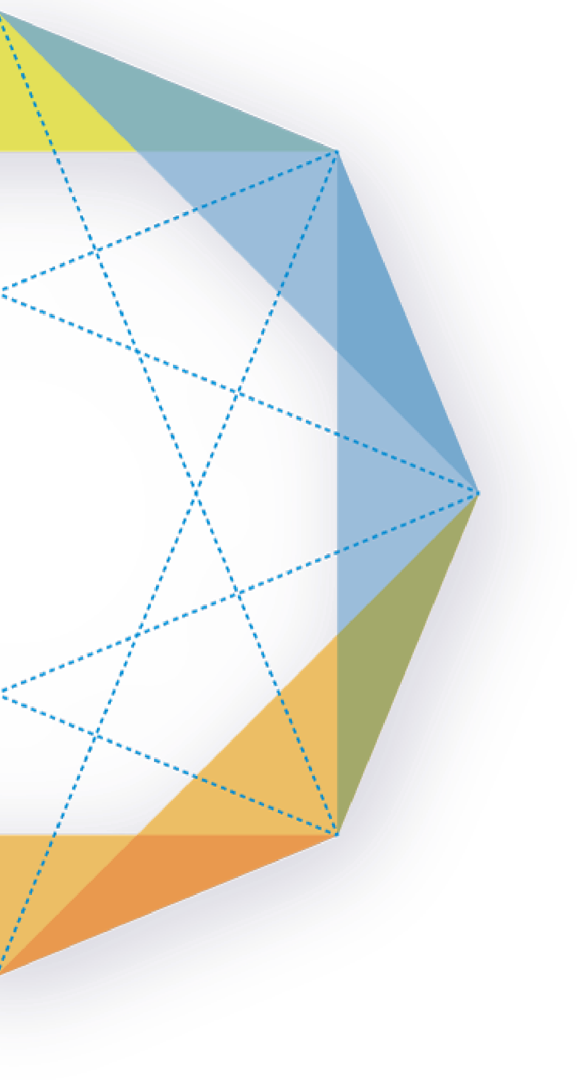
Position Paper

Smart Sector Integration, towards an EU System of Systems

Building blocks, enablers, architectures, regulatory barriers, economic assessment

July 2021



ETIP SNET

European Technology and Innovation Platform
Smart Networks for Energy Transition

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1. EXECUTIVE SUMMARY

The goal of the paper is to address topics related to the EU sector integration strategy, beyond the focus on the technology of energy conversion. It is a follow-up to the first Sector Coupling Paper published by ETIP-SNET in 2020. The energy transition context and the closely linked hydrogen strategy developments are presented considering all the relevant building blocks: architectures, enablers, economic assessment criteria, regulatory and market issues, as well as the related research and innovation needs.

The need for a consistent cross-sector approach to the use cases is emphasised, proposing a template for the use cases is proposed. The related industry use cases are introduced and were augmented by the reference projects spanning over the heating, mobility, clean gas, hydrogen, water sectors.

It is recognised that the future energy system will require more integrated and enhanced dynamics between all steps. Power-to-Gas, often referred to as PtG, P2G,will support this integration by both to supply green molecules and by adding flexibility and long-term storage, complementary to electrochemical one. A taxonomy of true green molecules is needed, as well as a system for Guarantees of Origin. Producing hydrogen from electricity implies an increase in primary energy demand, and its cost depends also on solving the trade-off between high utilisation rates and using cheap surplus electricity.

The future energy system will need to address all value chains of the energy sectors while delivering energy transition and decarbonisation goals, linking in an optimal way various energy resources and networks to the consumption sectors. This brings to a System of Systems vision, where electricity becomes the leading energy carrier, with power grids as the backbone for the decarbonisation of all energy sectors. In this context, smart sector integration is expected to deliver a scalable solution to improve overall system efficiency, resiliency, allowing greater integration of renewables, while enabling flexible consumption and deeper consumer empowerment. ETIP-SNET Vision 2050 and Roadmap 2020-2030 with its identified functionalities will be needed for effective implementation.

While there is wide consensus on the underlying concept, i.e. plan and operate in a co-optimised manner the electricity system and several mutually interacting systems; however different terms are sometimes used as synonyms and reversely, the same term is used to indicate or include different processes. A set of consistent definitions is proposed, under several viewpoints (energy flows, processes, semantic meaning) for sector coupling, sector integration, Power-to-X, Multi Energy Systems.

The rationale for sector integration projects coupling sectors, and even more integrating them, under common planning and/or operation framework may derive from different drivers, which can also co-exist and reinforce each other. The three main rationales, which have been analysed in this Paper, are Energy efficiency/decarbonisation, Asset & Networks optimisation, and improving system flexibility/reliability.

The rationale for sector integration projects coupling sectors, under common planning and/or operation framework are identified as contributing to energy efficiency and overall decarbonisation, asset and networks optimisation, and improving system flexibility while impacting overall system reliability.

While decarbonisation and carbon-free electrification are becoming the pillars of the European Smart Sector Integration Strategy greater integration and interfaces development will be needed based on a market approach. New molecules-based complementary solutions such as electrolytic hydrogen and renewable gases are to become market-based solutions under a revised, functional and transparent European gas market.

Smart sector integration will encourage further stakeholder cooperation facilitated by digital platforms and interoperable solutions based on advancements of TSO-DSO-aggregator cooperation on flexibility and storage and a revamped EU Emission Trading Scheme, possibly extended to sectors such as fossil-fuelled heating and transportation, which would set the right signals and scale-up Europe's sector coupling and decarbonisation ambitions.

Holistic architectures need to take the many-to-many interfaces based on bidirectional participated governance models and integrations into consideration. *LINK*-holistic architecture promotes the bidirectional CHPs (Coupling Component) that efficiently interfaces with all three energy silos: Electricity (bidirectional), Gas (bidirectional) and Heat. ICT and other enabling technologies could facilitate integration in a faster way while avoiding barriers, such as interoperability, lack of seamless interfaces or fragmentation, and lack of transparent governance.

The ICT backbone and the enabling technologies as well data related considerations are of high importance for successful implementations. The system of systems approach that takes all of the components forming cyber-physical considerations for smart sector integration is necessary. Close collaboration with the evolving EU-wide initiatives focused on data policies, management, and security and governance topics is required.

Recommendations for the consistent economic assessment of sector integration projects requires a structured approach considering rationale, boundary conditions and positive and negative externalities. The base case reference, against which KPIs and socio-economic impact, the economics of the sector coupling projects are to be evaluated should be based on explicit needs and compared to the best alternative to reach the same goals.

To scale up deployment of smart sector integration related projects and solutions, the following main regulatory aspects are recommended: Fostering cross-sector and cross- member states level playing fields, removing unnecessary or double taxation on electricity, incentivising Power-to-X solutions, new flexibility solutions such as demand-side response including V2G models and beyond, whereby decarbonisation and carbon-free electrification are to become the pillars of the European Smart Sector Integration Strategy. Encourage and foster stakeholder cooperation for “platformisation” TSO-DSO-aggregator cooperation on flexibility and storage and a revamped EU Emission Trading Scheme, possibly extended to sectors such as fossil-fuelled heating and transportation, which would set the right signals and back Europe’s sector coupling and decarbonisation ambitions. Boost electricity and gas sector coupling for new products such as electrolytic hydrogen and renewable gases.

ETIP-SNET intends to follow-up this with two other dedicated papers, on hydrogen impact on power systems and another electromobility impact on electric systems. Both papers aim to extend and deepen the development of the concepts discussed in this paper. Also, close collaboration with the evolving EU partnerships is recommended as well as considerations for Smart Sector Integration Observatory to monitor progress from the multi-stakeholder approach.

2. INTRODUCTION

On July 8th 2020, The European Commission set ambitious goals to "achieve decarbonisation at the lowest possible cost" as published in "An EU Strategy for Energy System Integration" (European Commission, 2020e). The "smart integration of renewables, energy efficiency and other sustainable solutions across sectors" such as heating and cooling, transport, gas, industry and agricultural sectors are expected to bring renewable energy production, infrastructures and demand-side closer while this transition towards phasing out of fossil fuels, decarbonisation of economy enabled by smart integration is anticipated to create economic opportunities along with reaching climate neutrality by 2050.

This paper develops further the concepts introduced in the ETIP SNET WG1 preceding White Paper "Sector Coupling: Concepts, State-of-the-art and Perspectives" (ETIP SNET, 2020) and focuses on complementary areas forming a holistic approach. Regulatory barriers, research and innovation needs, complimentary building blocks considerations such as ICT architectures, the related tools, the enabling use cases and solutions are introduced with the aim of facilitating the scale-up relying on a system of systems approach leading towards faster market uptake and integration. The goal is to anticipate, advance and drive the process instead of considering the topics after the issues are identified as challenges, barriers or roadblocks.

The smart sector integration considerations to address Vision 2050 of ETIP SNET stretch well beyond advanced technologies. The concepts introduced in this paper are building on the Working Group 1 mission related to "Reliable, economic and efficient smart grid" that can integrate all energy vectors through a holistic approach addressing the need for a "more circular energy system, with 'energy-efficiency-first' at its core" while "accelerating the electrification of energy demand, building on a largely renewables-based power system". In addition, the need for promoting "renewable and low-carbon fuels, including hydrogen, for hard-to-decarbonise sectors" (European Commission, 2020e) while aiming at more integrated energy infrastructures and digitalised energy systems supported by innovation networks are introduced.

There are many mission-critical components to sector integration beyond technological conversions introduced in the chapters of the paper from the conceptual frameworks to ICT enablers and facilitators to the regulatory challenges and possible ways forward. Specifically, the impact criteria and the use cases template for sector coupling along with the reference use cases are introduced.

The conclusions and the recommendations of the paper aim at facilitating the implementation process while offering a number of policy recommendations as well as a format progress monitoring.

The Working Group intends to continue working in the direction from "what to how" in the sector integration framework and focus on the follow-up topics in 2021.

3. CONCEPTUAL FRAMEWORK

The initially introduced term “sector coupling” was pointing towards a few sectors interfaces, such as electricity and gas, subsequently it was augmented by direct and indirect electrification concepts (BNEF, 2020) and wider in scope approach, progressing towards energy ecosystem on broader terms “across multiple energy carriers, infrastructures and consumption sectors” (European Commission, 2020f).

Today, there is no unique and generally accepted definition of sector integration. EU Commission’s Energy System Integration Strategy was published in July 2020 (European Commission, 2020e). The following statement defines the scope of “the coordinated planning and operation of the energy system ‘as a whole’, across multiple energy carriers, infrastructures and consumption sectors”. There is wide consensus on the underlying concept: plan and operate in co-optimised manner the electricity system and several mutually interacting systems. However, when it comes to scope, targets, terminology, and sectors to be included, a diversified array of interpretations and nuances appear, depending on the individual stakeholder vision, its vested interest or just its legacy industrial compound. As a practical consequence, different terms are sometimes used as synonyms and reversely, the same term is used to indicate or include different processes.

In the following chapters, an attempt is made of proposing a possible set of consistent definitions to be utilised homogeneously in the analysis of sector integration initiatives and, in general, to constitute a common base of understanding the narrative of the relevant documentation. The proposal is articulated through different approaches which can then be adopted as such or combined in relation to the specific aim and intended use of the definitions.

3.1 ENERGY APPROACH

The broader energy system can be considered consisting of several sub-systems, typically not very integrated except for being a supplier/client of one sector of another in a unidirectional supply chain. New and improved conversion and storage technologies allow several reverse energy flows, which enable more efficient decarbonisation paths as well as further optimised use of infrastructures.

A high level and a very simplified global view aimed at fixing definitions of energy sectors (sometimes used in misleading ways as synonyms or interchangeable terms) is proposed in the following list and related graphical representation as seen in Figure 1.

Electricity system consists of all electric components in generation, transmission & distribution, consumer/prosumer devices.

Power system comprises:

- electricity system;
- primary energy components of generation plants: gas supply & logistics, biomass production, hydro reservoirs;
- storage devices exclusively servicing the electric system: pumped hydro, batteries, capacitors/super magnets, flywheels, CAES/LAES; these devices convert bidirectional electricity in another energy form (mechanical, chemical, electromagnetic static field, thermodynamic), but they do not couple to another energy sector.

Energy system comprises:

- power system;
- plants and components to generate/transport/store/consume thermal energy: heating, cooling, industrial processes;

- Plants and components to generate/transport/store/consume energetic molecules to be either combusted in exothermic chemical reactions for final use in transport/buildings/industry, either used as chemical feedstock (non-energetic use): fossil fuels extraction and refining, hydrogen and synthetic molecules production.
- Interdependencies of the system approach that is gearing towards greater electrification and renewable generation are apparent in the Figure 1 and 2 below.

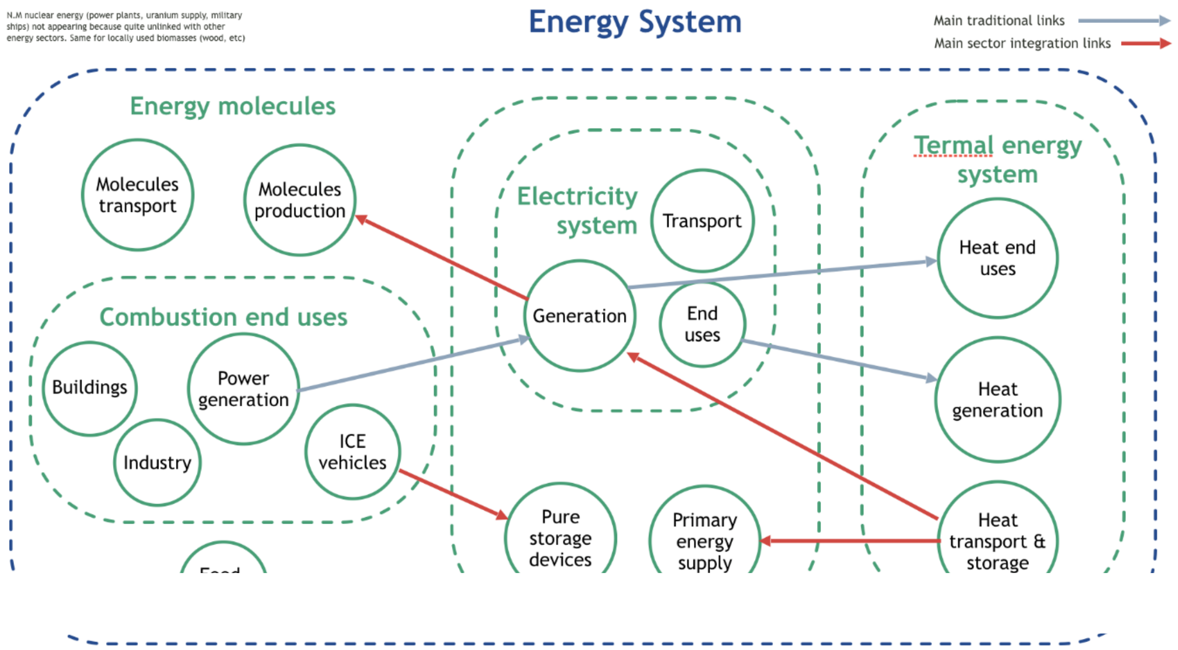


Figure 1. Holistic Energy Sectors Representation

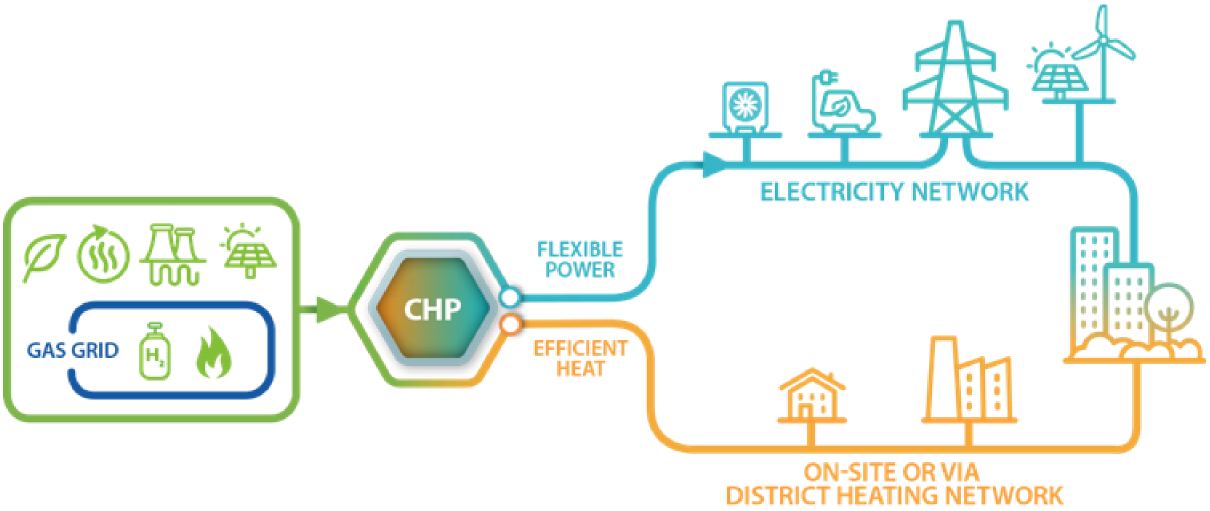


Figure 2. CHP solutions linking heat and power generation

3.2 SEMANTIC APPROACH

In a purely etymological sense, the differences between sector coupling, smart sector integration, power-to-X and multi-energy systems can be seen in the schematic tables below. Every table also explains the goals and focuses of each definition.

