector coupling.
- A full assessment of regulation, market and operational barriers.
- Assessment of capabilities, performance and constraints of conversion plants (P2X: heat, gas and or hydrogen) within the electric system as validated in pilot projects.
- Assessment of capabilities, performance and constraints of storage potentials laying within other energy sectors as validated in pilot projects.
- New business models (like multi-vector bids) and new markets design (like coupling market).

SOFTWARE, TOOLS, ALGORITHMS, MODELS

- System planning toolboxes to determine the optimal sizing, location and distribution of energy storage systems to facilitate their optimal use at different grid levels.
- Aging models' definitions for several storage technologies according to the operating conditions and required regulation services.
- Communication tools, platforms and devices for increased observability/controllability of the resources and measurement acquisition.
- Flexible stand-alone systems and tools for living quarters and small and medium sized businesses and industries based on renewable generation, sector-coupling and storage components.
- System planning toolboxes to determine the optimal location and utilisation rate of energy conversion plants available.
- Tools to quantify the flexibility provided by sector coupling as a new dispatchable resource integrated in electric system operation.
- A flexibility dashboard for TSOs operation and processes.
- A storage flexibility dashboard for TSOs, identifying standards and required performance for new services that can be provided by storage facilities, prequalifying flexibility services and actors providing them.
- System planning toolboxes to determine the optimal sizing, location and distribution of energy storage systems to facilitate their optimal use for (TSO-DSO) coordinated use of non-frequency grid services as well as for other time frames such as operational planning and operation.

DEMONSTRATION

- Pilots demonstrating the techno-economic value of LONG-TERM (weekly, seasonal) energy storage systems (from pumping hydro to other alternative solutions as P2X). Validated tools and platforms enabling effective sector coupling as tested in large demonstration projects.
- Methodologies and balancing procedures for the integration of storage systems from other energy sectors and conversion plants validated in pilot projects.
- Consolidated methodology to evaluate the impacts on OPEX and CAPEX connected to the integration of flexibility from storage and other energy sectors.
- Optimised dynamics of coupled networks (such as electricity vs. heating)
- Main regulation, market and operational barriers identified and addressed; for instance, reduction of risk factors connected to service provision from other networks (with different dynamics, actors, and regulation).
- A coupling market with multi-carrier bids.
- Validated methodologies to integrate new bulk storage solutions (such as CAES).
- Validated tools to assess the integration of electric system with the pan-EU energy system, considering all energy vectors.
- Implementation of solutions for district heating and cooling as sector integration for flexible operation at different energy levels and carriers.
- Solutions for industry and industrial clusters for integrated flexible generation, consumption and storage.

PARTICIPATING STAKEHOLDERS:

Research & Academia	Energy Suppliers	Regulated (Grid) Operators	Power technology providers	Storage technology providers	ICT providers	Heating and cooling operators, gas and water system operators

TRL and related BUDGETS:

5 Research related tasks (TRL 3-5) with a budget of €40 million

RA 5: FLEXIBILITY ENABLERS and SYSTEM FLEXIBILITY

TOPIC 5.4: Network flexibility (FACTS, FACDS, smart transformers and HVDC)

CHALLENGE

The progressive decarbonisation of the energy system relies on the deep integration of variable renewable energy sources, requiring the use of all sources of flexibility. A key issue is the increased electricity network observability and controllability, to improve the optimal management of power flows and voltages. Power Electronics has strong potential to increase cost-effective system flexibility at all network levels.

Development and deployment of innovative technologies and tools, to increase network observability and controllability, communication and monitoring, as well as increased interaction and information exchange, are enablers to provide local, regional and system wide flexibility solutions.

Transmission and Distribution networks, HVDC systems and on-shore and off-shore RES generation plants need the development and standardization of new components and devices, based on power electronics, to ensure full interoperability, optimal flow control, improved grid controllability, thus helping greater flexibility and stability of operation. Extensive demonstration of ready-to-use network flexibility devices is necessary.

SCOPE

The TOPIC addresses the flexibility improvements gained in the T&D networks thanks to the use of advanced Power Electronics.

Standardization activities will cover HVDC converter stations, Dynamic Line Rating solutions, and ready-to-use Power Electronics devices and components.

Extensive demonstration activities will be conducted, focussing on Smart inverters and Smart transformers, providing grid support functions, on full scale interoperability of HVDC Converter stations and on innovative solutions for HVDC multi-terminal networks.

SHORT-TERM IMPACT:

- Better system controllability which can benefit from utilization of large-scale new power generation technologies.

LONG-TERM IMPACT:

- Leverage flexibility on the generation side to integrate variable RES in the electricity system and for heating and cooling and carbon-neutral gas systems.

The following tasks[8] will be investigated in R&I projects:

Task No	PRIORITY[9]	Tasks	Functionalities
1	3 BB	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, and fault current limiters.	F1, F2, F4, F5, F6, F7, F8, F9, F10,
2		2. Flexibilities provided by **distribution network reconfiguration.**	F1, F2, F6, F7, F9, F10,
3		3. Standardised **HVDC multi-terminal networks to coordinate power flows** among different regions and to connect off- and on-shore wind power plants.	F1, F7, F9, F10,
4		4. **Dynamic Line Rating** (DLR) solutions in capacity calculations of transmission and distribution grids.	F6, F7, F8,

OUTCOMES OF R&I PROJECTS WORKING ON THIS TOPIC

KNOWLEDGE

- Standards for HVDC converter stations for enabling full scale interoperability.
- Comprehensive methodologies to support the selection of optimal power flow control technologies considering system security criteria and efficiency of grid investments.
- Evaluation of the effectiveness of state of the art on Dynamic Line Rating solutions with analysis of the synergies with forecasting models and tools.
- Regulatory framework and standardization updates for the application of Dynamic Line Rating solutions and TSO's harmonization for the use of DLR systems.
- Studies and analyses on new technologies based on Power Electronics, to increase network controllability.
- Simulation of DER-provided flexibility for Distribution, under various scenarios, considering Total Expenditure (TOTEX) approach.
- Improved flexibility and service capabilities of RES to provide the necessary ancillary services in scenarios with very large penetration of renewables.

SOFTWARE, TOOLS, ALGORITHMS, MODELS

- Simulation analysis with new technologies; real-time analysis of new technologies with extensive power electronics; use of HIL (HW in the loop) simulation to validate new technologies; simulation at local level, national level, cross-border level and pan-European effects; preparation for risk-controlled field demonstrations.

DEMONSTRATIONS

- Smart inverters providing grid support functions
- Smart transformers providing flexible connection between MV and LV AC networks and enabling AC and DC microgrids at LV level.

- Remote planning, monitoring and control systems with AI-based algorithms for the smart management of DER.
- More accurate technologies assessment, forecasting methods and tools for economics calculation and comprehensive Cost-Benefit Analysis (CBA).
- Demonstration and assessment of reliability of controllable off- and on-shore solutions for the vendor-independent HVDC multi-terminal networks.
- Experimental results from testing and demonstration of full-scale interoperability of HVDC converter stations.
- Testing and demonstration of solutions (such as storage and distributed resources) for the optimisation of the transmission grids flexibility with respect to grid congestion.

PARTICIPATING STAKEHOLDERS:

Research & Academia	Regulated (Grid) Operators	Power technology providers	ICT providers

TRL and related BUDGETS

4 Research related tasks (TRL 3-5) with a budget of €24 million

RA 5: FLEXIBILITY ENABLERS and SYSTEM FLEXIBILITY

TOPIC 5.5: Transport flexibility (V2G/EV; railway, trams, trolleybus)

CHALLENGE

The progressive decarbonisation of the energy system relies on the deep integration of variable renewable energy sources. All sources of flexibility must be employed along the entire value chain, to guarantee the stability and efficiency of the system at all time and geographical scales. The transport sector, with the growing penetration of electricity, could offer a valuable potential of flexibility to the grid.

There is a lack of charging infrastructures and storage systems, both in urban and extra-urban areas. They should be planned and developed, keeping into account the mobility needs, the impact on network adequacy (especially at the level of Distribution) and the flexibility and balancing potential offered. Suitable market models are missing. They must be developed and tested, where effective price signals could orientate customers in the offer/demand of recharging services (V2G), keeping into due account the peculiarities of mobility services. Electrified public transport (both urban and long-distance) could as well offer flexibility and balancing potential, provided careful planning and operation methodologies to be adopted.

There is a strong need of reliability analysis, quantification and optimization of the impact (opportunities and constraints) of EV interaction with the grid (Smart Charging and V2G) on urban and transmission grids. Services offered to the distribution and/or transmission network (flexibility and balancing) by electricity penetration in transport sector – both V2G and urban/long-distance pubic transport – need to be quantified and demonstrated.

SCOPE

The TOPIC addresses the grid flexibility and balancing opportunities offered by electric transport, taking into account both V2G (Vehicle to Grid) and electricity transport networks.

V2G has high potential to support the grid. The flexibility potential of electric transport in the future depends on how rapidly the amount of electric vehicles and machinery increases and this depends heavily on the policy measures. In any case, electrification of the transport sector is expected to proceed rapidly and IEA estimates total electricity consumption for EVs to be at the range of 640 - 1100 TWh in 2030 of which 100-200 TWh in Europe depending on the scenario (IEA Global EV Outlook 2019). A significant portion of the total EV fleet can be utilized to provide flexibility and balancing to the system and, therefore, the potential is high. Typically, V2G will give the substantial benefit of load shifting, useful for balancing out spikes (both upwards and downwards) in supply and/or demand.

Scenarios will be tested and simulations will be performed, to assess the impact of transport system electrification on distribution grids. Recharging and storage facilities management systems and algorithms are to be developed and tested, enabling integration of V2G into urban distribution grid. Future mixed electric and carbon-neutral fuels vehicles strategies will be investigated, to ensure smooth transition to a fully de-carbonised mobility.