	Semantic meaning	Goal	Focus
Sector Coupling	Developing synergic interactions between two traditionally separate energy sectors	Optimise respective asset base, exploiting substitutional effect (e.g. dual fuel)	Reciprocal benefits/services rendered (e.g. flexibility)

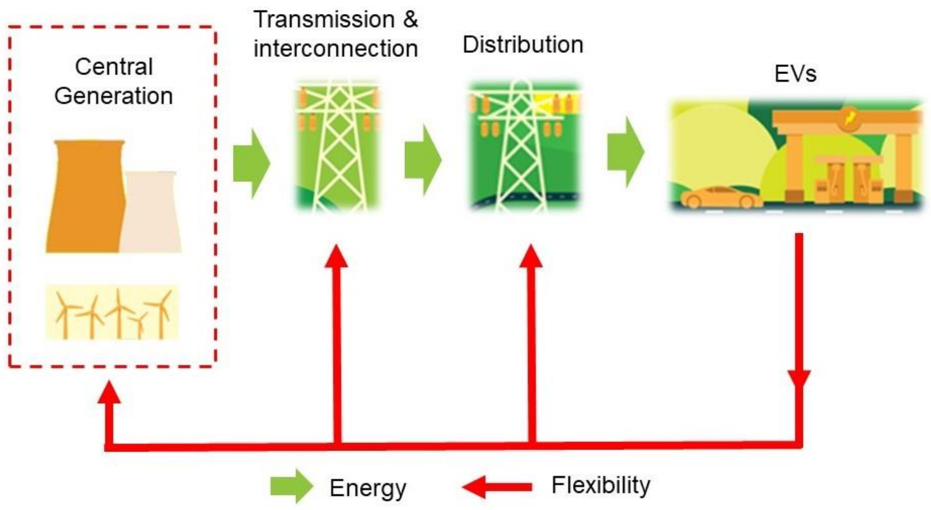
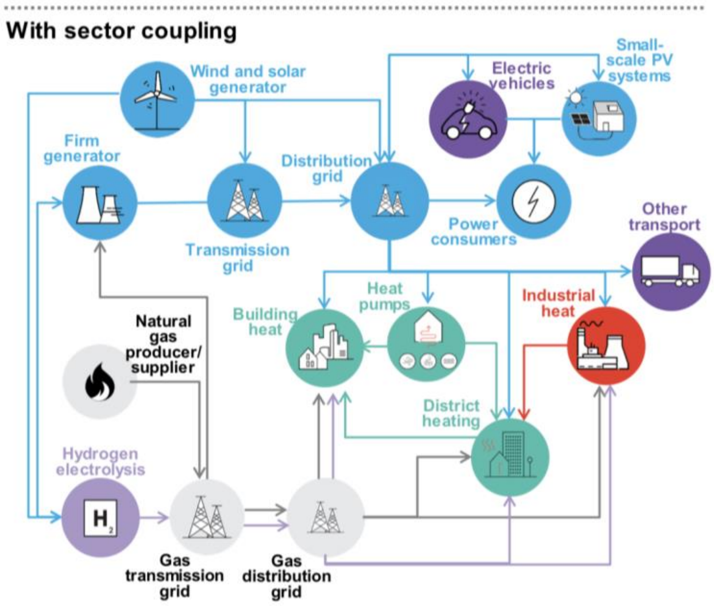


Table 1. Graphic representation of Sector Coupling concept

The semantic meaning of sector coupling is to develop synergic interactions between two traditionally separate energy sectors. The main goal of the interactions is to optimise the respective asset base, exploiting substitutional effect (e.g. optimal investment mix in either of the two coupled sectors, or minimum cost operation of modular systems). In some instances it is also intended to include large-scale electrification, where electricity would substitute fossil energy vectors (natural gas, oil fuels, lignite/brown coal) for end-use applications like buildings, transport, process heating in the industry. This will increase the demand for electricity, and thus provides the possibility of connecting additional, distributed energy resources, with the aim of improving the share of renewable energy in these sectors (on the assumption that the electricity supply is, or can be, increasingly renewable). Therefore, it is necessary to achieve synergies across sectors to optimise and facilitate the path to decarbonisation. In a nutshell, sector coupling focuses on reciprocal benefits/services rendered through a strategy allowing to provide greater flexibility to both coupled sectors so that decarbonisation can be achieved in a more cost-effective way.

	Semantic meaning	Goal	Focus
Smart Sector Integration	Deep integration between final energy demand and supply chain options	Overarching goal is the most efficient decarbonisation	System view, at broader level

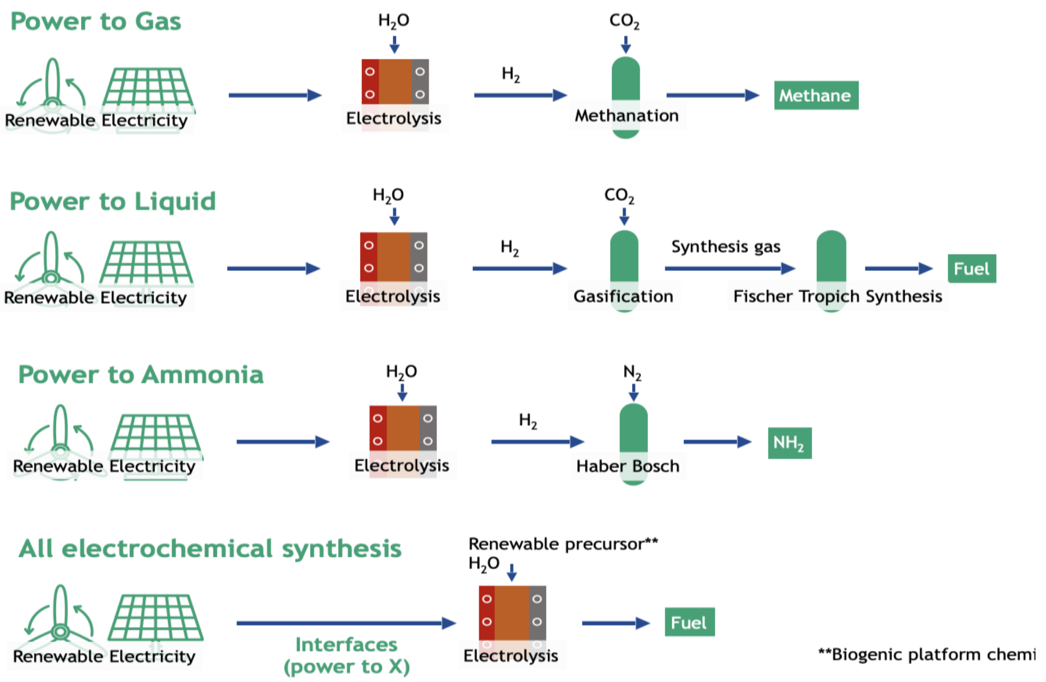


Source: BloombergNEF.

Table 2. Graphic representation of Smart Sector Integration concept (BNEF, 2020) (Note: Heat pumps usually include thermal storage, which can be used as a sector coupling asset)

The definition of sector coupling is very similar to that of energy system integration, however energy system integration focuses on a system view, at broader level and along the whole supply-transport-end use chain (Table 2). This view focuses on a deep integration between final energy demand and supply chain in order to achieve the most efficient decarbonisation with minimum impact on the environment. The process should coordinate both the operational activities and planning of energy systems integrated multiple pathways to ensure cost-efficient energy services as well as their reliable delivery.

	Semantic meaning	Goal	Focus
Power-to-X	Conversion among different forms of energy, either for end-use or for efficient storage	Develop affordable conversion processes for more efficient storage or transport of energy	Focusing on energy conversion technologies and performances as the interface among sectors



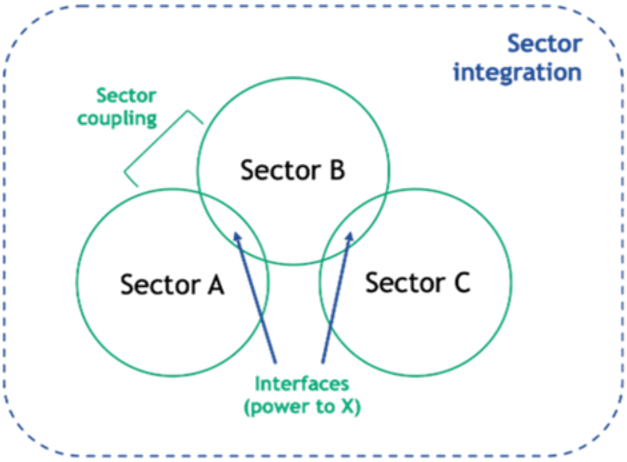


Table 3. Graphic representation of Power-to-X concept

The semantic meaning of Power-to-X is conversion among different forms of energy (Table 3). As illustrated in the picture above, this type of conversion includes but is not limited to:

- Power to gas (hydrogen, methane, etc);
- Power to liquid (CO2-free liquid fuels, methanol, light hydrocarbons);

- Power to chemicals (ammonia, nitrates, etc);
- Power to heat/cool (electric heating, heat pumps, etc);
- Power to heat/cool (electric heating, heat pumps, etc);
- Power to transportation, Vehicle-To-Grid (V2G);
- Fuel (gas, liquid, waste heat, biomass) to Power & Heat (cogeneration/CHP).

The goal of Power-to-X is to develop efficient and affordable conversion processes to be utilised at large-scale as a high-performance interface for sector coupling projects.

Table 3 also shows the combination of the three previous concepts, with individual energy sectors coupled through the Power-to-X interface, under a broader aim of smart sector integration for efficient decarbonisation and infrastructures optimisation.

	Semantic meaning	**Goal**	**Focus**
Multi-Energy Systems	Portfolio of energy-related services offered to customers through grids on same territory	Develop synergies from bundling different services and different markets for customers	Distribution networks, end-customers, small-medium geographical perimeters (e.g. cities), prosumers and citizens energy communities

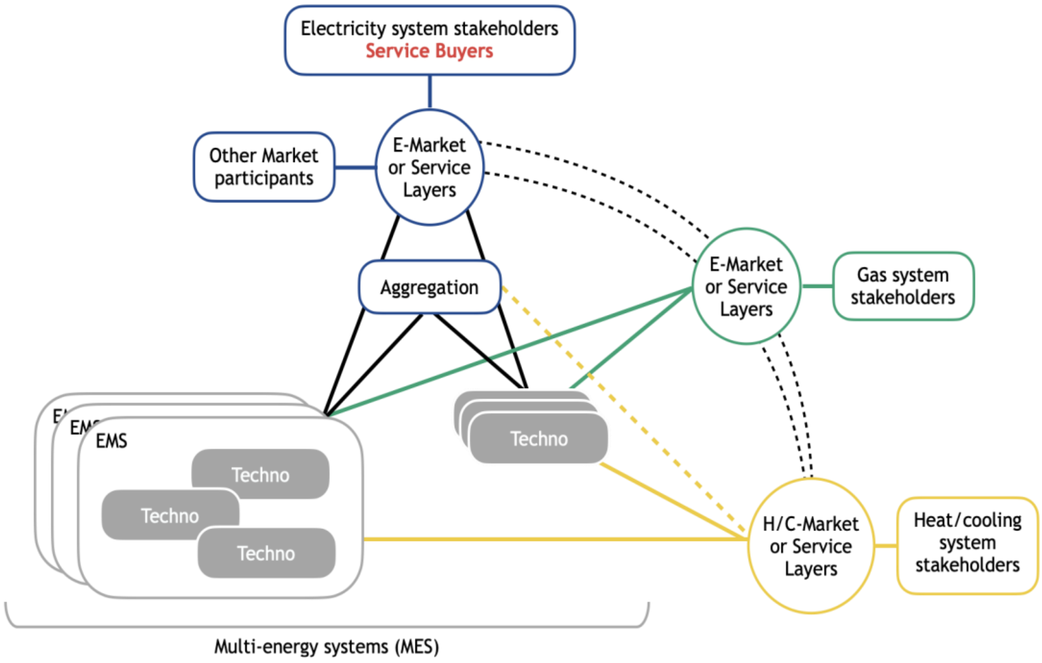


Table 4. Graphic representation of Multi-energy systems concept

Multi-Energy Systems (MES) focus on distribution networks, end-customers, small and medium geographical perimeters (e.g. cities). Several perspectives and complexity typically characterise them, namely:

- The geographical perspective, where it is pointed out how Multi-Energy Systems can be intended at different levels of aggregation in terms of components. These aggregation levels may go from buildings, different types of equipment producing different energy vectors interacting with each other, to broader areas including the crucially important cases of district energy systems and finally to regions.

- The network perspective, where energy networks (for electricity, gas, district heating and cooling, hydrogen, and so on) play a major role, particularly in terms of facilitating the development of multi-energy technologies and their interaction to optimise system operation while ensuring maximum benefits for the environment.
- The multi-service perspective emphasises the optimal integration of energy vectors, especially at the level of providing various services and products resulting from the use of different energy resources, targeting the maximum satisfaction of the final customer, prosumers.
- The multi-fuel perspective highlights how different types of fuels can be combined to obtain optimal performances, both economic and environmental (from natural gas to biomass and renewable energy sources for both electricity and heat).

4. SECTOR COUPLING WITHIN THE GREEN DEAL CONTEXT

4.1 ENERGY TRANSITION CONTEXT

By looking at the overall climate commitments in line with the Paris Agreement, carbon neutrality must be achieved by the electricity sector in 2040 and in all sectors altogether by 2050. Thus, additional measures to reach net negative emissions after 2050 are necessary.

The Renewable Energy Sources (RES) share in the primary consumption is expected to reach a range between 69% (Global ambition) to 82% (Distributed Energy) according to two scenarios developed by ENTSO-E and ENTSO-G. These scenarios are considering in one case (distributed generation) more solar development while in the second case RES deployment based more on the use of biomass, bioliquids and natural gas is used for a longer period.

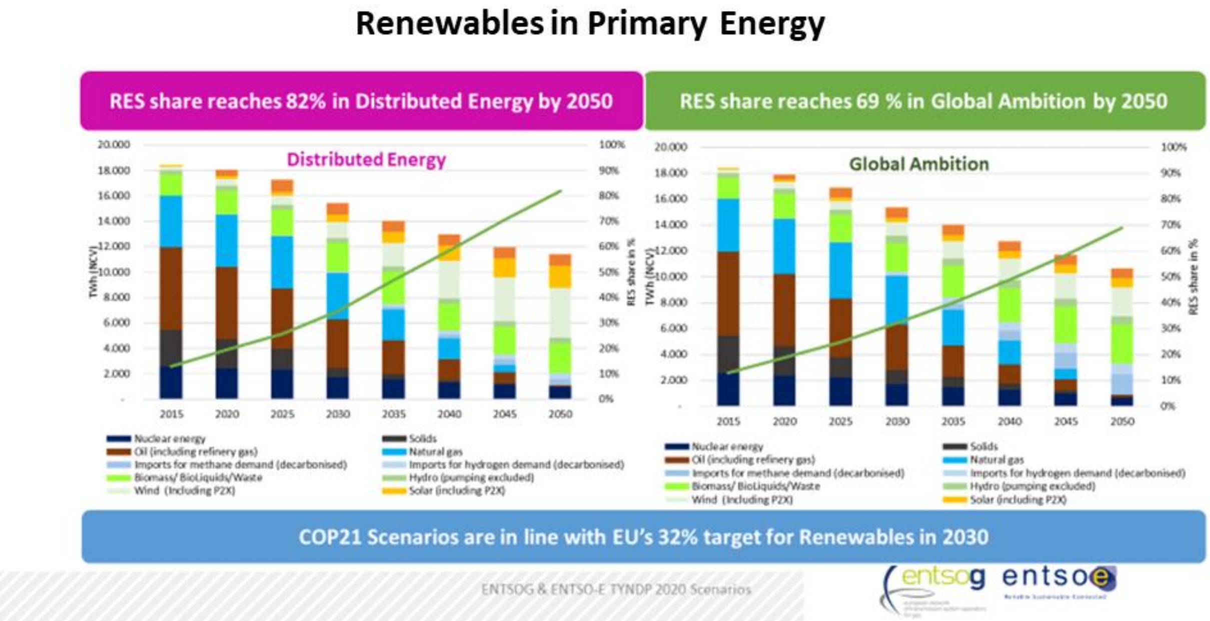


Figure 3. ENTSO-G & ENTSO-E TYNDP scenario - Renewables in Primary Energy

Sector coupling should be viewed from the perspective of: interlinkages between energy carriers, related technologies and infrastructure. Major processes in this regard are gas-fired power generation, Power-to-Gas (P2G) as part of the broader Power-to-X and hybrid demand technologies. P2G becomes an enabler for the integration of variable RES and an option to decarbonise the gas supply. Hydrogen and synthetic methane or liquids (P2L) allow for carbon-neutral energy use in the final sectors.

Depending on the assumptions to be used, two types of scenarios can be envisaged. The first being a more centralised approach making use of strong offshore RES development and the second being a decentralised approach based on enhanced deployment of photovoltaics and more customer centric approach. The need for P2G and P2L will vary accordingly.

ENTSO-E's 10-year network development plan (TYNDP, https://tyndp.entsoe.eu) scenarios from (2020) estimates that in case of distributed Energy, the requirement for P2G and P2L will be of 1,460 TWh dedicated power generation per year with more than 490 GW of capacities for wind and solar in 2040 to produce renewable gas.

In case of limitation of sector coupling (P2G) to substitute otherwise curtailed electricity supply the P2G will amount to 27 TWh with 22 GW to produce renewable gas.

Final energy demand can achieve ambitious reductions in energy volume due to changes to end user applications and energy efficiency measures.

Renewable energy as electricity holds the promise of deep decarbonisation. Greater penetration of renewables and electricity is expected and as a result more electricity will be added to the energy mix. The International Renewable Energy Agency (IRENA), illustrates the higher penetration of renewables in an electrified energy system to be achieved by 2050 (IRENA, 2019).

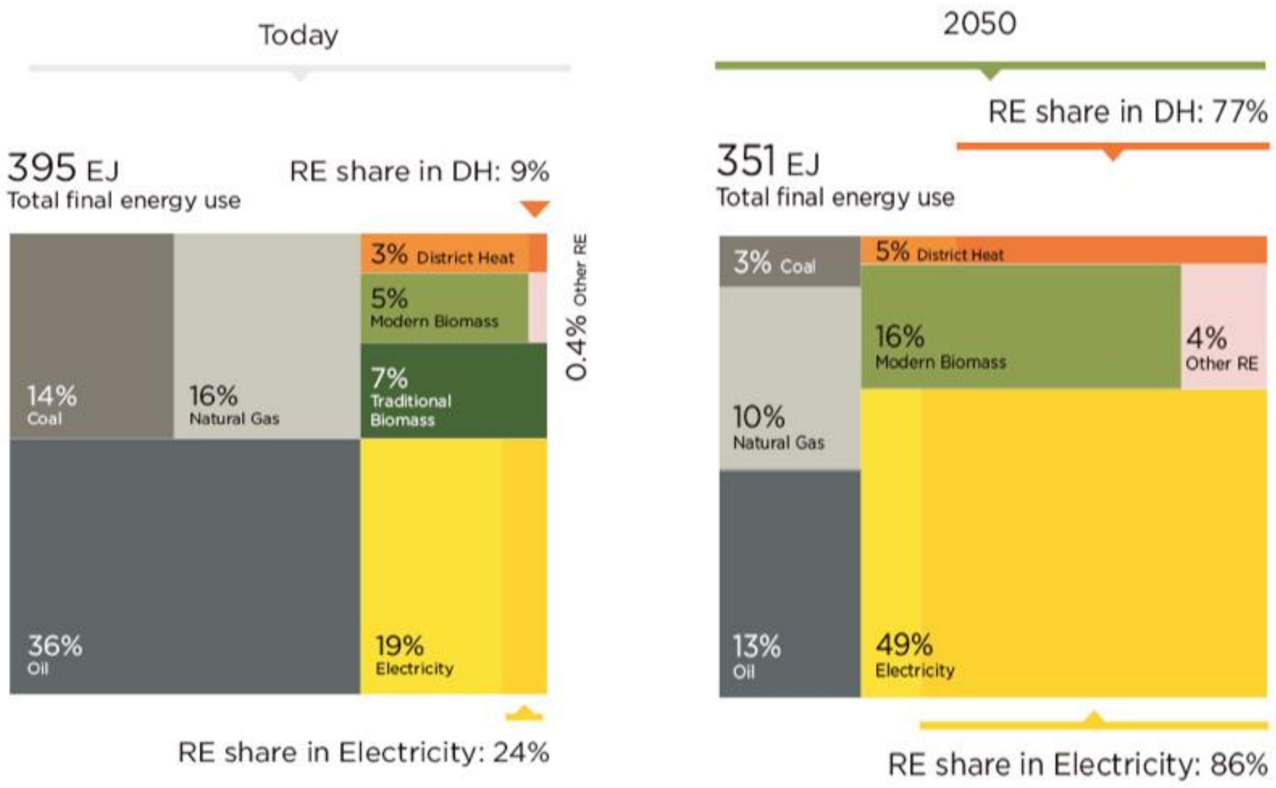
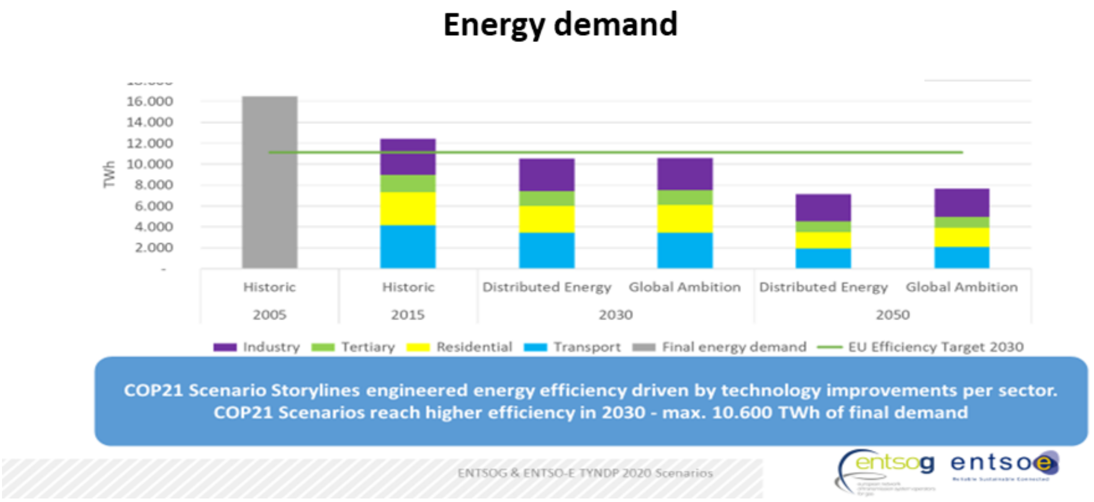


Figure 4. IRENA 2050 renewable energy penetration, 2019

Sector integration provides flexibility solutions to the grid on all levels of smart sector integration to a greater or lesser extent. Grid edge solutions as well as scale up opportunities evolve. These synergies are expected to be by directional and facilitating renewable generation. It is recognised widely that all technologies and solutions will be needed to reach the climate goals outlined in the Paris Agreement.



COP21 Scenario Storylines engineered energy efficiency driven by technology improvements per sector.
COP21 Scenarios reach higher efficiency in 2030 - max. 10.600 TWh of final demand

Figure 5. ENTSO-G & ENTSO-E TYNDP Energy demand scenario

The deep electrification, direct use of electricity is an important option as it optimises conversions. As such, while the energy demand due to energy efficiencies will decrease, it is expected that the electricity demand will increase (based on ENTSO-E, ENTSO-G, TYNDP scenarios) and mostly in the case of distributed energy scenarios. Distributed Energy is the scenario storyline with the highest annual electricity demand reaching around 4,000 TWh in 2040 and around 4,300 TWh in 2050. This increase is mainly due to EVs, electrical and hybrid heat pumps or electricity demand for data centres. The electrification of the transport and heating sector will have an effect on the hourly profiles.

The estimations of the number of heat pumps and EVs and hybrid electrical passengers by different timeline horizons is presented in where a comparison with estimations from other studies for alignment and consistency is also presented.

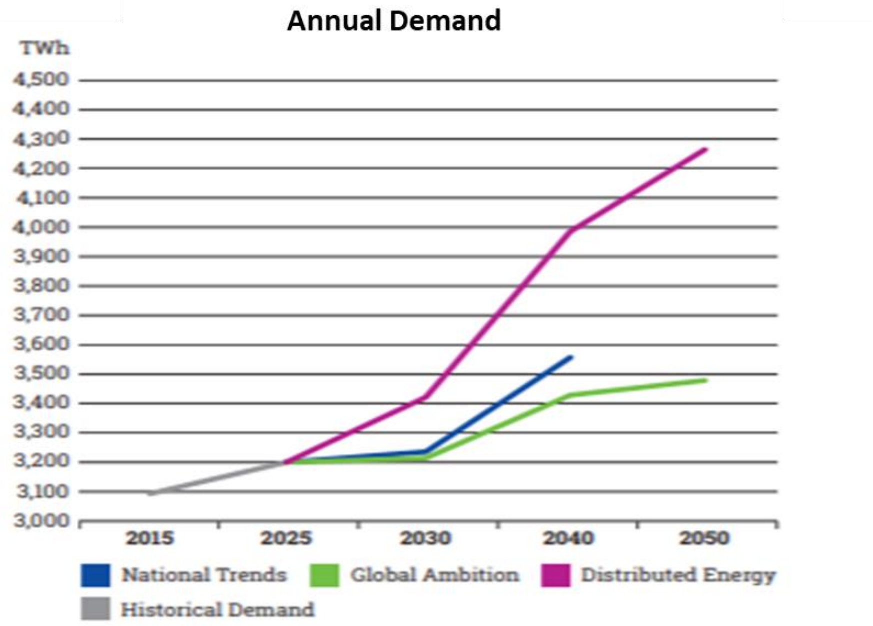
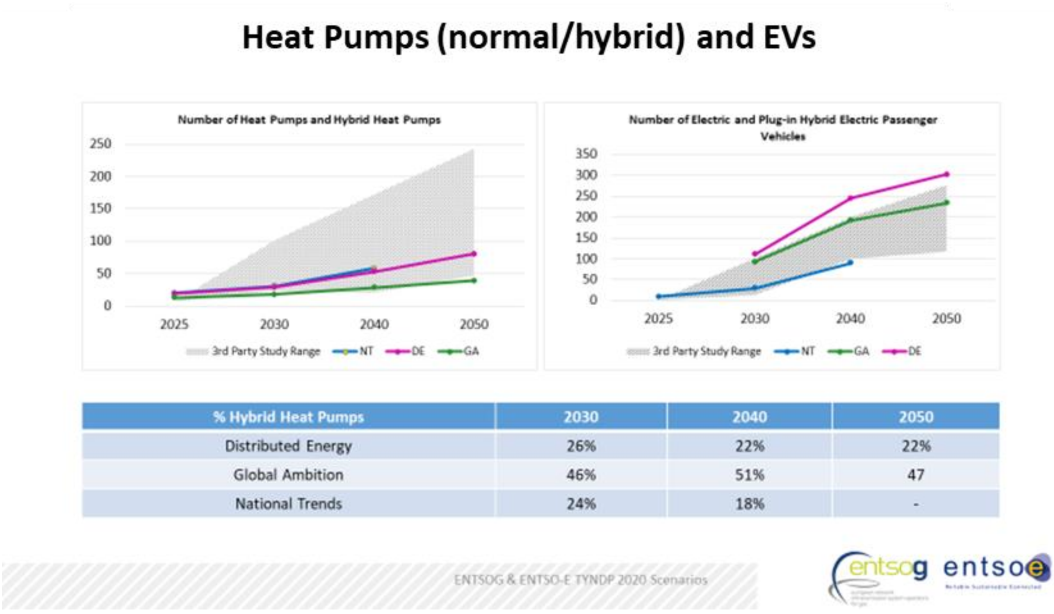


Figure 6. ENTSO-G & ENTSO-E TYNDP Annual demand scenario



Heat Pumps (normal/hybrid) and EVs

% Hybrid Heat Pumps	2030	2040	2050
Distributed Energy	26%	22%	22%
Global Ambition	46%	51%	47
National Trends	24%	18%	-

ENTSOG & ENTSO-E TYNDP 2020 Scenarios

Figure 7. ENTSO-G & ENTSO-E TYNDP heat pumps and EVs scenario

It is estimated that in terms of flexibility, Demand Side Response (DSR) and battery technologies will cope with certain flexibility needs in terms of adequacy with a more pronounced participation of batteries as source of flexibility.