SHORT-TERM IMPACT:

- Growing integration into (especially distribution) network of EV smart charging stations and systems

LONG-TERM IMPACT:

- Integrated management of electricity transport network to offer services to the T&D network including V2G

The following tasks[8] will be investigated in R&I projects:

Task No	PRIORITY[9]	Tasks	Functionalities
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
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
3	R	3. Flexibility services offered by transport electrification, especially **Electric Vehicles with Grid to Vehicle G2V and Vehicle to Grid VtG** capabilities on distribution grid operation, especially for load flattening, system balancing and voltage support.	F2, F5, F7, F10, F11, F12

OUTCOMES OF R&I PROJECTS WORKING ON THIS TOPIC

KNOWLEDGE

- Development of suitable storage facilities and operational methodologies to allow ancillary services to distribution grid in the substation of the PCC (point of common coupling).
- Analysis (via scenarios and simulations) of the impact of transport system electrification on distribution grids.
- Hybrid systems for transportation. Mixed V2G strategies with full renewable fuels (bio and Power-to-Liquid (XtL).

SOFTWARE, TOOLS, ALGORITHMS, MODELS

- Development of innovative management systems and algorithms (both centralised and distributed) enabling smart grids integration of EV charging infrastructures.

PARTICIPATING STAKEHOLDERS:

Research & Academia	Regulated (Grid) Operators	Storage technology providers	ICT providers

TRL and related BUDGETS:

3 Research related tasks (TRL 3-5) with a budget of €18 million

RA 6: SYSTEM OPERATION

TOPIC 6.1: Supervisory Control and State Estimation

CHALLENGE

The extensive integration of variable renewables may threaten the continuity and quality of the electricity supply if adequate mitigation and protection measures are not taken. The delicate internal balance of the electricity system to guarantee its stability requires the real-time knowledge (by measurement and estimation) and control of all critical system parameters.

Supervision and control systems used in most of the present electricity networks have been designed according to the rules of fully controllable generation. The progressive integration of highly variable generation sources such as wind and PV requires a radical change in the ways the systems are managed, starting from the thorough evidence of the trend of the critical system parameters (such as frequency, voltage levels and phasors) at all system levels, thus requiring a strong cooperation among system operators.

Adequate and validated tools and systems are needed to foster the observability of the electricity system throughout the different levels (transmission, distribution, delivery). Methods are to be designed for an optimised use of system data in view of state estimation with the adequate time span from stability purposes to energy optimisation and efficiency.

SCOPE

The TOPIC will consider the entire process of observability and supervision of the electricity system in presence of high variabilities from generation (renewables), network (contingencies) and load and of all flexibility tools adopted (such as storage (batteries, heating and cooling storage, storage for carbon-neutral gases), and VtG).

The research and demonstration activities will start from the development of adequate sensors, methods and tools (such as WAMS and PMUs) for electric system observability, including the advanced algorithms for data elaboration based on the use of deep learning and artificial intelligence, to enhance the estimation of the state of the system (such as damping, system inertia, short circuit power in critical nodes) at all voltage levels, by all network operators (TSO-DSO cooperation) and at all time and geographical scales. Early detection of critical situations or nodes will be made possible. The activities will address the ICT infrastructures needed to enable the state estimation and visualisation, as well as the protocols for the adequate cooperation of network operators at all levels.

SHORT-TERM IMPACT:

- Increased hosting capacity for variable RES.
- Use the entire span of possible working conditions for the energy system, thus increasing its availability and security.

LONG-TERM IMPACT:

- System hosting capacity for 100% and more variable renewables.
- Full observation of the distribution grids though the right combination of sensors, monitoring equipment and algorithms, software, at total minimal cost.

The following tasks[8] will be investigated in R&I projects:

Task No	PRIORITY[9]	Tasks	Functionalities
1	R	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
2	R	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
3		3. **Real-time observability of RES** (algorithms and tools) and **improved forecasts** for operational planning purposes.	F9, F10, F11, F12

OUTCOMES OF R&I PROJECTS WORKING ON THIS TOPIC

SOFTWARE, TOOLS, ALGORITHMS, MODELS

- Validated tools and methods for system state estimation based on AI.
- Scalable hierarchical observability methods and systems enabling the utilisation of monitoring data at different geographical scale in a coordinated manner.
- Consolidated operational ICT-platforms for real-time communication and data exchange among European TSOs.
- Experimental results from in-field demonstration of real-time estimation of intrinsic grid parameters.

DEMONSTRATION

- Innovative sensors for the monitoring of power systems with the aim of an increased observability at all voltage levels.
- Validated prototypes of ICT-platform for real-time communication and data exchange among European TSOs.
- Regional WAMS applications operational in TSOs control rooms.
- Validated tools for real-time estimation of intrinsic power system parameters (damping, system inertia, short circuit power in critical nodes).
- Demonstrated techniques for early identification of critical situations and for the real time stabilisation of interarea oscillations in low inertia systems.
- Integration of distribution grids and dispersed generation data into the set of TSOs observable systems.
- Full observability of the European transmission grid based on phasor measurement linear/hybrid state estimation.

PARTICIPATING STAKEHOLDERS:

Research & Academia	Energy Suppliers	Aggregators	Regulated (Grid) Operators	Power technology providers	Storage technology providers	ICT providers

TRL and related BUDGETS:

2 Research related tasks (TRL 3-5) with a budget of €19.2 million
1 Demonstration related tasks (TRL 6-8) with a budget of €6.8 million

CHALLENGE

The integration of extensive shares of variable renewable energy sources connected to the network via inverters and the use of power electronics (FACTS, smart transformers etc.) throughout the power system requires a rapid evolution of methods and tools adopted to guarantee system stability.

The stability of the present electricity system leverages on the existence of the physical mass of rotating generating machines enabling, through their inertia, the damping of oscillations in front of rapid perturbations, thus allowing the intervention of the primary control systems. The extensive use of power electronics devices, used especially in the connection of variable renewables sources will create issues for the system stability of the power system because of the decrease in physical inertia. Moreover, the adoption of power electronics will substantially change the system protection philosophies.

Systems are needed to control and protect the Pan-European power system in an effective way, by being ready at any time for handling the normal operation as well as different types of contingency system states through preventive and corrective actions based on a system-wide, highly coordinated, fully interoperable grid observability, state estimation, new containment measures and protection criteria, under all scenarios (for example weather, failure, or attack).

SCOPE

The TOPIC addresses the innovative system operation, focussing on the short-term control techniques, 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.) in inverter-dominated grids.

With significant integration of converter interfaced generation (CIGs), loads, and transmission devices, the dynamic response of power systems has progressively become more dependent on (complex) fast-response power electronic devices, thus, altering the power system dynamic behaviour. The time scale related to the controls of CIGs ranges from a few microseconds to several milliseconds, thus encompassing wave and electromagnetic phenomena next to electromechanical phenomena. Considering the proliferation of CIGs, faster dynamics will gain more prominence when analysing future power system dynamic behaviour compared to stability phenomena within the time scale of several milliseconds to minutes of conventional power systems. There is a need therefore to develop models and tools able to extend the bandwidth of the phenomena to be examined and include faster dynamics within electromagnetic time scales when the faster dynamics is of importance and can affect overall system dynamics.

The operator needs to be able to accurately simulate a the dynamic performance of his system in order to ensure that the system can ride through any contingency without losing its angular, voltage or converter driven stability. The main question that the operator needs to answer is if the system will be stable and secure after any credible contingency; to the extent that it is not, what corrective action needs to be taken so that the system becomes operationally feasible.

Dynamic operation, fast response to contingencies, resilience to major disturbances are becoming a paramount challenge for grid operators; security of supply is here at stake, i.e. in case of wide spread blackouts. Therefore the benefits are measured in terms of avoided loss of load hours, where each lost MWh is typically valued at €5-30k.

Moreover, not just real-time and continuous prediction but also measurement can be devoloped. Critical to get ‘model validation’ right, we see with higher renewables that correlation between reality and models can go down as model complexity increases.

The research and demonstration activities addressed in this TOPIC will start from the development and validation of models and tools for the investigations of dynamic stability issues for AC and AC/DC hybrid grids, at all voltage levels. Network-based SHORT-TERM control and protection in presence of high variability conditions (operational, planning) will use improved data analytics (such as AI and machine learning), data collection and processing (such as Big Data), also using fast real-time and continuous prediction of dynamic stability margins and preventive mechanisms and the market-based activation of cross-border dynamic stability services (such as ancillary services).

SHORT-TERM IMPACT:

- Smarter and safer grid operation.
- Improved, more reliable network state knowledge.
- Real-time estimation of intrinsic power system parameters.
- Boosted coordination between TSO and DSOs and cross border actors to increase amount of ancillary services and flexibility resources across the interconnected borders and market zones.
- Comprehensive methodologies to support the selection of optimal power flow control technologies considering system security criteria and efficiency of grid investments.
- Evaluation of the effectiveness of state of the art on Dynamic Line Rating solutions with analysis of the synergies with forecasting models and tools.

LONG-TERM IMPACT:

- Increased level of flexibility in transmission and distribution grid management to allow full integration of RES (beyond 100% of demand) while maintaining the security of supply at the pan-European level.
- Optimised real-time transmission and distribution grids architecture and operational efficiency.

The following tasks[8] will be investigated in R&I projects:

Task No	PRIORITY[9]	Tasks	Functionalities
1	€	1. Optimal **Load Frequency Control** considering requirements for telecommunication infrastructures, latencies and reliabilities.	F6, F7, F9, F10
2		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.	F5, F7, F10
3		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, and VPPs.	F7, F9, F10, F11, F12

OUTCOMES OF R&I PROJECTS WORKING ON THIS TOPIC

SOFTWARE, TOOLS, ALGORITHMS, MODELS

- Validated tools and solutions for the management of the Pan-European transmission network, for secure operation of the power system with steadily increasing (beyond 100% of demand during certain intervals) inverter-based RES, through fast real-time and continuous prediction of dynamic stability margins and preventive mechanisms and the market-based activation of cross-border dynamic stability services (such as ancillary services).
- Use of real-time simulation capabilities to better evaluate impact on system operation and network management under stress situations (extreme level of RES, extreme weather).
- Open sources models and software for dynamic stability investigations for AC and AC/DC hybrid grids, for all voltage levels.