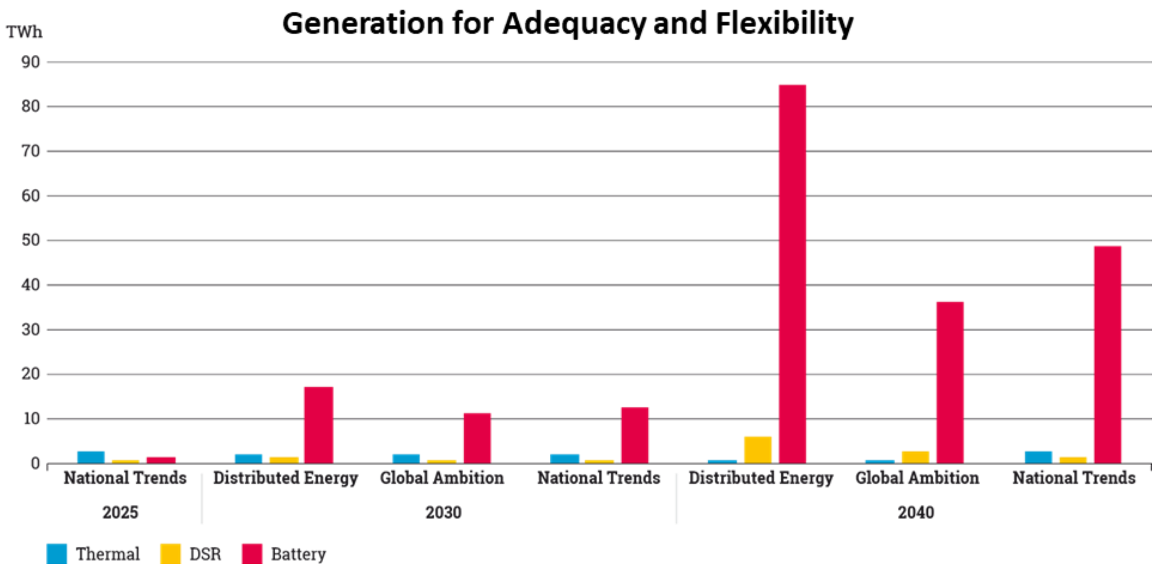


Figure 8. ENTSO-G & ENTSO-E TYNDP scenario – Generation for adequacy and flexibility

Furthermore, sector coupling from the perspective of Power-to-X is presented in Figure 9. Power-to-X capacities are mainly associated with wind capacities onshore and offshore as one means of integrating excess electricity from RES but also for decarbonising the gas supply.

Sector Coupling enables a link between energy carriers and sectors, thus it becomes key in contributing to achieving the decarbonisation target. In the long-term, Power-to-Gas will play a key role in both the integration of excess electricity from variable renewables and decarbonising the gas supply.

Figure 9. ENTSO-G & ENTSO-E TYNDP scenario – capacities for P2x

With production of hydrogen starting to accelerate by 2030, especially in the case of Distributed Energy scenario, hydrogen and derived fuels are estimated expected to reach capacities of 300-500GW by 2050.

Figure 10 plots ENTSO-E, ENTSO-G scenarios for RES gas production against EC scenarios (1.5 Life and 1.5 Tech) which underlines the need of use of all technologies (e.g. P2G and biomethane as well) in order to reach net zero emissions by 2050.

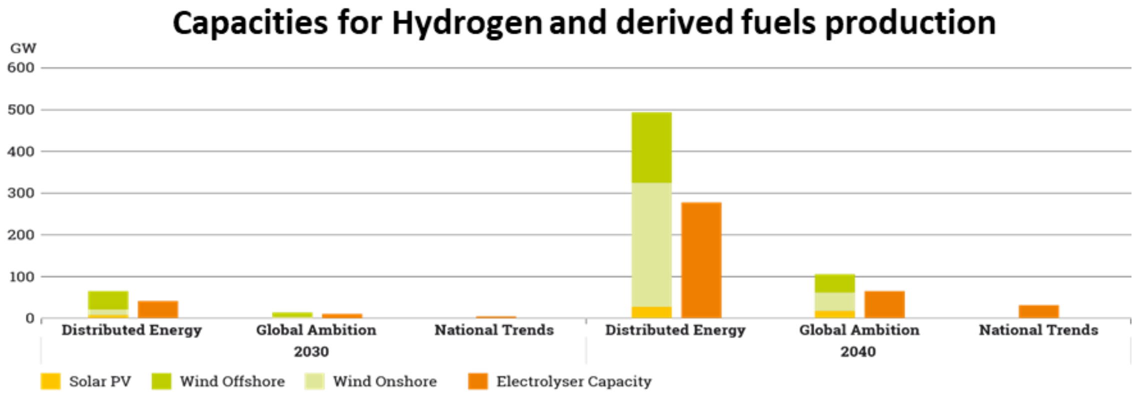


Figure 10. Figure 10. ENTSO-G & ENTSO-E TYNDP scenario – Hydrogen and derived fuels production

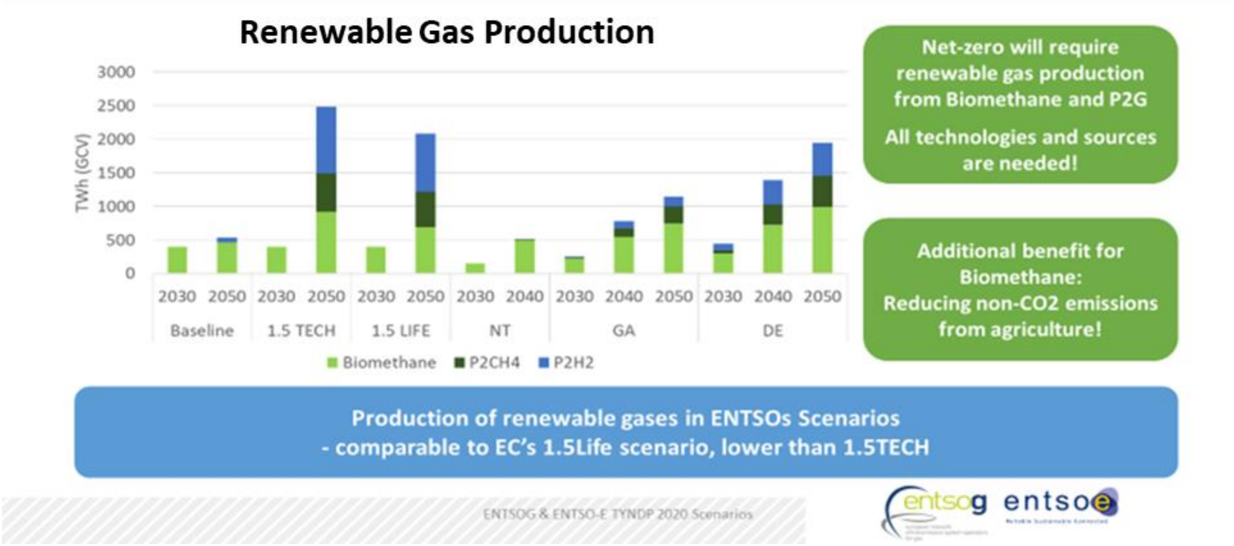


Figure 11. ENTSO-G & ENTSO-E TYNDP scenario – Renewable gas production in EU28

The European Green Deal ambition of a decarbonised European economy by 2050 will require the massive deployment of RES, electrification and decarbonisation of other sectors. As such, cross-sector integration of the different energy carriers and networks (electricity, gas, heating and cooling, and transport) will enhance the pooling respective storage features and will optimise flexibility and consequently increase the system's overall efficiency, reliability, and adequacy.

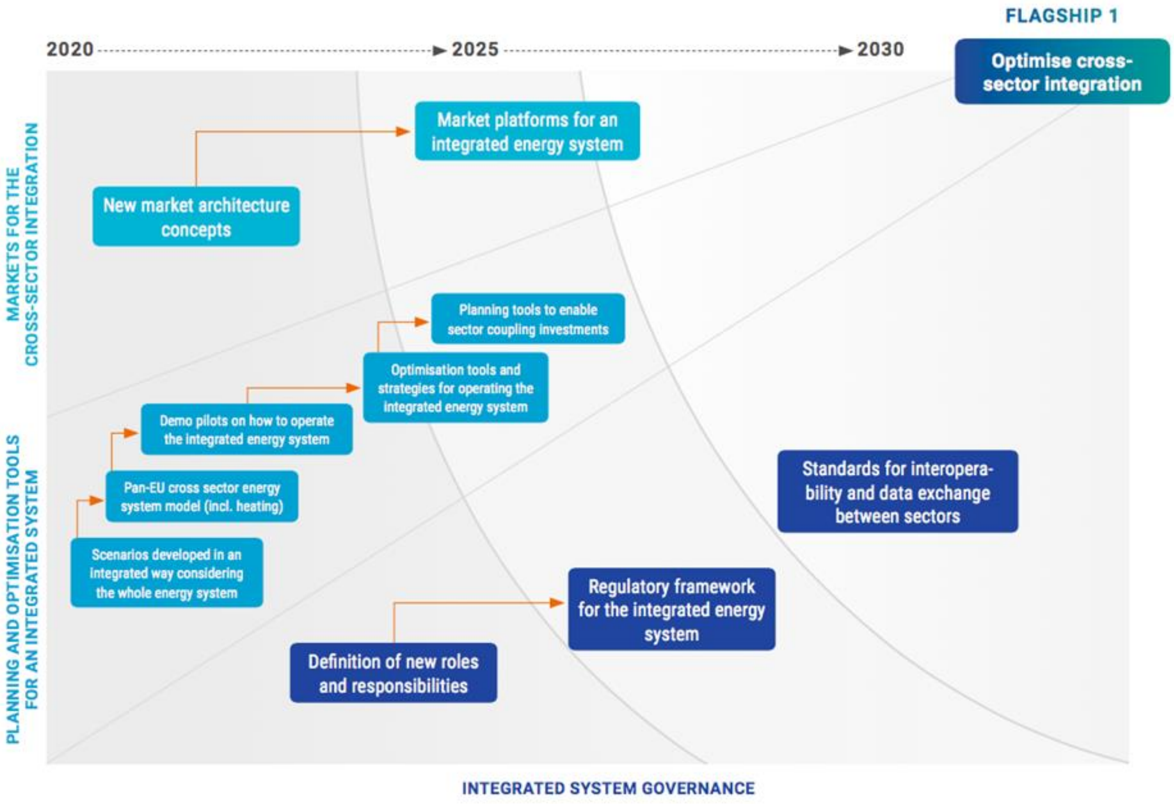


Figure 12. ENTSO-E Roadmap – Smart sector integration

Optimised joint operations and common validated scenarios, tools, and ICT platforms to deploy cross-sector integrations at the systems level are needed. Evolution of current market structures and the development of new market architecture concepts to deploy suitable market platforms for the newly integrated energy system is a very important element in this respect.

Integrated scenarios should take into account the whole energy system and look for the development of a pan-EU cross-sector energy system model. This requires the transparent cooperation of involved stakeholders. The next step required would be the development of optimisation tools and strategies for operating the integrated energy system as well as planning tools to enable sector coupling investments.

An integrated energy system also requires effective governance with the definition of new roles and responsibilities for actors and the associated regulatory framework for the integrated energy system needs to be modified. Important innovation steps to reach the optimised cross-sector integration include, among others things, the availability and application of standards for interoperability and data exchange between sectors.

4.2 GUIDELINES & OUTCOMES OF EC SMART SECTOR INTEGRATION COMMUNICATIONS

4.2.1 EC COMMUNICATION

The European Commission announced as part of the European Green Deal, launched in December 2019, its intention to make Europe the first climate-neutral continent by 2050. The EC's 2020 Work Programme announces the adoption of a Strategy for smart sector integration, an initiative about creating a smarter, more integrated and more optimised energy system, in which all sectors can fully contribute to decarbonisation, including those where progress has been slow so far (such as transport, certain parts of industry, buildings).

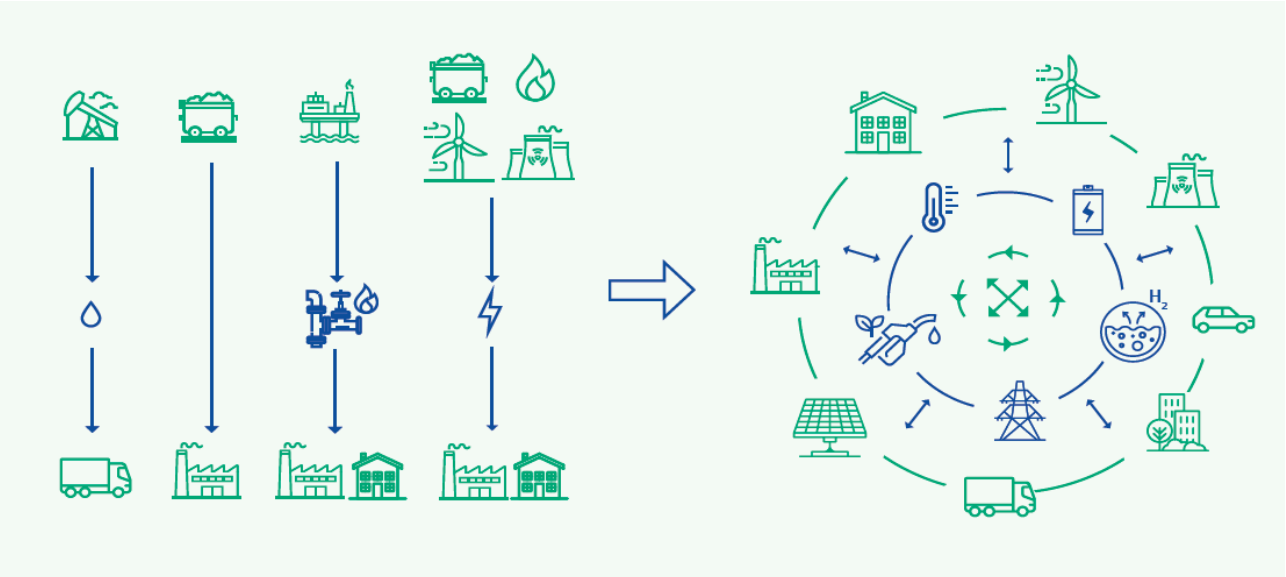


Figure 13. Visual representation of energy system integration

Setting the path to this Strategy, the EC launched a public consultation from May to June 2020, with a draft Roadmap and indicating the goals of the Strategy. "This strategy aims to better link the different energy sectors in the EU (electricity, gas, buildings, transport, industry) to help them reduce carbon emissions. This means replacing fossil fuels with renewable electricity, or with other renewable and low-carbon fuels where electrification is not possible, while ensuring energy remains secure and affordable (ETIP SNET, 2020). The strategy will propose concrete action needed to build a climate-neutral energy system. This will help achieve the climate targets set out in the European Green Deal" (2020).

As referred to in the Roadmap, "Achieving a well-integrated energy system by better linking the different sectors, electricity, gas, buildings transport and industry will be necessary to deliver in a timely and cost-effective manner on the ambitions of the Green Deal. It will also provide increased opportunities for investment and growth for EU industries and jobs for citizens. The initiative should allow new low-carbon energy carriers, such as hydrogen, to emerge and facilitate the progressive decarbonisation of the economy, including the decarbonisation of the gas sector". Feedback was received on the consultation; all 156 responses are public (European Commission, 2020b).

Following the period of public consultation, an EU Communication was published on the 8th July 2020 titled "An EU Strategy for Energy System Integration" (European Commission, 2020e).

The Communication defines energy system integration as "the coordinated planning and operation of the energy system 'as a whole', across multiple energy carriers, infrastructures, and consumption sectors – is the pathway towards an effective, affordable and deep decarbonisation of the European economy in line with the Paris Agreement and the UN's 2030 Agenda for Sustainable Development."

The Communication proposes an Action Plan to accelerate the clean energy transition through energy system integration. Six pillars are identified where coordinated measures are outlined to address existing barriers for energy system integration. The six pillars are named below, and the recommendations within each pillar can be found in the original communication document.

- A more circular energy system, with 'energy-efficiency first' at its core;
- Accelerating the electrification of energy demand, building on a largely renewables-based power system;
- Promote renewable and low-carbon fuels, including hydrogen, for hard-to-decarbonise sectors and seasonal storage;
- Making energy markets fit for decarbonisation and distributed resources;
- A more integrated energy infrastructure.