DEMONSTRATION

- Assessing in demonstrations the capacity of devices and technologies like DLR, FACTS, WAMS, and PMU to enable the operation of the transmission system closer to its physical limits with high reliability and to defer new infrastructure while absorbing more RES power.
- Grid forming control functionalities demonstrated for vRES and storage systems with possible support from FACTS/FACDS.
- Exploring the role and impact of existing and emerging ICT for grid observability and controllability; using co-simulation techniques able to simulate ICT impact in power systems to ensure a reliable digitization of pan European system.
- Demonstration of benefits of the use of tools and solutions for the management of the distribution networks in presence of high variability conditions (operational, planning) based on improved data analytics (AI, machine learning, and digital twins), data collection and processing (like Big Data).
- Identify and demonstrate technologies and solutions for the enhancement of the distribution networks (with electricity as the backbone of a multi-energy-sector energy distribution system) such as:
  - New algorithms integrated into the operation systems to improve the quality of service
  - ICT architectures and processes to cope with increasing amounts of data
- Innovative solutions developed and demonstrated to counteract the decrease of short circuit current and increased voltage/frequency interactions resulting from the increased penetration of PE-connected generation.
- On-line dynamic security assessment (voltage, frequency, angle) of interconnected power systems based on active distribution networks, inverter-based generation and loads acting as grid sensors and as integrated part of new network protection schemes.
- Impact on stability, coming from the deployment of the PE “synthetic inertia” services, assessed at system level.
- Techniques developed and applied to detect cascading mechanisms possibly triggered by multiple contingencies or interarea oscillations; proof of concept of wide area defence systems aimed to limit the extension and consequences of the disturbance, also resorting to islanding, reconnection and grid formation capabilities by PE-connected generators.
- Mature technological solutions tested and proved for the provision of increased controllability and flexibility on both TSO and DSO voltage levels.
- Contribution to system controllability from large-scale new power technologies (including from new materials) assessed and demonstrated.
- Assessment of the impact of network controllability (achieved by methods and tools for optimal and coordinated use of flexibility resources) on the global social welfare and ancillary services sharing. DSA demonstrator, DSO/TSO interfaces.

PARTICIPATING STAKEHOLDERS:

TRL and related BUDGETS:

1 Research related tasks (TRL 3-5) with a budget of €6 million
2 Demonstration related tasks (TRL 6-8) with a budget of €14 million

TOPIC 6.3: Medium and long-term control (Forecasting (Load, RES), secondary & tertiary control: LFC, operational planning: scheduling/optimisation of active / reactive power, voltage control)

CHALLENGE

In addition to being stable and reliable, the electricity system must be efficient and able to ensure the adequate level of power quality. Measures to reduce internal inefficiencies such as the excessive reactive power flows and the energy imbalances, especially in presence of uncertainties need to be designed and applied.

The evolution of the power system in a resources-constrained context must be ensured minimizing stranded assets and prioritizing investments. This can be achieved by identifying and implementing medium and long-term control strategies and tools (reactive power control) and enhancing the performances of forecasting the exogenous parameters influencing the behaviour of the system.

Solutions are needed to optimise the production of renewable energy sources by means of generation forecasting/nowcasting and forecasting and profiling of load and consumer behaviour, as influenced by the variable market conditions and mechanisms. Medium and long-term control strategies and tools are needed to support system operations, effective and sufficient security margins assessment, load sharing between substations, and control systems in secondary substations.

SCOPE

The TOPIC addresses the solutions for operational planning of the energy systems, with special reference to resources scheduling (through adequate generation and load forecasting) and optimisation of active/reactive power and voltage control.

The research and demonstration activities will start from the development of forecasting and monitoring tools for primary energy sources, system behaviour and load dynamics and profiles of real-time tools for improved security analysis and decision making, using probabilistic algorithms, enhanced forecasting of RES integrated in the short-term operational planning optimisation. Validated tools for the dynamic power unit commitment, reserve allocation and optimal power flow for the highest integration of vRES will also be developed.

SHORT-TERM IMPACT:

- More accurate forecasting of generation, system behaviour and load.
- Risk analysis capability of forecasting errors and remedial actions.
- Identification of grids constraints and mitigation of effects of congestions.

LONG-TERM IMPACT:

- Self-setting energy system integrating large shares of vRES, leveraging the advanced forecasting capabilities of exogenous and endogenous parameters and the controllability of the system.

The following tasks[8] will be investigated in R&I projects:

Task No	PRIORITY[9]	Tasks	Functionalities
1		1. Advanced **RES forecasting** considering weather forecasts, local ad-hoc models, historical data and on-line measurements.	F5, F6, F7, F9, F10, F11
2		2. **Hydropower forecasting** based on weather, precipitation models and live sensors.	F1, F9, F10
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
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
5		5. Optimal **distribution network configuration** including increased monitoring capabilities at distribution level, automatic LV and MV System Topology identification and day-ahead forecasting.	F7, F9
6		6. Massive use of **control technologies in secondary substations** and the resulting coordination needs for system operators.	F7, F10

OUTCOMES OF R&I PROJECTS WORKING ON THIS TOPIC

SOFTWARE, TOOLS, ALGORITHMS, MODELS

- Decision support methods and algorithms implemented in the Security Analysis Tools used by Regional Security Centres & individual TSOs.
- Improved, self-learning forecasts for RES generation.
- Improved adequacy analysis through mathematical tools and probabilistic methods as tested in pilot projects.

DEMONSTRATIONS

- Validated close to real-time tools for improved security analysis and decision making, using probabilistic algorithms, enhanced forecasting of RES integrated in the short-term operational planning optimisation.
- Risk-based assessment of power system security and resilience.
- Control room decision support systems for operational planning, defence and restoration.
- Sensing technologies, automation and control methods integrated into monitoring, analysis and control architectures.
- System and tools to reduce over voltage issues generated by non-synchronous generators (such as large solar power plants).
- Forecasting and monitoring tools for primary energy sources, system behaviour and load dynamics and profiles.
- Validated tools and software for the study of distribution grids with very low (no) inertia.
- Validated tools for the dynamic power unit commitment, reserve allocation and optimal power flow for the highest integration of vRES.

PARTICIPATING STAKEHOLDERS:

Research & Academia	Energy Suppliers	Aggregators	Regulated (Grid) Operators	Power technology providers	Storage technology providers	ICT providers

TRL and related BUDGETS:

2 Research related tasks (TRL 3-5) with a budget of €8.1 million
4 Demonstration related tasks (TRL 6-8) with a budget of €28.9 million

TOPIC 6.4: Preventive control/restoration (Contingencies, Topology including Switching optimisation, Protection, Resilience)

CHALLENGE

Extreme events linked with climate change are increasing in frequency and intensity. Cyber-threats and intentional attacks may be increasingly dangerous for systems relying on extensive digitalisation. The power system is exposed to different types of threats both natural or intentional and needs to increase its level of resilience.

Evaluating and increasing the resilience of the power system starts from the analysis of normal and abnormal operational conditions, identifying threats from external natural and intentional origin, assessing the system responsiveness to contingencies, minimising the risk, determining the right balance between “hardening” the power system infrastructures and smartening the network operation, identifying preventive and curative actions such as, for example, automatic fault clearing procedures and developing system restoration tools.

Solutions are needed to increase the system resilience: for example the ability to anticipate and prepare for critical situations, to absorb impacts of hazards, prevent deterioration in service to the point of failure, to respond to and recover rapidly from disruptions, and to make adaptations that strive to provide continued electrical supply under a new condition.

SCOPE

The TOPIC addresses the power system resilience, starting from the evaluation and forecasting of natural and human-related threats, assessing the system and components vulnerabilities, identifying and modelling the contingencies (single and multiple), evaluating the effects of mitigation of the threats through hardware (increasing robustness) or intelligence (smart management) solutions and identifying measures for the rapid restoration of power system performances (even reduced) to progressively restore the adequate level of supply quality.

The research and demonstration activities will follow the pathway of resilience evaluation and, namely:

- Threats: natural threats, such as natural disasters (earthquakes, tsunami, volcano eruptions etc.), extreme weather events like wind, heavy rains, snowfalls, heat waves, thunderstorms, and their consequences like draughts, floods, terrain drifts will be studied historically, to assess their return time and project their frequencies along climate changes scenarios and will be predicted (when applicable) using advanced forecasting methods. Cyberattacks and intentional threats (terrorism) will also be considered based on technology evolution and geopolitical analysis.
- Vulnerability: the power system vulnerability, intended as composed by the fragility of network components and the system vulnerability in front of different types and combinations of contingencies will be evaluated, based on equipment tests (such as fault-ride tests) and system simulation adopting stochastic reliability approaches, thus replacing the current reliability principles.
- Resilience: assessment and validation of self-healing techniques for defence and restoration, probabilistic approaches, and enhanced reliability criteria; general methodological frameworks (“resilience doctrine”) to be adopted by network operators to assess and to increase the power system resilience considering all the management phases (planning, operational planning and operation) and possible failures of both physical and digital infrastructures.
- Restoration: identification of pan European and regional system restoration algorithms, procedures and tools taking into consideration the possible contribution of DER/RES and storage systems (such as batteries, hot water tanks, cooling systems storage, storage for CO2-neutral or free gases), to system restoration and immediate power reserves (such as black start capability).

SHORT-TERM Impact:

- Increased RES penetration without undermining main system stability.
- Increased resilience – ability of society in emergency and partial failure situations to continue their activities with critical loads, and immunity so that the supply to energy communities is not disturbed in case of the main grid failures.
- Improved cyber incident management capabilities within energy organisations, quicker time to recovery.
- A consolidated methodology for resilience assessment and for identification of the optimal combination of measures to increase power system reliability and resilience, accounting also for failure modes of ICT, as validated in several pilots and demonstration projects across the whole Europe.
- Criteria indicators to help network operators take decisions for preventive and curative actions and to assess efficiency and cost-effectiveness of the different solutions.

LONG-TERM Impact:

- Reduced effects of major catastrophic events (such as wide-spread blackouts) on society.
- Increased local availability of critical operational activities during wide-spread blackouts by resilient Microgrids (as temporary electrical islands).
- Full support by citizen and local communities.
- Available protection and control to enhance the component resilience and for precise fault location in both AC and HVDC systems.

The following tasks[8] will be investigated in R&I projects:

Task No	PRIORITY[9]	Tasks	Functionalities
1		1. Protection of **distribution networks with low fault currents** due to high penetration of PE interfaced DER.	F7, F9
2		2. **DC grid protection, protection relays and breakers,** multi-vendor solution with the consideration of interoperability, standardisation.	F7, F9
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
4	4 or 5 BB	4. **Bottom up restoration** by DER support and storage including intentional islanding techniques via Microgrids and Web-of Cells approaches. Synchronisation of DER and storage reconnection.	F1, F2, F4, F5, F6, F7, F8, F9, F10, F11, F12
5	D	5. **Self-healing techniques** at distribution level by automatic fault clearing procedures in automatic power system restoration.	F7
6		6. Efficient **Load Shedding techniques** and tools considering reactive power and voltage control.	F1, F7, F9, F11

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
8	R	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. Minimise negative impacts of switching actions from one Transmission System to the neighbouring ones.	F1, F4, F5, F6, F7, F8, F9, F10

OUTCOMES OF R&I PROJECTS WORKING ON THIS TOPIC

KNOWLEDGE

- Rules and tools for the integrated energy system security assessment in coordination of all components of the security chain (from local/global authorities, fire brigades, civil protection, network operators, and police).
- Probabilistic and extreme-scenario-based approaches to contingencies and resilience, addressing all phases of the process, including threats, vulnerability, resilience and restoration also considering intentional electrical islands and microgrids.
- Guidelines for the customer risk evaluation and handling in case of contingencies in the energy system.
- Procedures and standards for testing equipment to fault avoidance or fault ride-through aptitude.
- A general methodological framework ("resilience doctrine") to be adopted by TSOs to assess and to increase the power system resilience considering all the management phases (planning, operational planning and operation) and possible failures of both physical and digital infrastructures.
- Results from innovative sandboxes of specific regulatory frameworks focusing on how to effectively involve distributed resources in the restoration process, including role and responsibility of the various actors in order to foster coordination efforts.
- A consolidated methodology for resilience assessment and for identification of the optimal combination of measures to increase power system reliability and resilience, accounting also for failure modes of ICT, as validated in several pilots and demonstration projects across the whole Europe.
- Criteria indicators to help network operators to take decisions for preventive and curative actions and to assess efficiency and cost-effectiveness of the different solutions.
- Circular economy methodology to process reengineering and projects.

SOFTWARE, TOOLS, ALGORITHMS, MODELS

- Tools and solutions for mitigation support actions to be implemented in planning, operational planning and operation phases to prevent system failures and consequences in terms of time to recovery (such as enhanced selectivity of relay protection and fault location systems).
- Tools and solutions for planning and operation of the electricity system (as backbone to the other energy carrier systems) under higher risk conditions, based on probabilistic approaches to resilience.
- Pan-EU and regional system restoration algorithms, procedures and tools.
- Innovative approaches and tools for TSOs to accurately assess and to increase power system reliability with respect to normal and extreme events by identifying possible options for complementing or replacing the current reliability principles.

- New simulation tools and methods to accurately estimate intrinsic power system parameters (damping, system inertia, short-circuit power in critical nodes) and to detect system weaknesses (vulnerabilities) with respect to different kind of natural and anthropic threats, taking into account multiple power system contingencies and failure modes (including ICT and sensors).
- New simulation tools to support resilience assessment, self-healing techniques for defence and restoration, probabilistic approaches, and enhanced reliability criteria.
- New simulation tools to assess the possible contribution of DER/RES and storage systems also connected at DSO level, to system restoration and immediate power reserves (such as black start capability) as compared to conventional approaches.
- Tools and technical solutions for real-time estimation of intrinsic power system parameters as tested and validated in pilot projects and relevant portions of the power system.
- Methodologies, and new stochastic models of market operations on different timescales to improve transmission system reliability and resilience in the TSOs day-by-day business.

DEMONSTRATION

- Equiment and tools as countermeasures to reduced inertia in power systems with high penetration of power electronics.
- Automatic fault clearing procedures and related system control devices and actuators.
- Experimental validation/results of protection and control solutions to enhance the component resilience and for precise fault location in both AC and HVDC lines whether they are overhead, underground, submarine or any of their combinations.

PARTICIPATING STAKEHOLDERS:

- Research & Academia
- Energy Suppliers
- Aggregators
- Market operators
- Regulated (Grid) Operators
- Power technology providers
- Storage technology providers
- ICT providers

TRL and related BUDGETS:

5 Research related tasks (TRL 3-5) with a budget of €22.6 million

3 Demonstration related tasks (TRL 6-8) with a budget of €31.4 million

RA 6: SYSTEM OPERATION

TOPIC 6.5: Control Center technologies (EMS, platforms, Operator training, Coordination among Control Centers)

CHALLENGE

The management of the integrated energy system under progressively new constrained conditions requires the development of control center technologies, the associated new skills and the training of operators to cope with the new responsibilities. Decisions on more complex systems will be taken more rapidly to guarantee the continuity, safety and quality of service.

Innovative training systems are to be made available leveraging the available technologies such as AI and AR to be massively introduced into control rooms and operators training centres.

Automated monitoring and control of networks at all voltage levels (HV, MV and LV), using digital and advanced operators control centres environments are needed to foster decision making, thus enhancing time and quality of reaction; these environments must be complemented and enhanced for the training of operators so as to adapt to Network Energy Management platforms using real-time system implementation (digital twin) to simulate human grid operator roles and intervention.

SCOPE

The TOPIC addresses the necessary network operators control room features as well as the operator training tools at all level of the integrated system development, management and operation to ensure adequate level of decision making and the uniform level of skills and approaches.

The research and demonstration activities will start from the analysis and development of the functions to be implemented for a combined central and decentralized control of energy systems based on advanced smart power systems architectures. The tools developed will be used also for training network operators based on close-to-real world concepts (like digital twins), able to react to all types of perturbations and system variabilities and events; tools for training of grid maintenance operators, assisted by AI and AR (Augmented Reality) during their interventions, thus facilitating the operators' full adaptation to the new digital environment will also be considered.

SHORT-TERM IMPACT:

- Increased observability and controllability of the power systems, with a higher degree of transformation of data into information and knowledge to the advantage of network operators, thus increasing their decision-making capabilities and improving their time and quality of rection to disturbances and threats.

LONG-TERM IMPACT:

- A self-healing power system supervised by system operators fully trained using AI, AR, digital twins to continuously optimize the network operation during normal service as well as in front of all types and levels of threats.

The following tasks[8] will be investigated in R&I projects:

Task No	PRIORITY[9]	Tasks	Functionalities
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
2	R	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
3	R	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
4	€	4. **Control center architectures for distributed network control** (Web-of-Cells and Microgrids) considering new sensors, such as fault detectors, voltage and current sensors in generation, storage, buildings, EVs, industry and MV levels with limited bandwidths.	F1, F2, F5, F7, F8, F9, F10, F11, F12
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	€	6. Advanced **Training simulators for DSOs and TSOs** (**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
7	R	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

OUTCOMES OF R&I PROJECTS WORKING ON THIS TOPIC

KNOWLEDGE

- Resilient self-healing network power system by design.

SOFTWARE, TOOLS, ALGORITHMS, MODELS

- Tools and systems for the training of network operators based on close-to-real concepts (like digital twins), able to react to all types of perturbations and system variabilities and events.
- Tools and systems for training grid maintenance operators, assisted by AI and AR (Augmented Reality) during their interventions, thus facilitating the operators' full adaptation to the new digital environment.

DEMONSTRATIONS

- Combined central and decentralized control of a portion of the energy system based on advanced smart power systems architectures and TSO, DSO- control – components.

PARTICIPATING STAKEHOLDERS:

Research & Academia	Energy Suppliers	Aggregators	Regulated (Grid) Operators	Power technology providers	Storage technology providers	ICT providers

TRL and related BUDGETS:

5 Research related tasks (TRL 3-5) with a budget of €32.9 million
2 Demonstration related tasks (TRL 6-8) with a budget of €31.1 million

III. Detailed Budget for the ETIP SNET R&I Implementation Plan 2021–2024

The budget calculation methodology is detailed in Annex I.