4.2.2 COMMENTS ON EC SECTOR INTEGRATION COMMUNICATION

The EU Strategy for Energy System Integration proposed by the EC sets the very important principle that sector integration is complementary and conditioned to more direct decarbonising ways, so it is an instrument and not a target itself; multiple dimensions are brought together, in a holistic view:

- Demand side: it proposes more energy efficiency (including this concept in buildings), more demand flexibility, creation/adaptation of regulation to encourage demand side flexibility, mentioning especially electro mobility and V2G. At the same time, it promotes electrification of end demand and leaves room for other green fuels in hard-to-decarbonise sectors.
- Supply side: it proposes the efficient use of resources, using for example also waste-heat, biofuels, renewables, etc. It also proposes to improve the way "green" sources are defined.
- Infrastructure: It encourages more coordination in infrastructure planning, especially between electricity and gas. Moreover, it also mentions opportunities for hydrogen and CO2 transportation. The governance of the process will be reviewed.
- Taxes and levies: it tries to harmonise the taxation between sectors.
- Digitalisation, Research, Development and Innovation: emphasises the relevance of digitalisation, especially for decentralised solutions. At the same time, it proposes funding for Research, Development and Innovation (RD&I) in order to produce or improve new technologies that will be useful for decarbonisation.

Main concepts behind energy system integration are:

- A more ‘circular’ energy system, with energy efficiency at its core.
- A greater direct electrification of end-use sectors.
- The use of renewable and low-carbon fuels, including hydrogen, for end-use applications where direct heating or electrification are not feasible.
- A more integrated system will also be a ‘multi-directional’ system in which consumers play an active role the in the supply of energy; so, there is an integration not only among sectors, but also between supply and demand.
- Provision of additional flexibility for the management of the various energy sectors, in a reciprocal and mutually beneficial way.

Considerations on proposed main concepts:

- The **optimisation target** occurs not only at energetic level (operation) but also, and more importantly, at infrastructures level; by rendering the process of planning a coordinated and eventually joint exercise among several energy sectors and vectors, with the overall aim to co-optimise the development of grids, supply and demand plants, storage and conversion plants. This aspect is paramount because these are CAPEX intensive and long-term investments, with high risks on one side of suboptimal decisions and on the other side of stranded assets, especially considering the rapid evolution of the ecosystem and of technologies.
- **Hydrogen:** its role can become very relevant, provided economic feasibility (in wider terms, i.e. cost-benefit analysis with externalities) versus other carbon free alternatives is proven, indeed some projects on conversion or supply-only stage are asking heavy public support without an end-to-end picture (i.e. demand and utilisation stage, and overall decarbonisation effect). Green Gases Taxonomy and certification of carbon removals shall also help, to avoid industry investments and innovation efforts in wrong directions.
- **CCS & CCU role**: viable CCS, if achieved, would change completely the decarbonisation speed and impact on the power system, so it may deserve a separate scenario (even on coal plants, not only gas, considered by EC). CCU would lead to releasing CO2 emissions to the atmosphere in a later stage and also requires energy for the process.
- Storage technologies should develop and find market uptake according to their utilisation scope/location (generation plant, consumer plant, distribution/transmission grid) in competition versus other available technologies of storage as well as versus other forms of flexibility (demand response, sector coupling, etc.) on a case-by-case typology basis; grid operators must be very technology neutral and agnostic on this.
- **V2G development** should be accelerated to be able to leverage EV storage across Transport and Electricity sectors while avoiding over investment in standalone home storage.
- **Renovation Wave** in buildings will mean a deep change in load profile, and consequential needs for more flexibility.
- **Waste heat** from industrial sites, data centres, etc.: being low temperature heat, this is an efficiency improvement in the heating sector rather than an example of sector coupling; district Heating & Cooling should deserve high attention.
- For demand that cannot be cost-effectively or technically electrified, thermal energy (**green gases, H2, bioenergy, waste, waste heat, solar thermal**) will still be required to cover remaining demand and help balance the power system. Energy efficiency must be prioritised to maximise the use of these fuels. Optimising cogeneration (or combined heat and power) across a range of increasingly renewable fuels will ensure that heat is delivered efficiently and that dispatchable and flexible electricity can cover residual demand and mitigating increasing seasonal, weekly and daily peak demand (Artelys, 2020).
- New schemes need to be put in place to **monitor the carbon intensity of the heat** delivered depending on the type of fuel used and the real time electricity mix delivered by the Grid.
- **Review of Primary Energy Factor:** this will impact the assessment of efficiency gains and decarbonisation effect at target-setting level in modelling and decarbonisation metrics.

- **Primary energy factors should consider daily electricity mix fluctuations** and not rely on long term averages.
- **Levelled taxes and CO2 cost/price in different energy sectors**: it is an important point when making undistorted economic benchmarks, as in the Use Cases / Business Cases utilisation.
- **Transport-Power system integration and Alternative Fuels Directive**: they impact on adequacy, load profiles, and new flexibility options.

4.2.3 EU HYDROGEN STRATEGY

As part of an integrated energy system, hydrogen can support the decarbonisation of industry, transport, power generation and buildings across Europe. The EU Hydrogen Strategy (European Commission, 2020a) launched also in July 2020 by the EC, addresses how to transform this potential into reality, through investments, regulation, market creation and research and innovation.

Hydrogen can provide energy to sectors that are not suitable for direct electrification and offer storage to balance variable renewable energy flows. However, this can only be achieved with coordinated action between the public and private sector. The development of renewable hydrogen, produced using mainly wind and solar energy should be a priority, but in the short- and medium-term other forms of low-carbon hydrogen are needed in order to rapidly reduce emissions and support the development of a hydrogen market at affordable costs. The EU Hydrogen strategy proposes a phased approach for this transition. From 2020 to 2024, the Commission’s objective is to support the installation of at least 6GW of renewable hydrogen electrolysers in the EU, in order to produce up to 1 million tons of renewable hydrogen. From 2025 to 2030, hydrogen needs to become an intrinsic part of Europe’s integrated energy with at least 40GW of renewable hydrogen electrolysers and the production of at least 10 million tonnes of renewable hydrogen in the EU by 2030. From 2030 to 2050, renewable hydrogen technologies should reach maturity and be deployed at large scale across all hard-to-decarbonise sectors, such as industry, transport and buildings.

Green hydrogen can not only provide a solution for avoiding curtailment of renewables, but also facilitate the exchange of energy within sectors, while providing storage vector options for reconversion. Flexibility options that green hydrogen as an energy carrier can provide addresses topics of resiliency.

4.2.4 EUROPEAN CLEAN HYDROGEN ALLIANCE (ECH2A)

The alliance, also launched in July 2020 by the EC as part of the new industrial strategy for Europe, aims at establishing an investment agenda for hydrogen, supporting the scaling up of the hydrogen value chain across Europe. The implementation of the European Hydrogen Strategy will be facilitated by the Hydrogen Alliance (EC, 2020b).

The investments needed in the next decade for green and blue hydrogen were estimated to reach €430 billion until 2030. Hydrogen has been deemed an essential element in the bid to accelerate the decarbonisation of industry and maintain industrial leadership in Europe. The alliance intends to also support scaling up production and demand for renewable and low-carbon hydrogen, coordinate action, and provide a broad forum to engage civil society. The Alliance will also be important in the context of the new energy system integration strategy.

4.2.5 RESEARCH & INNOVATION IN HYDROGEN

RD&I efforts are needed to ensure that hydrogen can be widely adopted in many new applications to contribute fully to the energy transition. New and affordable solutions need to be developed and tested in areas such as materials for electrolysers and fuel cells, efficiency, durability, costs, safety, business models so that hydrogen can become a technically feasible option, as well as an efficient and competitive one. There are increasing fields of application for hydrogen, not only in the energy sector (power, heating and gas) but also industry and transports, and research and innovation are necessary to fulfil the potential of hydrogen in all these areas, and investment needs to be directed to production and supply chain, storage, transport and transformation of clean hydrogen for the whole economy and replace fossil fuels.

Financial instruments, such as grants from Horizon Europe (2021-2027) are expected to be available to support these RD&II efforts in the coming years, as FP7 and Horizon 2020 have been so far, granting around €985 million for over 250 projects.

Some of these funded projects, in key research areas of the hydrogen strategy and contributing to the sector integration processes, are identified in Annex 1 of this document as Use-Cases. Also, hydrogen-related projects in various sectors were featured in a European Commission brochure (2020).

The Fuel Cell and Hydrogen Observatory published an updated map of National and Regional Roadmaps / Strategies existing in Members States. Figure 14 shows the situation as of February 2021 in terms of the published policy documents.

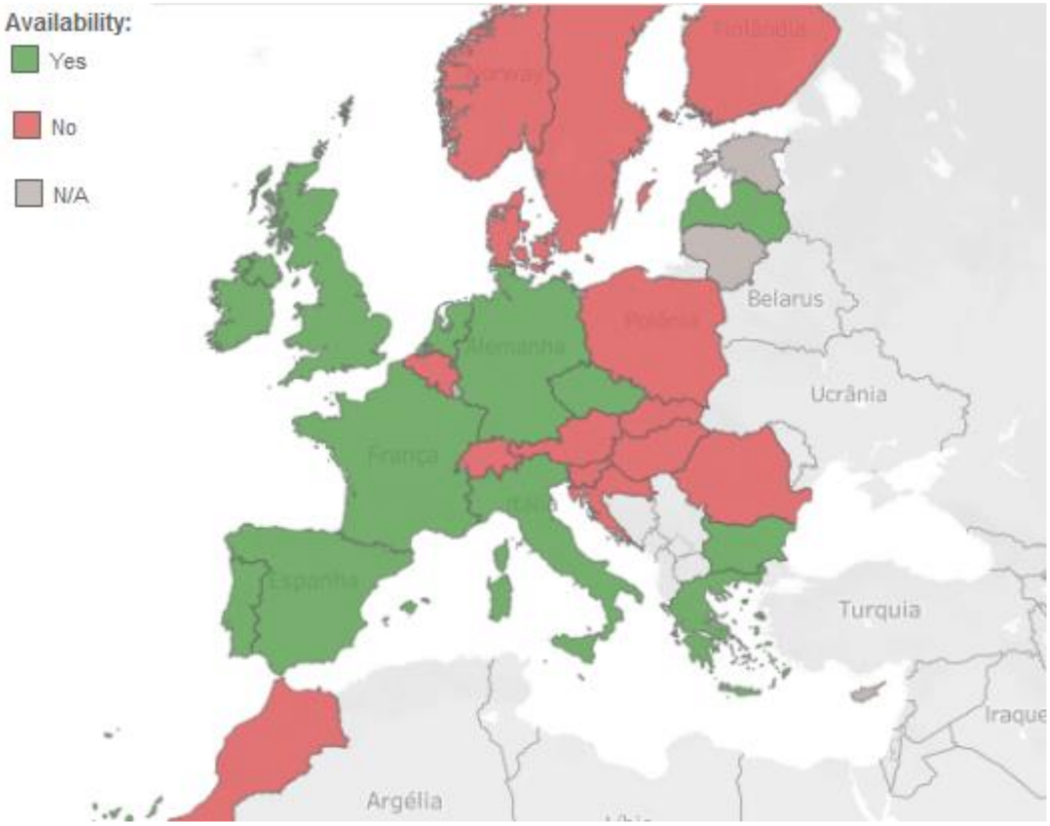


Figure 14. National Hydrogen Strategies in EU/EEA Member States (and UK) (Fuel Cells and Hydrogen Observatory, 2021)

Utilising hydrogen for energy uses, namely to enable sector coupling and develop energy storage capacities, is strategic for many European Member States. It is seen as a potential means to deal with grid imbalances, especially considering an increase of the renewable share in the energy mix.

The discussion about Hydrogen in the energy systems has picked up recently and there are a number of countries that have published national hydrogen strategies. By early September 2020, five EU and EEA countries had released national hydrogen strategies (France, Germany, the Netherlands, Portugal, Spain, and Norway) in 2020. Other EU countries are expected to publish their own shortly (Austria, Estonia, Luxembourg, Poland, and Slovakia, among others), showing that the European countries that have Hydrogen strategies.

4.3 SECTOR COUPLING WITHIN EC R&D/R&I PROGRAMMES

Sector coupling represents a unique opportunity to link innovation and R&D in the energy sector to the changes intrinsic to the new paradigms. The reliance on active contribution by all market participants, with prosumers adjusting in real time their consumption patterns according to price signals, grid usage and quality / source of supply, implies the involvement of an important share of population, previously excluded from the participation to the market, as well as of industries and other energy consumers. Therefore, sector coupling, besides representing quintessentially a pivotal industry challenge, offers also the opportunity for a relevant societal improvement in the way consumers approach the energy sector, in which welfare benefits and overall system efficiency and financial profitability are deemed equally important.

The new European framework programme for research and innovation, called Horizon Europe, covers the period from 2021 to 2027 (European Union, 2019), with a total budget of €100 billion to be dedicated to R&D activities supporting the delivery of scientific, technological, economic and societal impact. Framed into three pillars (Excellent Science, Global Challenges and European Industrial Competitiveness, Innovative Europe) with a specific mission area committed to "Adaptation to climate change including societal transformation". According to the European Commission, the focus *"will be on solutions and preparedness for the impact of climate change to protect lives and assets. It will include behavioural changes and social aspects by addressing new communities beyond usual stakeholders, which help lead to a societal transformation"* (European Commission, 2020d).

Consistently, Cluster 5 of Horizon Europe on Climate, Energy and Mobility envisages energy and mobility systems that are "*climate and environment-friendly, smarter, safer, more resilient, inclusive, competitive and efficient*" (EC, 2019). To achieve this objective, it is mentioned the development of "*a wide portfolio of cost-effective and efficient carbon-free alternatives for each GHG-emitting activity (including Life Cycle Analysis), often in combination with enhanced sector coupling, digitalisation and system integration.*"

Sector coupling perfectly fits with the above-mentioned scope, and therefore low TRL R&D research and pilot projects alike will be eligible to receive grants within the Horizon Europe framework and/or within other Funding Program, as previously happened in Horizon 2020 programme.

Horizon Europe will keep the three standard evaluation criteria envisaged for the former framework program: Excellence (soundness of concept and innovation potential), Impact (expected job creation, welfare and environmental benefits), and Quality and Efficiency of Implementation (appropriate allocation of tasks and resources, management structure). It is therefore recommendable to directly address these three criteria and incorporate relevant KPIs.

Consistently, an element of novelty is also given by the introduction Key Impact Pathways (KIP) to better measure scientific, societal and economic impacts of projects.

4.3.1 RATIONALE FOR SECTOR INTEGRATION PROJECTS

Current efforts at EU level aimed at ensuring full use of existing interconnectors and operational digital platforms along with the implementation of the provisions related to internal electricity market design is expected to bring further increase in the efficiency of electricity trading in Europe (EC, 2020a). Coupling sectors, and even more integrating them, under common planning and/or operation framework stems from different drivers, which can also co-exist and reinforce each other. Three main rationales are identified below:

- Reduce GHG emissions, in a more cost-efficient way than keeping silos across sectors;
- Improve optimised use of available energy resources and/or of energy infrastructures;

- Improve flexibility and resilience through new services enabled by advances in enabling digital solutions.

In any case, assessment of an initiative or a project should be made against other(s) ways to obtain similar results, under given scenario assumptions.

The impact areas within sector integration "system of systems" approach are summarised in Figure 15 below.