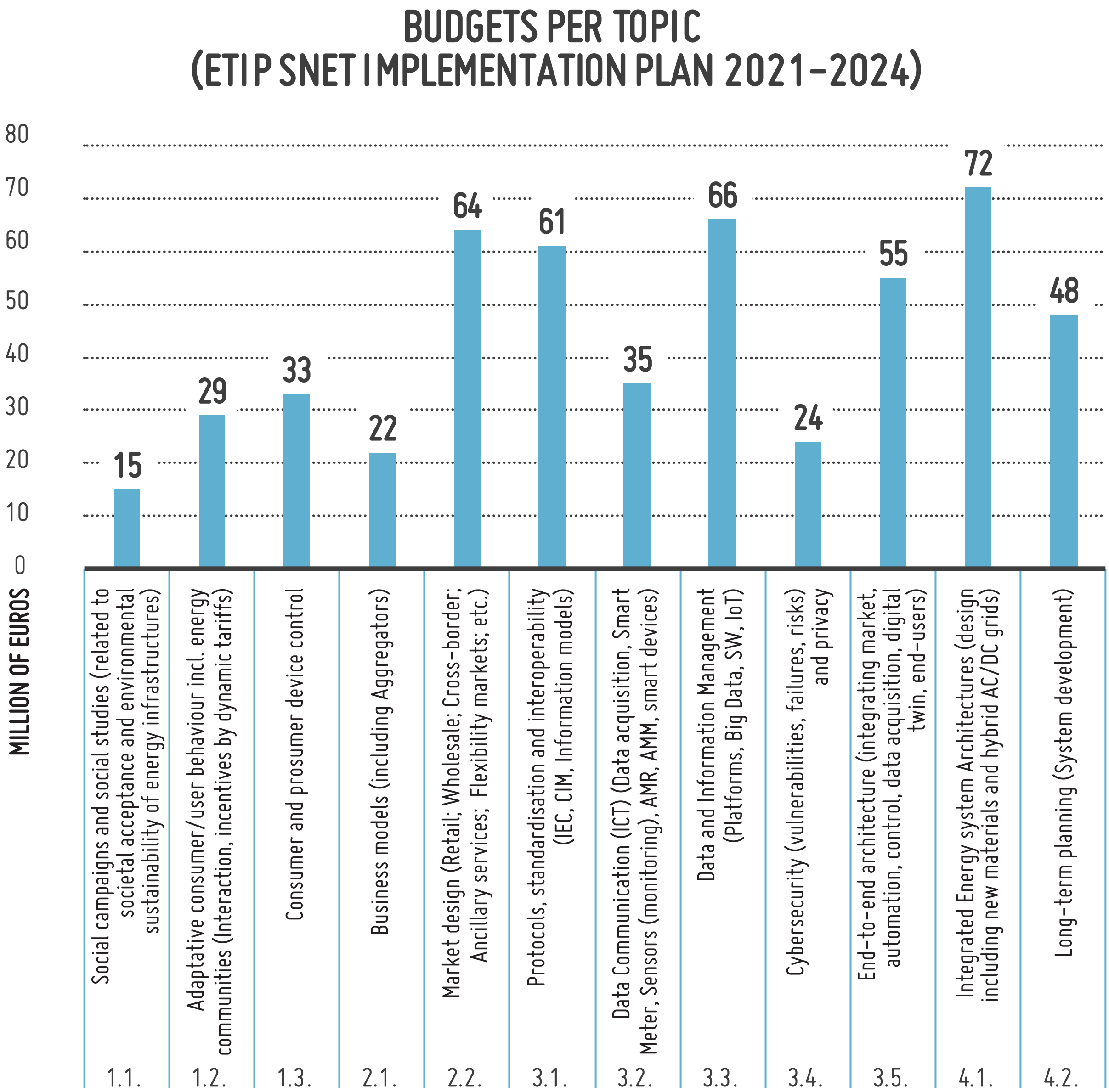
The figures below show the expected budgets for the period 2021-2024, split into TOPICS and into FUNCTIONALITIES. The total budget for the ETIP SNET R&I Implementation Plan 2021-2024 is approximately €955 million.

Related to proposed 24 TOPICS, the largest budget is for TOPIC 4.1 "Integrated Energy system Architectures (design including new materials and hybrid AC/DC grids)" with €72 million of the total 2021-2024 expected budget, followed by TOPIC 3.3 "Data and Information management" with €66 million, followed by TOPIC 2.2 "Market design and governance" with €64 million and TOPIC 6.5 "Control Center technologies (EMS, platforms, Operator training, Coordination among Control Centers)" also with €64 million, then followed by TOPIC 3.1 "Protocols, standards (ICT)" with €61 million and 6.4 "Preventive control" with €54 million of the total budget 2021-2024.

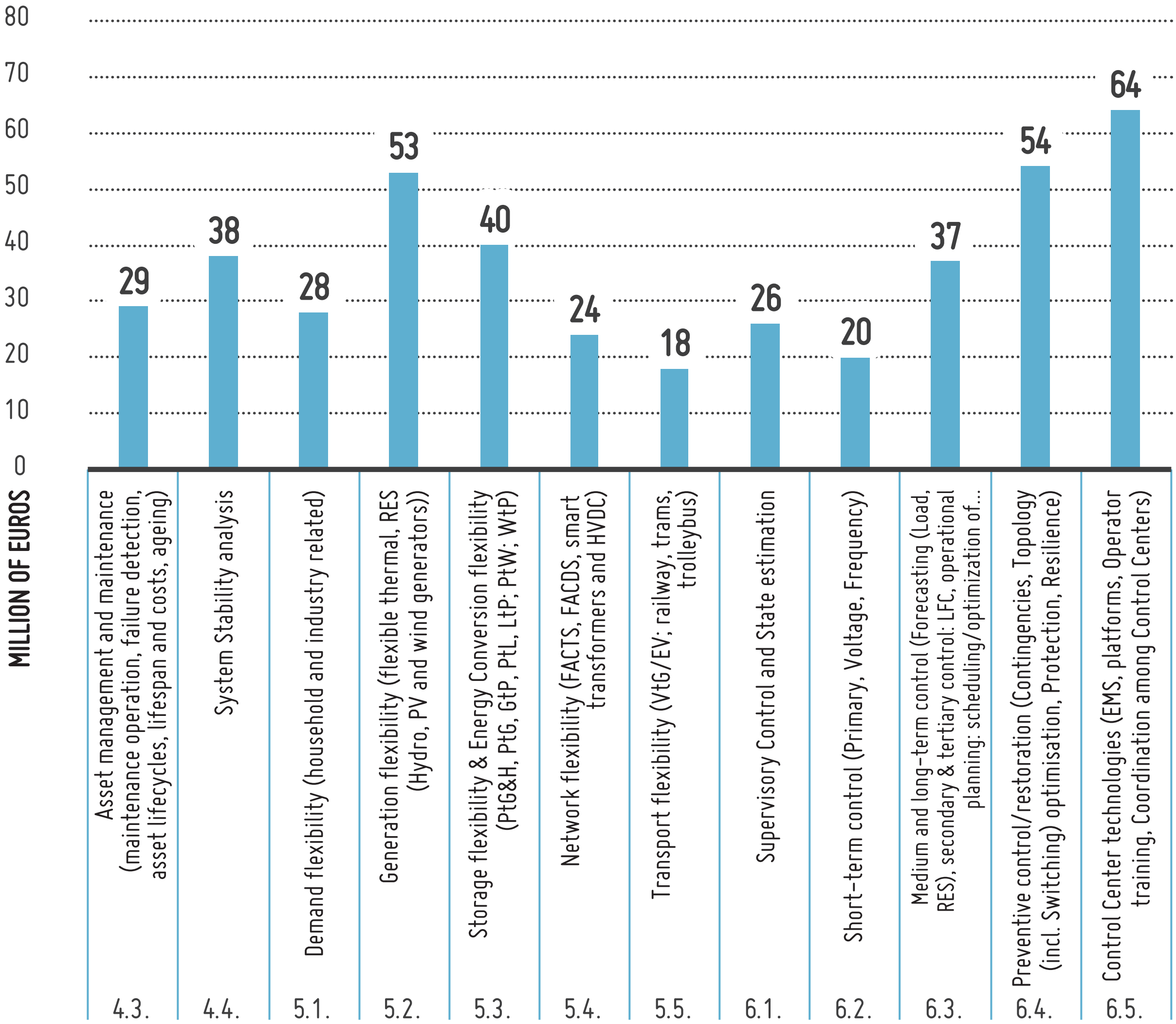
The budget needs on the level of Research Areas for the ETIP SNET R&I Implementation Plan 2021-2024

- The ETIP SNET R&I Implementation Plan 2021-2024 has a distinct expected budget for each research area.
- The sequence in budget-descending order for the Research Areas shows at the first place (highest budget needs) **3. Digitalisation:** This subject will drive the R&I in the coming period 2021-2024. Digitalisation is overarching over the entire energy system and the energy system stakeholders have the perception that it will be a key enabler in all the processes.
- The second place in terms of expected budget needs is **6. System Operation:** This area is one of the biggest challenges of the integrated energy system: how to manage a system with 100% RES and where electricity, gas, and heat must work together with the system operation goal of an overall reliable, robust, resilient and affordable energy system.
- The third expected budget place is **4. Planning Holistic architecture and assets**, close to **5. Flexibility enablers and system flexibility:** this is due the bulk of the system (assets) and its flexibility needs (also based on conversion technology, such as Hydrogen and Power-to-Gas).
- Finally, **2. System economics and 1. Consumer, Prosumer and Citizen energy community.**

Table 8: The budget for the 24 TOPICS and the time period of the ETIP SNET R&I Implementation Plan 2021-2024

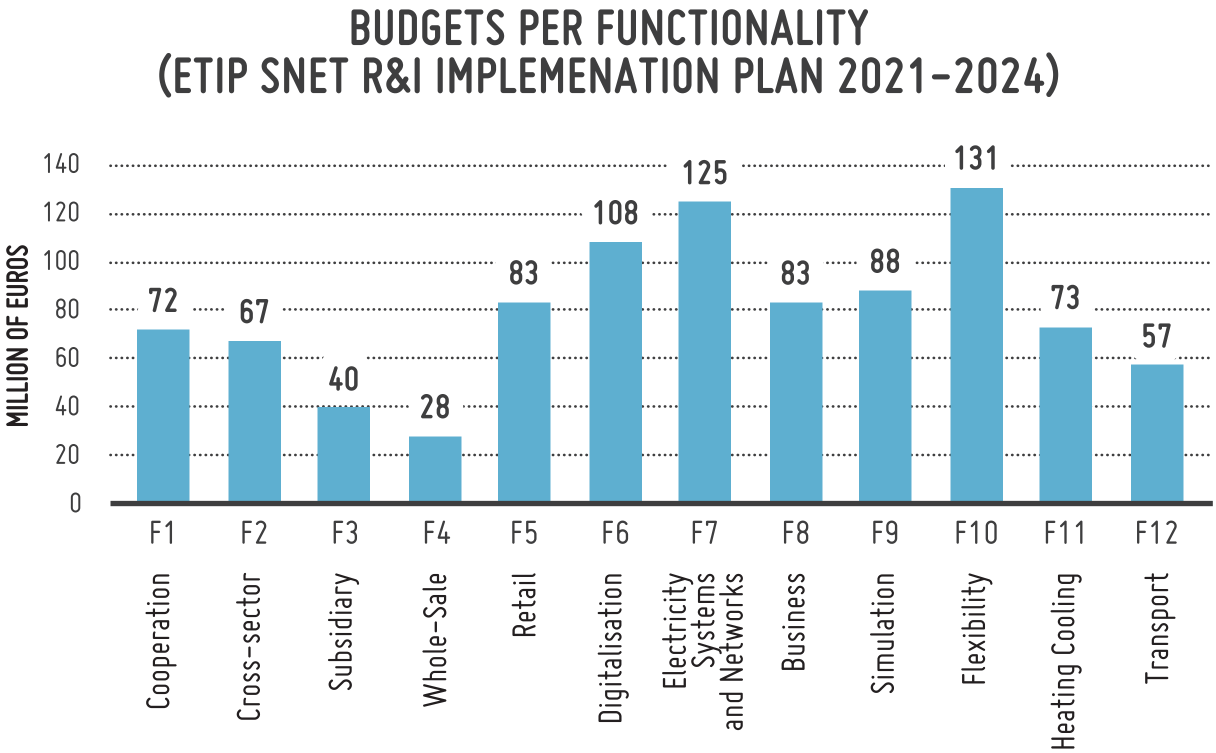


BUDGETS PER TOPIC (ETIP SNET IMPLEMENTATION PLAN 2021-2024)



Related to FUNCTIONALITIES (Figure 9) the largest budget of €131 million is for the tasks contributing to FUNCTIONALITY F10 (Integrating flexibility in generation, demand, conversion and storage technologies), followed by €125 million for F7 (Upgraded electricity networks, integrated components and systems), followed by €108 million budgets for F6 (Integrating digitalisation services, including data privacy, cybersecurity).