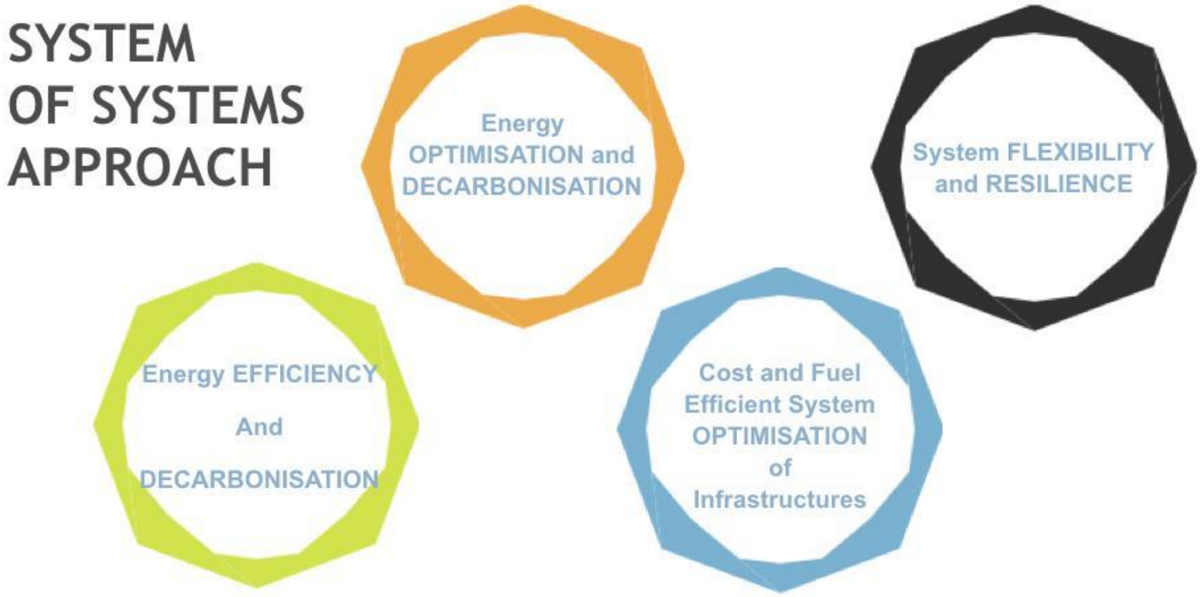


Figure 15. Visual representation of the system of systems approach

4.3.2 SECTOR COUPLING FOR ENERGY EFFICIENCY AND DECARBONISATION

The achievement of the ambitious EC decarbonisation targets will require a wide range of measures to be undertaken, with energy efficiency being the first option, whenever possible, followed by electrification as a second major building block of a climate-neutral energy policy. Thanks to the intrinsic efficiency of the electricity carrier and the maturity of RES, it is widely recognised that electricity will become the dominant energy carrier of the European energy system, with a degree of electrification in final energy consumption that will grow from 22% in 2015 up to 53% (EC, 2018) or even 65% (Eurelectric, 2020; Wind Europe, 2019) by 2050.

In respect of the electricity sector, sector coupling has two deployment configurations:

1) Electrification of end-users, or direct electrification

2) Cross-vector sector coupling (power-to-X), or indirect electrification.

From an energy-efficiency perspective, the higher the direct electrification, the lower the RES required in the energy system, the lower the primary energy demand. This is due to the intrinsic efficiency of the electricity carrier that reduces energy losses while bringing the same output result. For instance, an electric vehicle could run up to 7 km with 1 kWh of energy input, while the same amount of energy in a hydrogen (produced via vRES) vehicle results in roughly one third of travelled distance (Agora Verkehrswende, 2018).

In indirect electrification, the transformation of electricity into molecules implies a loss of exergy since the product (heat energy or chemical energy) cannot be fully converted into mechanical energy without losses. The unquestionable benefits of chemical fuels, such as oil, gas and carbon, besides the actual low prices, are the ease of production/extraction and transport and the energy density, both per unit of weight and per volume. For instance, electricity struggles to decarbonise long-haul transport because of its high energy density requirements: electrochemical batteries mass density ranges from 0.36 to 0.875 MJ/kg [13], while their volume density ranges from 0.9 to 2.63 MJ/L. Chemical fuels, by comparison, have values at least 30 times higher, thus requiring 30 times less mass or volume to store the same amount of energy. Therefore, the current capacity of electrochemical storage systems is not enough for applications such as aviation or maritime transport.

For demand that cannot be cost-effectively or technically electrified, thermal energy (green gases, H2, bioenergy, waste, waste heat, solar thermal) will still be required to cover remaining demand and help balance the power system. Energy efficiency must be prioritised to maximise the use of these fuels. Optimising cogeneration (or combined heat and power) across a range of increasingly renewable fuels will ensure that heat is delivered efficiently and that dispatchable and flexible electricity can cover residual demand and mitigating increasing seasonal, weekly and daily peak demand. The Artelys study (2020) shows how CHP can play a key role based on the Commission's 1.5 TECH scenario, in meeting increased peak demand when PV/wind are insufficient. This applies to the 1.5 TECH scenario which is highly electrified and RES based.

Moreover, some end-uses of the chemical industry, such as the production of ammonia, methanol, olefins, formaldehyde, already require the physical and chemical properties of molecular fuels such as hydrogen to be performed. In this context, electrification is not an option. Power-to-X technologies and, in particular Power-to-Gas, are the best candidates to decarbonise these feedstock requirements.

4.3.3 SECTOR COUPLING FOR ENERGY OPTIMISATION AND DECARBONISATION

The smart sector integration is also expected to support the further deployment of smart grids at different scales improving operating efficiency through greater digitalisation to allow the growing penetration of distributed generation and resulting in the integration of demand-side flexibility resources. The evolving flexibility markets supported by digital platforms are expected to create services driven by revenue opportunities for sector-coupling technologies that can also be delivering congestion management goals. It could be further explored as to how these approaches can contribute towards Risk Preparedness goals and solutions (European Union, 2019) in addition to demand side flexibility.

The digitalisation of the energy infrastructures is a clear enabler of sector coupling in energy systems. The gap between different markets can be overcome, providing the bridge between supply and demand at the disaggregated level. This transformation is supported by the use of novel sensors, Big Data tools, artificial intelligence, 5G and distributed ledger technologies resulting in data handling being increased through interoperable platforms. Real-time communication and technologies implementation within advanced data exchange infrastructures while enabling the participation of flexible consumption by engaged consumers within dynamic markets.

Besides monitoring, forecast and management of distributed generation will be improved. In addition, the optimisation and increase in efficiency, connecting the various energy carriers and the flexibility and resilience of the energy systems is also expected to increase. The consumers are empowered by being part of a system that connects them to different suppliers, namely replacing imported natural gas and petroleum products with local production in a distributed energy supply, helping to reduce the dependency on energy imports and creating a more circular energy economy within Europe.

The following three areas could be enabled by smart sector integration: connected dynamic markets, the advanced data exchange infrastructures rollout, increased data handling capacity enabled by close to real-time communication and technologies.

4.3.4 SECTOR COUPLING FOR INFRASTRUCTURE OPTIMISATION

The role of renewable hydrogen and hydrocarbons (i.e. produced via RES) is unquestionable in a climate-neutral energy system. Direct and indirect electrification are both required, with a share that depends on the specificities of each country, from availability of natural resources, storage options and geographical location; every country has its own “recipe” to fulfil the energy transition. Therefore, whatever the dimension of the P2X capacity will be, synthetic molecules will have a role in the future energy system. Having recognised the role of P2X assets for decarbonisation, it is important to investigate the potentiality of such assets, in particular P2G, to work as storage systems, in relation to the electricity system flexibility needs and in comparison, with electrochemical storage.

The European Commission has mandated ENTSO-E and ENTSO-G to jointly submit a consistent and interlinked electricity and gas market and network model including both electricity and gas transmission infrastructure as well as storage and Liquefied Natural Gas (LNG) facilities. This has translated in a joint scenario and in an Interlinked Model, to be utilised for the Cost Benefit Analysis of gas and electricity infrastructure projects, within the grid planning process (TYNDP - Ten Years Network Development Plan). The Interlinked model shows how smart sector integration can be driven by infrastructure optimisation.

In the future TYNDP, the scenario building process should develop in the direction of integrating more sectors and/or to include those considering additional factors, such as the cost of technologies. Moreover, the supply side should also be quantified considering all sectors and it will be possible to identify synergies between sectors. Together with a rising number of sectors and applications that interact with the electricity system, the complexity of the TYNDP will increase. Furthermore, the number of actors that have a legitimate interest in the planning processes will rise. A collaboration of all the stakeholders in the process will lead to holistic planning as well as to facilitate innovative solutions and new benefits due to perspectives from other sectors. In addition, the project assessment phase should evolve to capture the benefits of projects in different sectors.

ENTSOs have assessed the integration of P2G facilities in their scenarios by developing methodologies for their quantification, distribution and optimisation. For instance, in the National Trends scenario, the economic viability of Power-to-Gas facilities is quantified by calculating the minimum full load hours for the facility to be economically viable in a country. The actual P2G production can vary depending on other factors, such as the distance of the RES facilities to the grid and the local excess electricity duration curve. The modelisation considers a two-step approach; first, the curtailed electricity from the electricity market model is considered as source of renewable electricity to produce renewable gases (hydrogen, methane and liquids); secondly, additional renewable electricity production is assumed and modelled to meet the demand for renewable gases. The modelling of P2X takes into account different configurations: P2G supplied by dedicated RES, at the interface of electricity and gas systems or at consumer facility and analysing their impact on electricity and gas infrastructures.

4.3.5 SECTOR COUPLING FOR IMPROVING SYSTEM FLEXIBILITY AND RESILIENCE

Generation from vRES clearly depends on weather conditions (i.e. presence of solar radiation and wind) and shows high daily and seasonal variability. Their non-programmability results in structural overgeneration and poor contribution to adequacy, since other generators as well as short/mid-term energy storages are required to meet demand when vRES generation is limited. Strong flexibility needs will emerge for the electricity system, in all timeframes: daily, weekly and annual flexibility.

In particular, daily flexibility needs are significantly related to the share of solar generation (see the Duck curve in Fig 16) causing negative values of residual loads (i.e. the net difference between electricity demand and wind and solar generation).

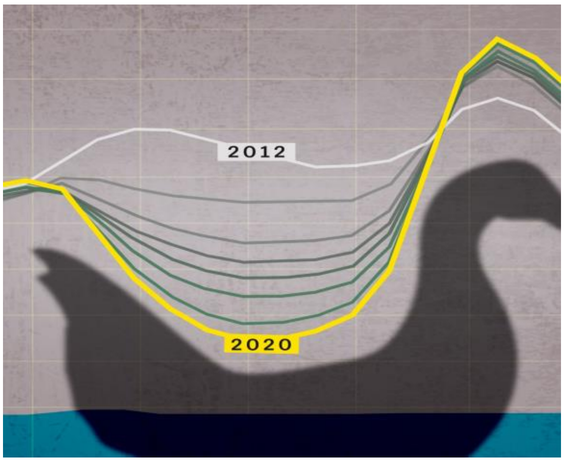


Figure 16. Duck curve, flexibility need, solar generation

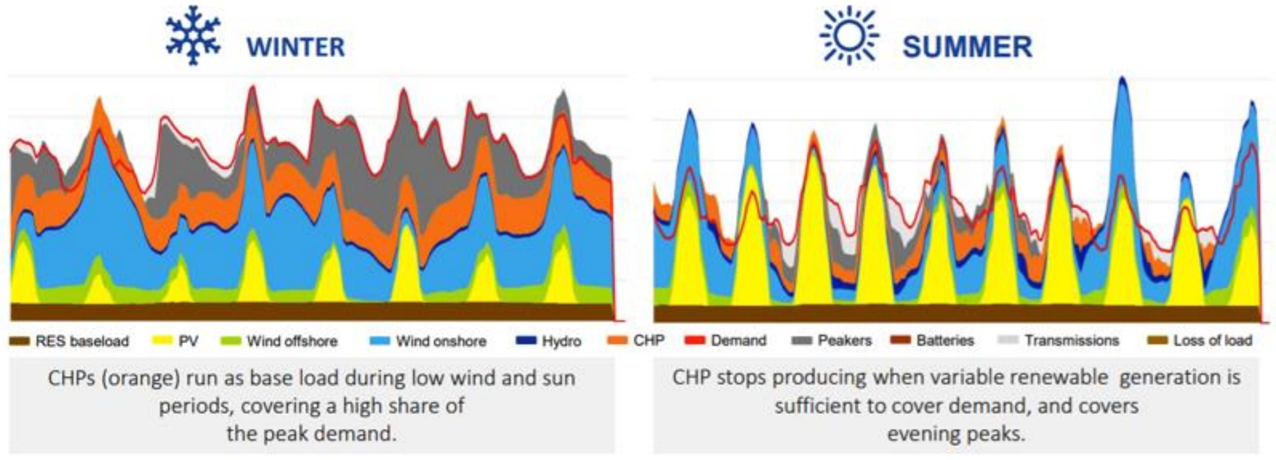
Seasonal flexibility at present can be provided only by large hydro reservoirs, therefore Power-to-X is expected to cover this gap; in particular Power-to-Gas, since molecules can be stored without losses for indefinite time.

To envision a secure and adequate electricity system based on RES, a set of coordinated and coherent actions need to be implemented: electricity network investments, energy and ancillary service market evolution, storage systems, both mature (pumped storage hydropower plants, electrochemical storage), some at their very early stage, including Power-To-X. Power-to-G, specifically, transforms electricity into chemical energy, i.e., a gas which could then be used in devices as turbines, internal combustion engines or fuel cells to produce electricity (what is called 'Power-to-gas-to-Power', P2G2P) and heat (in the case of cogeneration). Re-electrification of hydrogen should be preferably done in cogeneration; producing power and heat and achieve high fuel utilisation rates of 90% and more, thus implementing "energy-efficiency first" on the supply side. For exergy reasons, electric-to-chemical conversions should be avoided when possible and therefore systems such as batteries or pumped storage hydropower should be preferred over others. However, a certain amount of 'energy-degrading' conversion shall be useful for some of the needs of the electrical system. Therefore, some sector integration projects might find their main rational in providing flexibility and resilience to the electric system.

For thermal fuels still required in the system to complement electrification, energy efficient generation must be prioritised via cogeneration. Given the increased seasonal power peak demand, optimised cogeneration operation can be achieved through different strategies: 1) virtuous behaviour by only generating when it is cost-effective for the joint electricity and heat system; 2) decoupling heat and power production via heat storage to generate electricity at times of insufficient variable RES supply; 3) continuous heat and power generation to maximise efficiency and self-consumption primarily for industrial sites that require large quantities of process heat, which cannot be electrified (Artelys, 2020).

The dynamic operational management of CHPs is simulated with Artelys Crystal Super Grid. CHPs adopt a virtuous behaviour by only generating when it is cost-effective for the joint electricity and heat system.

In particular, CHPs, with a flexible price-driven operational mode, do not compete with, but **complements** variable renewable generation to meet seasonal peak demand due to high shares of electrified heat.