Table 9: The budget for the 12 FUNCTIONALITIES between 2021-2024.



IV. Synthesis

This chapter provides the synthesis on how budgets and Research & Demonstration tasks are distributed among the different Research areas and how they contribute to the five building blocks defined in the ETIP SNET R&I Roadmap 2020-2030. The following table shows how expected total budget of €955 million for the period 2021-2024 are divided among Research Areas and their contributions to each of the five building blocks.

The figures are based on a systematic methodology that each Research Area has one or more associated TOPICS and each TOPIC has several associated tasks. Each task contributes to a defined subset of the 12 FUNCTIONALITIES as shown in Table 2. The tasks are listed in the Annex II of the ETIP SNET Roadmap 2020-2030 and are reused in the TOPIC descriptions of this Implementation Plan.

The budgets for the first IP-Period 2021-2024 and the total for the whole Roadmap 2020-2030 has been defined by the ETIP SNET stakeholders in a consultative process. The split of the total budgets has then been done based on the budget methodology where each task has an associated expected budget based on the number of functionalities to which it contributes and the maturity level the task will reach in each IP-Period. These principles allow the computation of budgets in any aggregated way and per IP-Period.

The following table shows the expected budget for each Research area and each BUILDING BLOCK for the ETIP SNET R&I Implementation Plan 2021-2024, visualized by **background colour intensity**:

- **black background in table cells**: highest budgets in the period 2021-2024.
- white background in table cells: lowest budgets in period 2021-2024.

The first row of the table deals with the R&I efforts associated to Research Area 1 ("1. CONSUMER, PROSUMER and CITIZEN ENERGY COMMUNITY). The underlying tasks associated contribute in different intensities (budget, number of tasks, number of FUNCTIONALITIES) to the five building blocks.

These individual tasks of each Research Area and how they contribute to the Building blocks can be found in the ETIP SNET R&I Roadmap 2020-2030, Annex II and in the SCOPE sections of each TOPIC, described in detail in this ETIP SNET R&I Implementation Plan 2021-2024.

The following table can be interpreted in various ways. In total, the expected budget is €955 million which can be found as sum in the lower right cell. First, the R&I efforts per Research areas can be found in the 6 rows with totals in the right-hand-side column. Second, the R&I efforts can also be seen in terms of how they contribute to each of the five Building blocks by looking at the 5 columns with total budgets per Building block in the last row. From the research area point of view, the one with the biggest expected budgets is "3. Digitalisation" with €241 million, followed by "6. System Operation" with €201 million.

When looking at the Building blocks, "Infrastructure for Integrated Energy Systems as key enablers of the energy transition" has the biggest budget of €296 million, followed by the Building Block "Efficient Energy Use" with €261 million.

120 defined tasks are individually associated to the Research Areas and Building blocks: they are the basis for these expected budgets. The largest such association can be found for Research Area "3. Digitalisation" and the effects of its tasks on the Building Block "Infrastructure for Integrated Energy Systems as key enablers of the energy transition". It is the darkest coloured cell in Table 11 indicating the highest expected budget for a single research area on a single building block of €82 million.

Follow-up Implementation Plans

For the next work period, a mapping of the progress made in the energy systems research and innovation will be carried out. This progress will be monitored, summarised and structured with reference to the ETIP SNET R&I Implementation Plan 2021-2024, the ETIP SNET R&I Roadmap 2020-2030 and the SET Plan Action 4 Implementation Plan and based on several interactions with the European energy systems stakeholders.

An update is planned for the R&I Implementation Plan 2021-2024 which will be published by the end of 2021 covering the time period 2023-2026. Then, after an update of the ETIP SNET R&I Roadmap 2020-2030, an additional ETIP SNET R&I Implementation Plan will be published 2023 covering the period 2025-2028.

Table 10: IP Period 2021-2024 with expected budgets (budgets in millions of Euros)

		ETIP SNET Buidling Blocks (ETIP SNET Vision 2050)					
	Budgets ETIP SNET R&I Implementation Plan 2021-2024 for 5 building blocks and 6 Research Areas	The efficient organisation of energy systems	Markets as key enablers of the energy transition	Digitalisation enables new services for Integrat-ed Energy Systems	Infrastruc-ture 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
ETIP SNET Research Areas	1. CONSUMER, PROSUMER and CITIZEN ENERGY COMMUNITY	15	15	10	8	29	77
	2. SYSTEM ECONOMICS	18	18	6	19	25	86
	3. DIGITALISATION	56	26	47	82	28	241
	4. PLANNING - HOLISTIC ARCHITECTURES and ASSETS	29	18	13	71	56	187
	5. FLEXIBILITY ENABLERS and SYSTEM FLEXIBILITY	30	13	12	47	61	163
	6. SYSTEM OPERATION	30	21	20	69	62	201
	Totals	179	111	108	296	261	955

Annex I:
Budget Methodology for ETIP SNET R&I Implementation Plan 2021-2024

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 TOPICS and their Research areas. The table below shows the parameters (TOKENS) of the budget methodology applied to each task of each TOPIC of the ETIP SNET R&I Implementation Plan 2021-2024. In the following, R stands for "*Research" and D for "Demonstration". As used for the whole ETIP SNET R&I Roadmap 2020-2030, the following bottom-up calculation of each task budget was used:

Budget per task for IP Period 2021-2024 = R-Budget or D-Budget

where

R-Budget = R-Token * "the number of involved FUNCTIONALITIES", if task maturity in R&I Period 2021-2024 is Research

D-Budget = D-Token * "the number of involved FUNCTIONALITIES", if task maturity in R&I Period 2021-2024 is Demonstration

With:

- R-TOKEN = budget for a task and Research-TRL-Maturity (TRL 3-5) with a single FUNCTIONALITY. All tasks of a TOPIC have the same R-TOKEN.
- D-TOKEN = budget for a task and Demonstration-TRL-Maturity (TRL 6-8) with a single FUNCTIONALITY. All tasks of a TOPIC 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 the ETIP SNET R&I Roadmap 2020-2030.
- "the number of involved FUNCTIONALITIES": Each task has an implied number of key FUNCTIONALITIES to which it contributes or with which it is involved; see last column of Annex II of Roadmap.

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 = D-Token / R-Token

ETIP SNET Stakeholders have determined the individual budgets for each of the TOPICS for the time frame 2021-2024 in a consultative process. Using the above parameters (R-TOKEN and D-TOKEN per TOPICS, 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 budget for the tasks of each TOPICS is identical with the one as set by the ETIP SNET stakeholders.

This budget methodology reproduces the ETIP SNET stakeholder budgets for each of the defined TOPICS for the ETIP SNET R&I Implementation plan 2021-2024 and was used to determine the total expected budget for the ETIP SNET R&I Roadmap 2020-2030.

Table 11: TOPICS with R- and D-tokens and expected R- and D-budgets for the ETIP SNET R&I Implementation Plan 2021-2024 (in millions of Euros)

TOPIC	R-TOKENS	R-Budgets[10]	D-TOKENS[11]	D-Budgets	Budget per TOPIC (rounded)[12]
1.1.	0.5	3.6	0.9	11.4	15
1.2.	1.3	0.0	2.2	29.0	29
1.3.	1.8	0.0	3.0	33.0	33
2.1.	0.6	22.0	1.0	0.0	22
2.2.	0.8	45.6	1.3	18.4	64
3.1.	2.0	61.0	3.4	0.0	61
3.2.	1.7	23.7	2.8	11.3	35
3.3.	8.3	66.0	13.8	0.0	66
3.4.	1.4	24.0	2.4	0.0	24
3.5.	2.9	35.3	4.9	19.7	55
4.1.	0.9	34.5	1.6	37.5	72
4.2.	0.9	23.2	1.6	24.8	48
4.3.	0.9	17.9	1.6	11.1	29
4.4.	1.0	10.6	1.6	27.4	38
5.1.	0.7	9.5	1.2	18.5	28
5.2.	1.6	39.7	2.7	13.3	53
5.3.	1.3	40.0	2.1	0.0	40
5.4.	1.1	24.0	1.8	0.0	24
5.5.	0.9	18.0	1.5	0.0	18
6.1.	1.0	19.2	1.7	6.8	26
6.2.	1.2	6.0	2.0	14.0	20
6.3.	1.0	8.1	1.7	28.9	37
6.4.	1.0	22.6	1.7	31.4	54
6.5.	1.0	32.9	1.7	31.1	64
		587.4		367.6	955

10 R-Budget = R-Token * "the number of involved FUNCTIONALITIES", where task maturity in R&I IP Period 2021-2024 is Research (TRL 3-5)

11 D-Budget = D-Token * "the number of involved FUNCTIONALITIES", where task maturity in R&I IP Period 2021-2024 is Demonstr. (TRL 6-8)

12 These total budgets per TOPIC have been defined in a consensual process by the ETIP SNET Stakeholders.

Annex II: Details of Task Contributions to Individual Functionalities

In the following Table 12,

- 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 the number of **Demonstration** tasks, each with significant contributions to one or more of the 12 FUNCTIONALITIES for the period 2021-2024. Demonstration tasks may also include supporting Research.