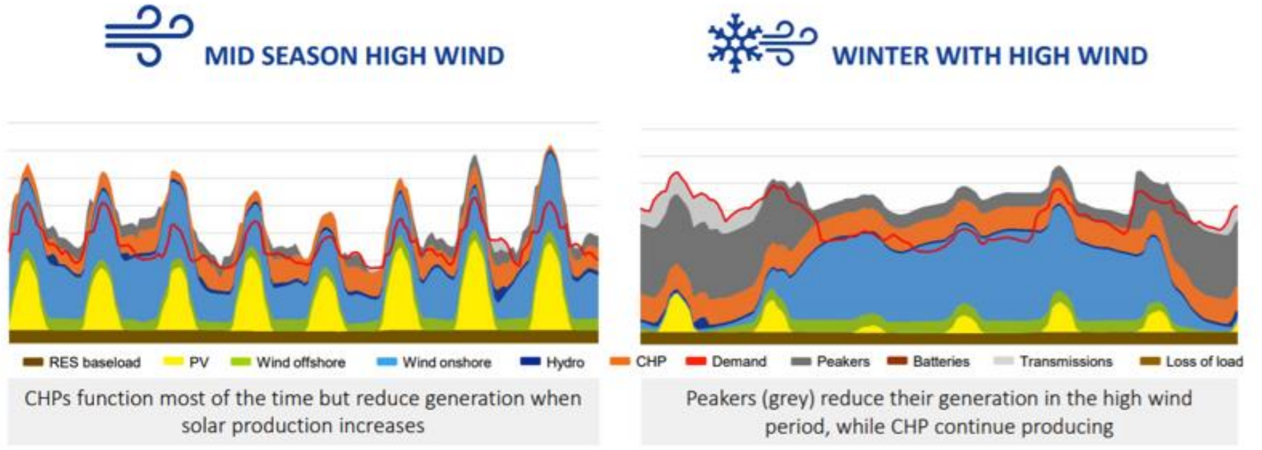

WINTER

SUMMER

CHPs (orange) run as base load during low wind and sun periods, covering a high share of the peak demand.

CHP stops producing when variable renewable generation is sufficient to cover demand, and covers evening peaks.

Figure 17. CHP flexibility benefits 1/2 (source: Artelys, 2020)

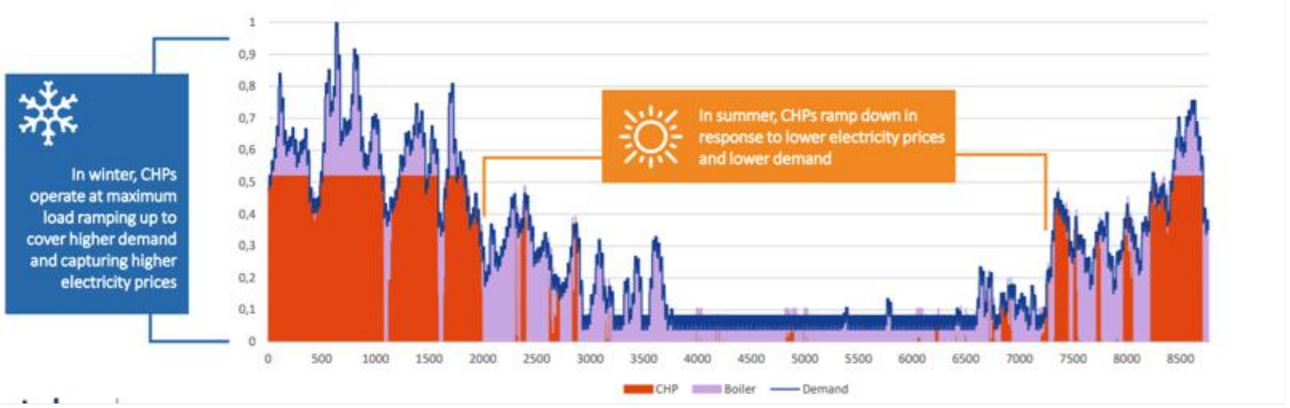

MID SEASON HIGH WIND

WINTER WITH HIGH WIND

CHPs function most of the time but reduce generation when solar production increases

Peakers (grey) reduce their generation in the high wind period, while CHP continue producing

Figure 18. CHP Flexibility benefits 2/2 (source: Artelys, 2020)


In winter, CHPs operate at maximum load ramping up to cover higher demand and capturing higher electricity prices

In summer, CHPs ramp down in response to lower electricity prices and lower demand

Figure 19. CHP Hourly operation - example for a thermosensitive heat demand (district heat for buildings) (source: Artelys, 2020)

Energy infrastructures development plans should strive for a higher level of integration by increasing the links through digital interfaces between energy carriers. Both large-scale and local infrastructures must be viewed within a new holistic approach that considers the protection and resilience of critical infrastructures and streamlining of supporting services. The demand side flexibility interoperable multi-vector solutions, storage solutions and the related services shared via marketplaces is expected to augment the network-based solutions while increasing overall system resilience. Smart sector integration demand-side flexibility from transmission level to behind-the-meter can enhance the use of the existing infrastructures[1] alongside the development of new infrastructures or re-purposing of existing ones.

Most district heating systems are infrastructures where only a few are highly efficient and based on renewables, yet they make up to 12% of the total final heating and cooling energy consumption (STRATEGO, 2015). The development of modern low-temperature district heating systems can connect local demand with either distributed energy sources or both the electric and gas grid, effectively optimising the integration between energy carriers in both supply and demand. Increase multi-sector flexibility, including the potential of demand-side flexibility is expected to increase overall system efficiency and social welfare (European Commission, 2017) provide greater consumer empowerment, security of supply and energy security through imports substitution while facilitating circular models implementation.

Electricity infrastructures while playing core role in renewable energy generation integration, further improvements in the deployment of innovative technologies and infrastructures beyond smart grids systems supporting green hydrogen networks and integrated offshore grids will play an important role in decarbonisation and system resilience, while facilitating the transition to sustainable and smart mobility.

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[1] https://smarten.eu/shaping-the-smart-sector-integration-strategy-smarten-contribution-to-the-european-commissions-consultation/

5. BUILDING BLOCKS

5.1 NEW TECHNOLOGIES

5.1.1 AN OVERVIEW OF KEY ENABLING TECHNOLOGIES

The European energy and climate targets call for decarbonisation of the entire energy system. In this regard, the concept of sector coupling or smart energy integration has recently gained increased attention. Although there are great expectations to the role that sector coupling can play in achieving a cost-efficient green energy transition, it is still somehow unclear to which extent the current and new technologies can contribute to these objectives.

Therefore, to shed light on sector coupling, ETIP SNET conducted a White Paper focusing on the concepts, state-of-the-art and perspectives of sector coupling (ETIP SNET, 2020). The purpose was to establish a shared ground of definitions, concepts and common understandings on this topic. Furthermore, it provided state-of-the-art and perspective of conversion and end-use technologies and gave an outlook of the potential deployment. Finally, it briefly identified early-stage barriers that could hinder the deployment, both technical and non-technical.

The energy system is expected to become increasingly integrated, thus creating a system-of-systems. The figure 20 illustrates a potential future energy system where integration between energy systems and sectors can generate synergies, which essentially can make the system cheaper and more efficient, both regarding investments but also in the operation of the system.

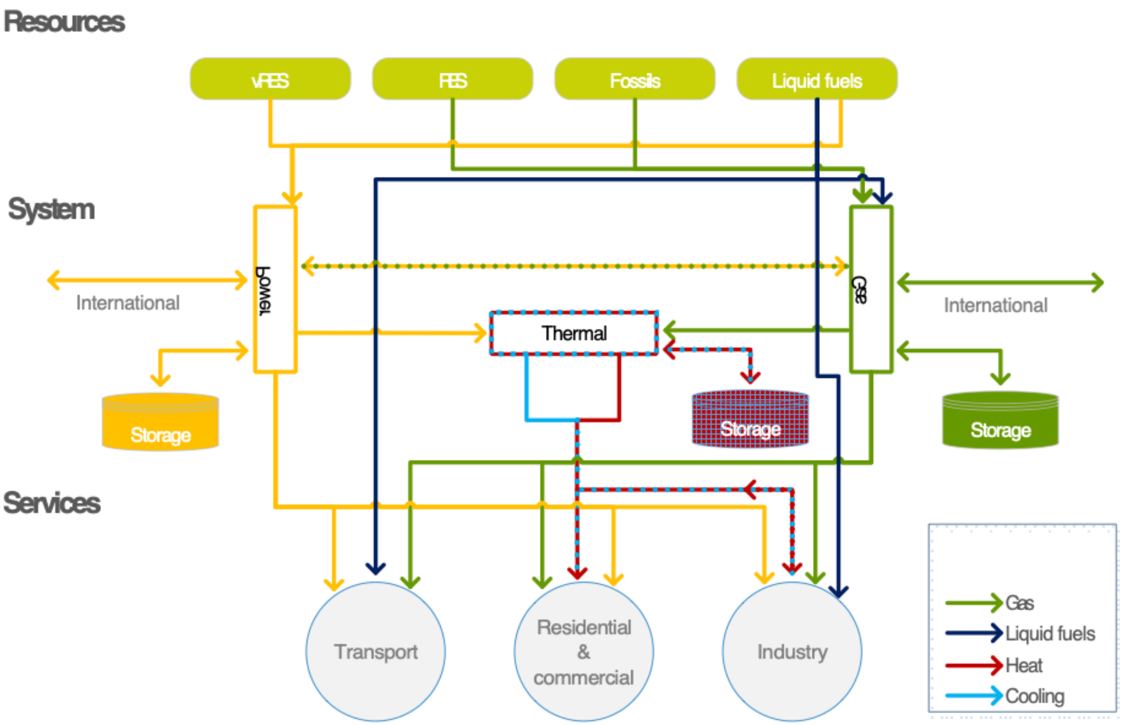


Figure 20. Potential future investment and economic synergetic system of system view (Source: ETIP SNET White Paper – Sector Coupling: Concepts, State-of-the-art and Perspectives (2020)

The electricity system will play an important role in the future integrated energy system, and many end-users might be electrified, for example, the electrification of heating, transport and industry. In addition, power to gas and liquid fuels can also serve as a facilitator, which integrate both the power, gas and heating systems.

Furthermore, synergies between the other systems and sectors might also appear and contribute to a cost-efficient energy transition.

The transition towards a future low-emission energy system requires the development of innovative technologies that can provide flexibility and integrate the power sector with the other sectors. However, across the energy system, different technologies have different technology readiness levels or maturity levels.

A significant contribution from the ETIP SNET White Paper on sector coupling was the provision of the state-of-the-art and perspectives of conversion and end-use technologies as well as the outlook of the potential deployment of these technologies. Systematically, it provides key figures related to techno-economic parameters such as costs and efficiencies, and it evaluates the maturity using the Technology-Readiness-Level (TRL) as a measure. While the ETIP SNET White Paper on sector coupling presents a thorough description of the key figures, summarises the status of conversion technologies, which can facilitate the integration of the power sector with the other energy systems (ETIP SNET, 2020).

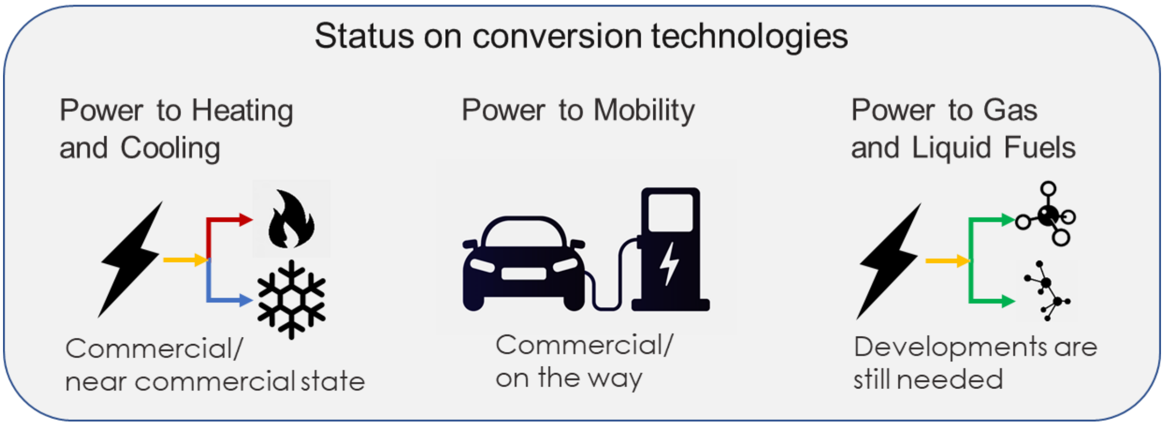


Figure 21. Status on conversion technologies

In general, technologies are available for making the first steps of sector coupling in all sectors. However, the variations of the TRL within each category of conversion technologies occur. The status of conversion technologies identified that particularly the power to heating and cooling technologies are at a commercial or near commercial stage. Power to heat technologies was, in particular, investigated taking into account the sectorial discrepancies between the power-to-heat technologies installed in residential buildings, in the industry and for district heating production.

Power to mobility is particularly gaining momentum for electric vehicles (EVs) and the related V2G evolving models in urban areas, where targets on local pollution apply; however, variations regarding the roll-out of electric mobility varies across countries. These evolving developments show great potential for future deployment and scaling up.

Power to gas and liquid fuel technologies still need developments to scale up the production and decrease the costs further. The potentials for future deployment of power to gas and liquid fuel technologies underlines the importance of further developments, as it can contribute to decarbonising, in particular, the hard-to-abate sectors such as long-haul transportation, heavy industry, as well as it can contribute to other end-use consumers using gas for different purposes, for example, heating in the residential sector.

Energy sector integration: opportunities and challenges

The exploration of smart energy integration as a means of achieving a cost-efficient green energy transition provides new opportunities, but it also brings new challenges. Figure 22 highlights some of the main opportunities and challenges related to an effective integration of sectors.

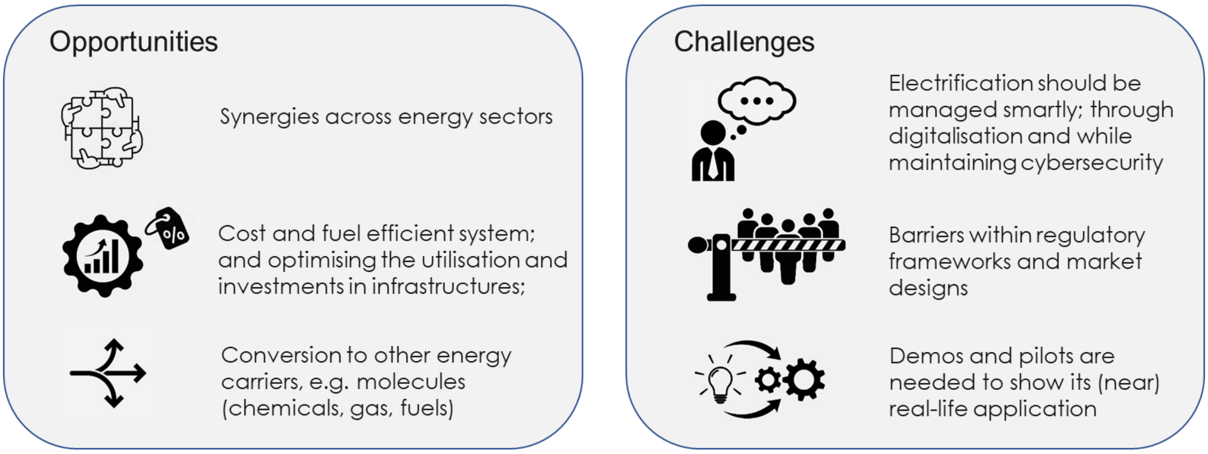


Figure 22. Energy sector integration challenges and opportunities

Opportunities:

Sector coupling can provide innovative solutions to the flexibility needs of the electric system, where synergies and complementarities can be exploited across energy sectors, essentially creating a cost- and fuel-efficient energy system if it is integrated smartly. A smart energy sector integration is thus required, and, if successfully integrated, can contribute to cost-efficient investment decisions in, and utilisation of, energy infrastructure. Furthermore, the integration of sectors enables new storage opportunities at multiple time scales, thus enabling higher penetrations of variable renewable energy sources to be integrated into the energy system. Finally, the conversion of power to other energy carriers, for example, molecules (chemicals, gas, fuels) allow an alternative transport of energy through existing or new energy infrastructures, e.g. gas or district heating infrastructure, and thus enables a greater variety of storages possibilities, even at longer time scales, e.g. over seasons. The opportunities related to smart integration of energy sectors, and the creation of a system-of-systems, can contribute to paving the way for a deep-decarbonisation of the future energy system.