In this period 2021-2024, some tasks have a desired maturity called "I", Innovation referring to deployment. This table does not explicitly mention **Deployment tasks and goals** during the period 20201-2024. However, they are implied to happen in the IP-periods after the tasks have 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 TOPIC and each FUNCTIONALITY for the ETIP SNET R&I Implementation Plan 2021-2024, visualised by **background colour intensity**:

- **black background in table cells**: highest budgets among all TOPICs and FUNCTIONALITIES of the period 2021-2024.

- white background in table cells: lowest budgets among all TOPICs and FUNCTIONALITIES of the period 2021-2024.

The first row of the table deals with the tasks associated to TOPIC 1.1 ("Social campaigns and social studies (related to societal acceptance of energy infrastructure))". These tasks contribute in different intensities (budget, number of tasks) to the 12 FUNCTIONALITIES.

- Tasks related to TOPIC 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 TOPIC 1.1 serve the achievement of FUNCTIONALITY F3 (largest **orange circles**).

- The highest budget share within tasks related to TOPIC 1.1 is dedicated to FUNCTIONALITY F3 (darkest grey colour of the cell within TOPIC 1.1).

The individual tasks of TOPIC 1.1 and all other TOPICS can be found in the ETIP SNET R&I Roadmap 2020-2030, Annex II and in the SCOPE sections of each TOPIC in this ETIP SNET R&I Implementation Plan 2021-2024.

Table 12: IP Period 2021-2024 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)

Research Areas (RA)	TOPIC No.	FUNCTIONALITIES => TOPIC ↓	F1 Coope-ration	F2 Cross-Sector	F3 Subsi-diarity	F4 Whole-sale	F5 Retail
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. DIGITALIZATION	3.1.	Protocols, standardisation and interoperability (IEC, CIM, Information models)					
	3.2.	Data Communication (ICT) (Data acquisition, Smart Meter, Sensors (monitoring), AMR, AMM, smart devices)					
	3.3.	Data and Information Management (Platforms, Big Data, SW, 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					

F6 Digitali-sation	F7 Electricity Systems and Networks	F8 Business	F9 Simula-tion	F10 Flexibility	F11 Heating Cooling	F12 Transport	
0101 1001 0110							MIO EUR expected Budget
							15M€
							29M€
							33M€
							22M€
							64M€
							61M€
							35M€
							66M€
							24M€
							55M€
							72M€
							48M€
							29M€
							38M€

Research Areas (RA)	TOPIC No.	FUNCTIONALITIES => TOPIC ↓	F1 Coope-ration	F2 Cross-Sector	F3 Subsi-diarity	F4 Whole-sale	F5 Retail
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)					
		TOTAL IP 2021-2024 BUDGET (MIO EUR)	72M€	67M€	40M€	28M€	83M€

F6 Digitalisation	F7 Electricity Systems and Networks	F8 Business	F9 Simulation	F10 Flexibility	F11 Heating Cooling	F12 Transport	
0101 1001 0110							MIO EUR expected Budget
							28M€
							53M€
							40M€
							24M€
							18M€
							26M€
							20M€
							37M€
							54M€
							64M€
108M€	125M€	83M€	88M€	131M€	73M€	57M€	955M€

Annex III:
Key R&I Stakeholder Groups Expected to Contribute to the ETIP SNET R&I Implementation Plan 2021-2024

The following table highlights the main stakeholder groups which, according to ETIP SNET, will contribute to each of the 24 TOPICS of this Implementation Plan. The table gives an indication on those main stakeholders seen as major contributors to the success of R&I projects. Depending on the TOPIC and on the tasks to be solved in the many R&I projects during 2021-2024, the proposed participating stakeholders may need to be enlarged, sometimes more focussed.

The stakeholder's categories contributing to more than 50% of the TOPICS are: Research and Academia (96%), Regulated (Grid) operators (92%), ICT providers (84%), Power Technology providers (72%), storage technology providers (68%), Energy suppliers and aggregators (both for 64%).

"Research and Academia" and "Regulated (Grid) operators" are assumed to typically participate in all R&I projects (respectively 96% and 92%). Both are critical to the success of the energy system transition:

- "Research and Academia" provides basic and applied science-related input from the various scientific fields, including from power engineering with specialised applications in the various power engineering and technology fields such as digitalisation, algorithms, software engineering, physics, social and human sciences, environment, economics, regulations.
- "Regulated (Grid) operators" must provide for the highest possible resilience, reliability and quality of supply of a grid-based energy system: their activities and costs are supervised by regulators.

Table 13: Main Stakeholders contributing to the 24 topics of the ETIP SNET R&I Implementation Plan 2021-2024

Stakeholders contributing to the ETIP SNET Implementation Plan 2021-2024	TOPIC 1.1 Social issues	TOPIC 1.2 Community	TOPIC 1.3 User Devices	TOPIC 2.1 Business	TOPIC 2.2 Market and Governance	TOPIC 3.1 Standards	TOPIC 3.2 Communication	TOPIC 3.3 Data & Info	TOPIC 3.4 Cybersecurity
Research & Academia	X	X	X	X	X	X	X	X	X
Consumers	X	X	X		X		X	X	
Citizen Energy Communities	X	X	X	X	X			X	
Energy Suppliers		X		X	X		X		X
Aggregators		X	X	X	X		X	X	X
Market operators		X	X	X	X		X	X	X
Regulated (Grid) operators	X	X		X	X	X	X	X	X
Power technology providers	X			X		X	X	X	X
Storage technology providers			X			X	X		X
ICT providers			X	X		X	X	X	X
Regulators, Certification authorities			X		X	X			
Heating and cooling operators, gas and water system operators, conversion plants manufacturers			X	X	X			X	X

TOPIC 3.5	TOPIC 4.1	TOPIC 4.2	TOPIC 4.3	TOPIC 4.4	TOPIC 5.1	TOPIC 5.2	TOPIC 5.3	TOPIC 5.4	TOPIC 5.5	TOPIC 6.1	TOPIC 6.2	TOPIC 6.3	TOPIC 6.4	TOPIC 6.5
Software Architecture	Energy System Architecture	Planning	Assets	Stability	Demand	Generation	Storage & Conversion	Network	Transport	System State	Short-term control	Longer-term control	Preventive control	Control center
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
X					X									
X														
X				X	X	X	X			X	X	X	X	X
X				X	X					X	X	X	X	X
X		X			X						X			
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X	X		X	X	X	X	X
X	X	X	X	X		X	X		X	X	X	X	X	X
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
X	X	X	X	X										
X	X	X	X			X	X							

Glossary

Active Demand	(see **Demand Side Response**)
Advanced Meter Management (AMM)	software that performs long-term data storage and management for the vast quantities of data delivered by smart-metering systems.
Advanced Metering Infrastructure (AMI)	an integrated system of smart meters, communications networks, and data management systems that enables two-way communication between utilities and customers.
Aggregator	Data Responsible who aggregates according to a defined set of market rules, e.g. of power generating modules, demand units and/or reserve providing units.
Alternating current (AC)	an electric current which periodically reverses direction.
Ancillary services	a service necessary for the operation of an electricity transmission or distribution system to support the electric power from seller to purchaser given the obligations of control areas and to maintain reliable operations of the interconnected electricity system.
Application Program Interface (API)	is a set of routines, protocols, and tools for building software applications. Basically, an API specifies how software components should interact. Additionally, APIs are used when programming Graphical User Interface (GUI) components.
Asset	an asset is something valuable or useful. Tangible assets are fixed, such as buildings and equipment; an asset is part of a TSO operator control area or located in a distribution system.
Balance Responsible Party (BRP)	means a market participant or its chosen representative responsible for its imbalances in the electricity market.
Balancing Service Providers (BSP)	in the European Union Internal Electricity Market, this is a market participant providing balancing services to its Connecting TSO, or in case of the TSO-BSP Model, to its Contracting TSO.
Blockchain	a system in which a record of transactions made in bitcoin or another cryptocurrency are maintained across several computers that are linked in a peer-to-peer network.
Carbon-neutral	situations where the energy system consumes as much CO_2 as it emits; the CO_2 balance is equal to zero.
Citizen	used here in reference to people who value the development of smart grids as an opportunity to realise "We-centred" needs or motivations, e.g. affiliation, self-acceptance or community. Citizens want to help ensure the quality of supply and support environmental preservation and the community.
Cogeneration	simultaneous production of electricity and useful heat. In a regular power plant, the heat produced in the generation of electricity is lost, often through the chimneys. But in a cogeneration plant it is recovered for use in homes, businesses, and industry. A tri-generation plant, or Combined Cooling, Heat and Power (CCHP), produces cooling (air conditioning) as well as heat and electricity.

Combined Heat and Power (CHP)	an energy efficient technology that generates electricity and captures the heat that would otherwise be wasted to provide useful thermal energy (such as steam or hot water) that can be used for space heating, cooling, domestic hot water and industrial processes.
Common Information Model (CIM)	an open standard that defines how managed elements in an IT environment are represented as a common set of objects and relationships between them.
Consumer	role of the energy user for electricity, heat and chemical energy (such as 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 or may not occur. In power systems, a contingency is when an element such as a transmission line or a generator, or the electric grid fails.
Conversion Technology (-ies)	any system that converts energy from one form to another, such as electricity, heat, work, and motion.
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.
Demand-Side Response (DSR) / Active Demand	a change in the power consumption of an electric utility customer to better match the demand for power with the supply. It is the capacity to change electricity usage by end-use customers (including residential) from their normal or current consumption patterns in response to market signals, such as time-variable electricity prices or incentive payments, or in response to acceptance of the consumer's bid, alone or through aggregation, to sell demand reduction/increase at a price in organised electricity markets or for internal portfolio optimisation.
Digital Twin	refers to a digital replica of physical assets, processes and systems that can be used for various purposes, for example for simulation and modelling. The digital representation provides both the elements and the dynamics of how an Industrial Internet of Things device operates and lives throughout its life cycle including continuous digital predictions through machine learning and artificial intelligence.
Direct Current (DC)	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. For example: a residential photovoltaic system is a distributed system.

Distribution/Transmission System Operators (DSO/TSO)	the role of the operating distribution and transmission grids of electricity supply is to plan, build and maintain 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. A DSO/TSO is responsible for its interconnections with other systems and ensures the long-term ability of the system to meet reasonable demands for the distribution/transmission of electricity or gas.
End-user (see Consumer)	
Energy Community / Citizen Energy Community / Local Energy Community (LEC)	a legal entity where citizens, SMEs and local authorities come together, as final users of energy, to cooperate in the generation, consumption distribution, storage (such as batteries, hot water, and CO2-neutral or free gases), plus provide supply, aggregation of energy from renewable sources, or offer energy efficiency/demand-side management services.
Energy Storage	system domain for appliances and assets storing energy within the group energy consuming units.
Energy Systems	electricity, gas, heating and cooling, liquid fuel systems, and other energy carriers (any system or substance that contains energy for conversion as usable energy later) are all considered energy systems.
Flexible AC Transmission / Distribution Systems (FACTS/FACDS)	a system composed of static equipment used for the AC transmission / distribution of electrical energy that is meant to enhance controllability and increase power transfer / distribution capability of the network. It is generally a power electronics-based system.
Functionality	range of impacts suited to achieve a specific purpose.
Gas-to-Heat (GtH)	combustion of gases to generate heat.
Gas-to-Power (GtP)	combustion of gases to generate electricity.
Gas-to-Power and Heat (GtP&H)	combustion of gases to generate at the same time and with high efficiency both electricity and heat.
General Data Protection Regulation (GDPR)	(EU) 2016/679 (GDPR) is a regulation in EU law on data protection and privacy in the European Union (EU) and the European Economic Area (EEA). It also addresses the transfer of personal data outside the EU and EEA areas.
Green Gas	a gas derived from the processing of organic waste or simply hydrogen produced by renewable electricity and the process of electrolysis from water.
Grid-to-Vehicle (G2V)	smart charging of motorised vehicles, large and small (see **Smart Charging**).
Hierarchical Control	a form of control system in which a set of devices and governing software is arranged in a hierarchical tree.
High Voltage (HV)	usually considered any AC voltage over approximately 35,000 volts.

Holistic Architecture	Holistic energy system architectures facilitate all processes which are necessary for the reliable, economic and environmentally-friendly operations of integrated smart energy systems with multiple energy carriers, having electricity grids as its backbone.
Information Technology (IT)	the use of computers to store, retrieve, transmit, and manipulate data or information.
Institute of Electrical and Electronic Engineers (IEEE)	here intended as a standardisation body.
International Electrotechnical Commission (IEC)	here intended as a standardisation body.
Internet of Things (IoT)	a system of interrelated computing devices, mechanical and digital machines provided with Unique Identifiers (UIDs) and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction.
Interoperability	the ability of two or more networks, systems, devices, applications, or components to interwork, to exchange and use information in order to perform required functions.
Levelized Cost Of Electricity (LCOE)	a measure of the average net present cost of electricity generation for a generating plant over its lifetime. The LCOE is calculated as the ratio between all the discounted costs over the lifetime of a electricity generating plant divided by a discounted sum of the actual energy amounts delivered.
Liquid-to-Power (LtP)	the combustion of liquid fuel to generate power.
Load Frequency Control (LFC)	used to allow an area to first meet its own load demands, then to assist in returning the steady-state frequency of the system to the nominal value.
Load Shifting	shifting large electrical loads from high-demand peak times to times where generation and shifted load match better.
Low-Carbon	a situation where the CO_2 balance (i.e. emissions vs sinks) is almost zero.
Low Voltage (LV)	usually refers to AC voltages between 50 and 1,000 volts.
Machine-to-Machine (M2M)	a direct communication between devices, including industrial instrumentation, enabling a sensor or meter to communicate the information it records to application software that can use it.
Machine Learning (ML)	the scientific study of algorithms and statistical models that computer systems use to perform a specific task.
Medium Voltage (MV)	usually refers to AC voltages between 1,000 and 35,000 volts.
Multi-Access Edge Computing (MEC)	a network architecture concept that enables cloud computing capabilities and an IT service environment at the edge of the cellular network and, more generally speaking, at the edge of any network.

Near Zero Energy Building (NZEB)	a building with zero net energy consumption, meaning the total amount of energy used by the building on an annual basis is equal to the amount of renewable energy created on the site or in other definitions by renewable energy sources offsite.
Net Transfer Capacity (NTC)	the maximum total exchange programme between two adjacent control areas that are compatible with security standards applicable in all control areas of the synchronous area and that take into account the technical uncertainties on future network conditions.
On Load Tap Changer (OLTC)	a tap changer in applications where a supply interruption during a tap change is unacceptable.
Organic Rankine Cycle (ORC)	a type of power plant using, instead of conventional (water/steam) an organic, high molecular mass fluid with a liquid-vapor phase change, or boiling point, occurring at a lower temperature than the water-steam phase change.
Overhead Transmission (OT)	electric power transmission through overhead power lines.
Phasor Measurement Unit (PMU)	a device used to estimate the magnitude and phase angle of an electrical phasor quantity (such as voltage or current) in the electricity grid using a common time source for synchronization.
Phase Shifting Transformer (PST)	a specialised form of transformer used to control the flow of active power on three-phase electric transmission lines.
Point of Common Coupling (PCC)	the point at which the interconnection between the public utility's system and the interconnection customer's equipment interface occurs.
Power Electronics (PE)	the application of solid-state electronics to the control and conversion of electric power.
Power Quality (PQ)	involves voltage, frequency, and waveform. Good power quality can be defined as a steady supply voltage that stays within the prescribed range, steady AC frequency close to the rated value, and smooth voltage curve waveform (resembles a sine wave).
Power System Stability	the ability of an electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variables bounded so that practically the entire system remains intact.
Power-to-Gas (PtG)	conversion of electrical power to a gas fuel. As an example of such conversion, electricity is used to split water into hydrogen and oxygen using the electrolysis principle, where hydrogen can then be converted to methane with CO_2 as input.
Power-to-Heat (PtH)	conversion of electrical power into heat/cooling. The conversion can be done for example by using conventional electric heaters or heat pump systems.
Power-to-Gas and Heat (PtG&H)	simultaneous conversion of electrical power to both gas and heat/cooling.
Power-to-Liquid (PtL)	process consisting in generating a synthetic liquid fuel by using renewable electricity, carbon dioxide from the atmosphere or other sources, and water.

Power-to-Water (PtW)	use of electrical power to pump water into higher-up hydro reservoirs and hydro dams for energy storage.
Prosumers	consumers of all types (households, tertiary, industry, transport and agriculture sectors) who also produce energy. Prosumers can be active market participants by engaging in the real-time control of their energy-consuming and producing devices.
Reliability	all the measures of the ability of the system, generally given as numerical indices, to deliver electricity to all points of utilisation within acceptable standards and in the amounts desired.
Renewable Energy Sources (RES)	energy derived from natural processes that are replenished constantly. In its various forms, it derives directly from the sun, or from heat generated deep within the earth. Included in the definition are electricity and heat generated from solar, wind, ocean, hydropower, biomass, geothermal resources, and biofuels and hydrogen derived from renewable resources.
Resilience	ability of a given system with generating sources, transmission and distribution, conversion capacity 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 grid infrastructure, for example.
Scalability	the ability to easily expand into a larger service or a more powerful product, such as the expanding the capacity to include more participants, a higher load, or more RES.
Security of Supply	the capability of a power system at a given moment in time to perform its supply function in the case of a fault
Smart Charging	charging system where electric vehicles, charging stations and charging operators share data connections. Through smart charging, the charging stations may monitor, manage, and restrict the use of charging devices to optimise energy consumption.
Smart Grid	an electricity network that can intelligently integrate the actions of all actors connected to it — operators of storage capacity (such as of batteries, CO2-neutral or free gases and liquids), generators and consumers — in order to efficiently deliver sustainable, economic and secure electricity supplies (European Technology Platform SmartGrids, 2010).
Smart Metering	the technology of recording usage in real time from metering devices and providing a two-way communication and/or control path extending from energy network to customer appliances.
Smart Transformer / Solid State Transformer / Intelligent Transformer	a power transformer which transfers power between power networks at two voltage levels (usually corresponding to MV and LV levels) by using power electronics ("solid state") and an internal power transformer operating at high frequency; it has usually also internal DC busbars, possible extensions of electrical energy storage and has local control which allows a flexible and smart power exchange between the two power grids. Smart Transformers are considered as an enabling technology for the future of distribution grids.
State-of-Health (SoH)	a figure of merit regarding the condition of an asset (such as a battery, a cell, or a battery pack), compared to its ideal conditions.

Subsidiarity	this principle means that energy systems are operated in such a way that actions are optimised locally (at the most immediate level) — actions that cannot be handled locally are handled at the next level.
System Architecture	a set of conventions, rules, and standards employed in a computer system's technical framework, plus customer requirements and specifications, that the system's manufacturer (or a system integrator) follows in designing (or integrating) the system's various components (such as hardware, software and networks).
Ten Years Network Development Plan (TYNDP)	an overview of the European electricity transmission infrastructure and its future developments, mapping the integrated network according to a range of development scenarios.
TOTal EXpenditures (TOTEX)	CAPEX (Capital Expenditures) + OPEX (Operational Expenditures).
Transmission System Operators (TSO)	see **DSO / TSO**
Vehicle-to-Grid (V2G)	feeding power and energy from the vehicle battery to the grid at the connection point.
Virtual Power Plant (VPP)	a cloud-based distributed power plant that aggregates the capacities of heterogeneous Distributed Energy Resources (DER) for the purposes of enhancing power generation, as well as trading or selling power on the electricity market.
Vulnerability	the openness to attack or damage.
Water-to-Power (WtP)	the process of deriving energy from falling or fast-running water, and in the near future also from waves kinetic movement.
Web of cells (energy cell)	compound comprehensive smart energy systems with subsidiary structures on the basis of decentralised generation and storage as well as decentralised, automated energy management in autonomously steered energy systems, which are able to run temporarily autarkic, such as in the case of failures.
Wide Area Measurement System (WAMS)	technology to improve situational awareness and visibility within power system of today's and future grids. It uses real time synchro phasor data to measure the state of grid that enables improvement in the stability and reliability of power grids.

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