Challenges:

Challenges exist for smart integration of energy sectors that needs to be overcome in order to realise the potential opportunities for achieving a future decarbonised energy system in an effective, cost-efficient and sustainable way.

A key element for the electrification of the system is that it needs to be managed smartly. In this way, the different appliances can contribute to balance and stabilise power grids. If the electrification is not managed smartly, a large expansion of power grids might be required with potentially stranded investments in power generation, grids and storage capacity. In this regard, digitalisation is key in order to manage future energy systems smartly. However, with increased digitalisation and smart management of the energy system, challenges related to cybersecurity also emerge.

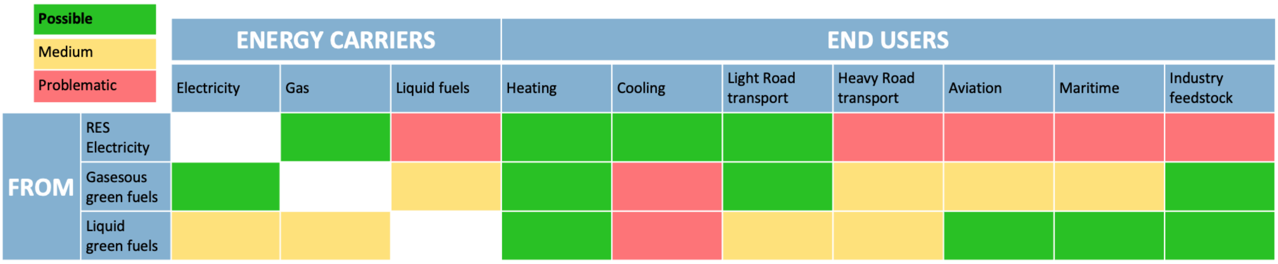
There exist barriers within the regulatory frameworks and market designs that potentially hinder the deployment of technologies enabling the integration of energy sectors. The barriers within regulation are starting form setting up coordination among the separated commodities markets as well as the services markets.

Demos, pilots, sand boxes and even small energy communities, in specific cases, deserve attention, as they can be used to show the (near) real-life application of technologies, devices and systems that are required for a smart integration of energy sectors. Challenges faced, and lessons learned, from these demonstration projects are needed to be communicated to the scientific and societal community as well as to industries. Thereby, open exchange of data, methods, and results can accelerate learnings if they are distributed to stakeholders and industries across sectors. In this way, even the required coordination of planning can be facilitated, which will be needed to efficiently unlock the potential synergies.

5.1.2 ENERGY INTERFACES IN THE DECARBONISED ENERGY SYSTEM

100% renewable supply will require electricity, as the only primary input, some electricity converted to gas and liquid fuels, all will be used in different applications.

Energy conversions and energy use in applications are heterogeneous, in some cases due to fundamental feasibility (long haul flights on electricity) but in most of the cases due to cost and efficiency of conversion.



🟩 **Possible**
🟨 Medium
🟥 Problematic

		ENERGY CARRIERS			END USERS						
		Electricity	Gas	Liquid fuels	Heating	Cooling	Light Road transport	Heavy Road transport	Aviation	Maritime	Industry feedstock
FROM	RES Electricity		🟩	🟥	🟩	🟩	🟩	🟥	🟥	🟥	🟥
	Gasesous green fuels	🟩		🟨	🟩	🟥	🟩	🟨	🟨	🟨	🟩
	Liquid green fuels	🟨	🟨		🟩	🟥	🟨	🟨	🟩	🟩	🟩

Figure 23. Interfaces among energy conversion, carriers, and end-users.

TRL levels are different across conversions especially for applications in the transport segment.

Economic impact/cost effectiveness are heterogeneous due to CAPEX and conversion losses but sometimes there is no other alternative, cannot be electrified directly.

R&I needs or barriers vary: e.g. in aviation the main challenge is to develop a hydrogen aircraft; compared to hydrogen production it is significantly more complex.

5.2 ARCHITECTURES

Vertically integrated infrastructure in every energy system provides important advantages, such as plug-n-play and hassle-less installation, reduced system integration efforts with an emphasis on inter-energy system integration.

The vertical infrastructures can have modular software structures, e.g. micro-services, providing important advantages to ensure interoperability with different technologies in one or multiple energy systems while preventing vendor lock situations through interoperability by design approach. The evolving data-driven initiatives driven by B2B Reference Architectures are dynamically evolving within the EU. The interlink and relevance of smart electric grids enabled by AI, IoT, Big Data, interfacing smart homes and buildings, industry and manufacturing are recognised as a dual strategy within recovery and resilience facility “Twin Transitions: Green and Digital” (EC, 2020c). Current digital initiatives could be extended towards reaching smart sector integration goals and the chapter below presents two relevant architectures: SGAM and LINK.

A reference architecture specifically tailored to address the smart sector integration complexity within energy value chains could lay the foundation for facilitating seamless B2B cross-stakeholders services addressing interoperability, build with open API approach while integrating technology enablers, solution providers and the evolving markets relying on network management platforms for near-real-time scalable event and data-driven synchronised market and network operations.

The ICT solutions should be supporting a decentralised and layered paradigm and nodal approaches while allowing connecting multiple stakeholders across energy vectors, facilitating “plug-n-play” despite legacy differences while facilitating platforms and services interoperability to achieve set integration goals.

5.2.1 SGAM MODEL FOR MULTI-ENERGY SYSTEM

Smart Grid Architectural Model (SGAM) has been traditionally developed for electrical networks. Nevertheless, the well-structured approach attracted the interest for an application also beyond electricity. Furthermore, with the emerging roles of sector coupling application becomes natural to ask the question if and how it is possible to extend the same formalism beyond the original application. In a nutshell, SGAM is seen as a perfect link to system engineering thinking and then it can be adopted for the abstraction of different infrastructures. This is demonstrated by the application of the same approach in different domains such as railways (Khayyam, 2016).

The topic has already been the focus of different research projects that have analysed this possibility. A good overview in this sense can be found in (Uslar, et al., 2019).This paper presents a wide list of examples of application of SGAM in a variety of fields. Interesting for the present paper is the analysis of the extensions proposed in the Smart City domain.

More from a theoretical perspective (L. Barbierato et al., 2020), defines a formal extension of SGAM in the direction of System of Systems analysis to better support an abstraction that goes beyond electricity.

The paper introduces GAMES, a General-purpose Architectural model for Multi-Energy Systems. The proposed approach integrates and extends the SGAM to deal with the definition of MES use cases. Similar to SGAM, GAMES exploits UML to characterise each component involved as a black-box but also integrates SysML to enable a systemic description of the MES component and their interconnections, following a grey-box approach. Thanks to this extension also complex co-simulation scenarios can be easily developed supporting the analysis of multi-energy systems with a formal development process.

A use case-based approach is needed for definition and development of GAMES considering:

- MES in different phases such as planning, operation, and maintenance;
- Interoperability between various energy systems with their different response time (e.g. slow thermal and fast electrical).

5.2.2 HOLISTIC APPROACH AND SECTOR COUPLING

Environment protection policies are fostering the deployment of sector coupling to provide greater flexibility to the energy system so that decarbonisation can be achieved more cost-effectively (European Commission, 2018). This ambitious vision requires holistic architectures (ETIP SNET, 2019) that enables structured and effective coupling of different sectors by introducing the new control paradigms on a large-scale (European Commission, 2020e). A long-term holistic architecture vision for future power systems is given in the ETIP SNET White Paper on Holistic Power System Architectures (2019), in which four different holistic architectures are described: Web of Cells, IDE4L, SmartNet and *LINK*-based holistic architecture.

Web of Cells provides a decentralised control using non-overlapping geographical areas of the power system, known as cells, to maximise the utilisation of renewable sources. It is developed mainly for the electrical networks and needs to be extended to consider the sector coupling.

IDE4L architecture enhances observability and controllability of the distribution networks and, therefore, enables more cost-efficient operation of the whole power system. Sector coupling is not taken into account. It needs to be extended to consider the sector coupling.

SmartNet focuses on the implementation of a flexibility market to provide optimised instruments and modalities to improve the coordination between the grid operators at national and local level (respectively the TSOs and DSOs). Five different coordination schemes were developed. Sector coupling was not the focus of development, but the possibility of extending the coordination schemes will be examined. TDXAssist, EUSysflex & Interrface projects also contributed in progressing in TSO-DSO key use case mapping as well as updates of the associated harmonised models.

LINK-based holistic architecture reorganises the management of the grid, electricity production, energy storage facilities and consumers and harmonises with the market. It facilitates the description of all power system operation processes such as load, generation balance, voltage assessment, dynamic security processes, price and emergency driven demand response, and so on and enables sector coupling. The highlights of embedding sector coupling in *LINK*-Architecture (Ilo & Schultis, 2021) are listed below.

5.2.3 *LINK*-HOLISTIC ARCHITECTURE AND SECTOR COUPLING

The purpose of a holistic architecture is to structure and organise the system in such a way that it operates reliably and economically. When the architecture is sound, it helps to better develop the system that is being described. Sector Coupling serves to deploy the integration of various sectors of the economy. The following chapter briefly describes how the sector coupling is embedded in the holistic architecture based on *LINK*-Paradigm, while Annex 10.2.1 shows the relationship between the *LINK*-Solution and the Energy Systems Integration.

A) Sector Coupling embedment in *LINK*-architecture

In a landscape with integrated energy systems, fuel, thermal, water and transport systems are systematically planned, designed and operated as flexible "virtual storage" resources for the power grid and vice versa (O'Malley, et al., 2016). Since Storage is defined as a unique and independent main element of the *LINK*-Architecture, the embedding of the sector coupling in it is obvious.

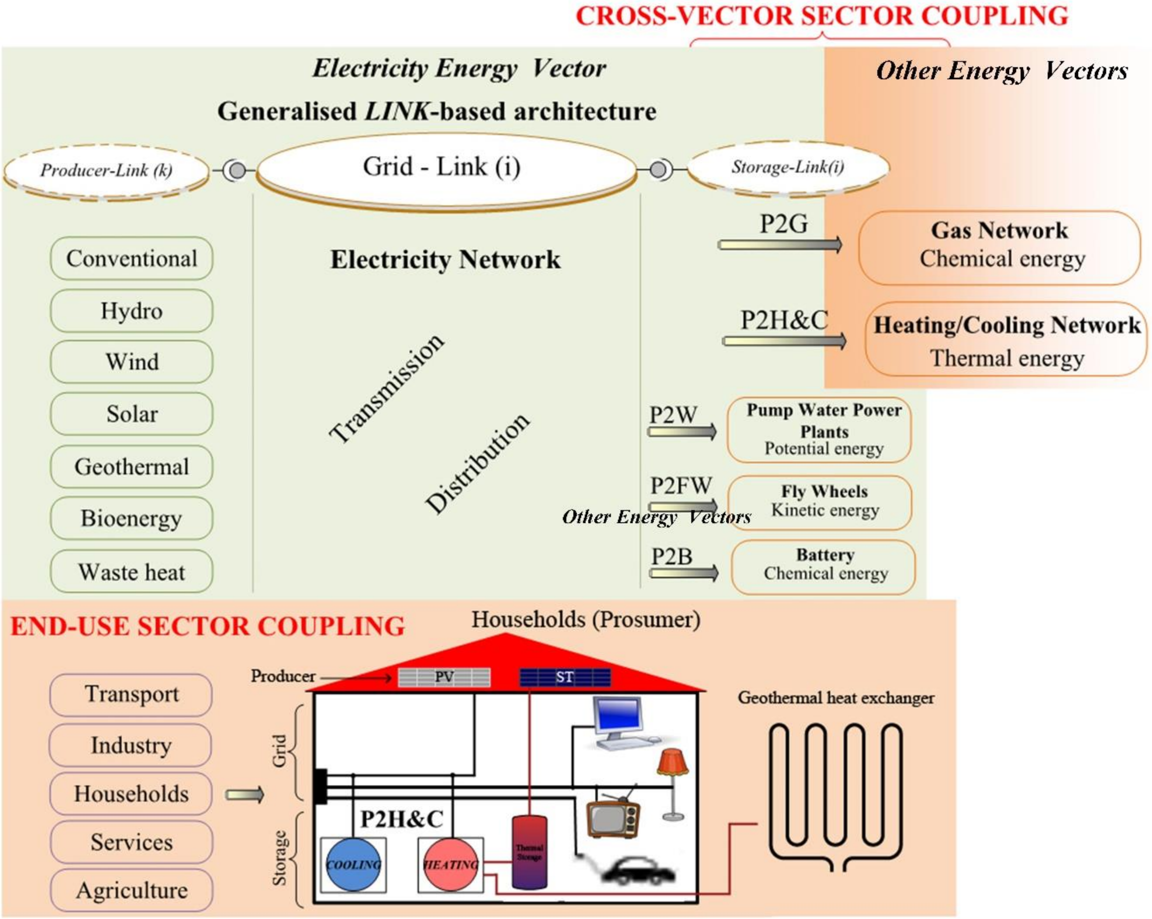


Figure 24. Cross-Vector and End-Use Sector Coupling embedded in the LINK-Solution

Figure 24 shows the Cross-Vector and End-Use sector coupling embedded in the *LINK*-Architecture. Energy vector areas are presented in different colours. The lime-green area presents the electricity energy vector, while the apricot area presents other vectors such as gas, heating and cooling, and so on. The generalised *LINK*-Architecture (Ilo, 2019) is outlined by its main elements:

- **Producers** that include all available plants regardless of size and technology such as conventional, hydro, wind, solar, geothermal, bioenergy, waste heating and so on.
- **Grids** that include transmission (very high and high voltage level) and distribution (medium and low voltage levels); and
- **Storages** that include all available facilities regardless of size and technology. Electricity is a form of energy that cannot be stored. Using coupling components, it is converted into storable forms of energy such as potential, kinetic, chemical energy. The traditional storage facilities and the “virtual storage” resources are included here. The traditional storage facilities are part of the electricity energy vector and include for e.g. Pump Water Power Plants that store electricity in potential energy. Coupling components are the pumps, which use electricity to increase the potential energy of water. Fly Wheels convert electricity in kinetic energy. Coupling components are motors. Batteries convert electricity in chemical energy. Coupling components are cathodes and anodes. The “virtual storages” are the result of the Cross-Vector Coupling exploiting the Power to Gas (P2G), Power to Heating and Cooling (P2H&C) processes and so on. These processes couple the infrastructures of electricity and gas utilities, or of electricity, and heating and cooling utilities. Coupling components are usually electrolyse cells.

B) Cross-vector sector coupling for P2G

Figure 25 shows the cross coupling of the electricity and gas vectors in the technical/operation level of the LINK-Architecture designed for the European. In the European type of power industry, TSOs usually operate the Extra- and Very High Voltage level, while the DSOs operate the high-, medium- and –low voltage levels; e.g. in Poland, Austria and so on. But there are also some cases in Europe that have a different power industry organisation that is more similar to the case of North America where the DSOs operate only the medium- and low voltage levels of the grid e.g. Italy, see Annex 10.2.2. In all cases, sector coupling takes place via the Coupling Components, CC.

LINK-Architecture spreads over the whole power grid including extra high-, very high-, high-, medium- and low voltage levels, customer plants, and the market. Storage in each voltage level splits in Cat. A, B and C according to the categorisation given above. The cross coupling between the electricity and gas vector may be realised in high-, medium- and low voltage levels through the storage of category B, Cat. B.

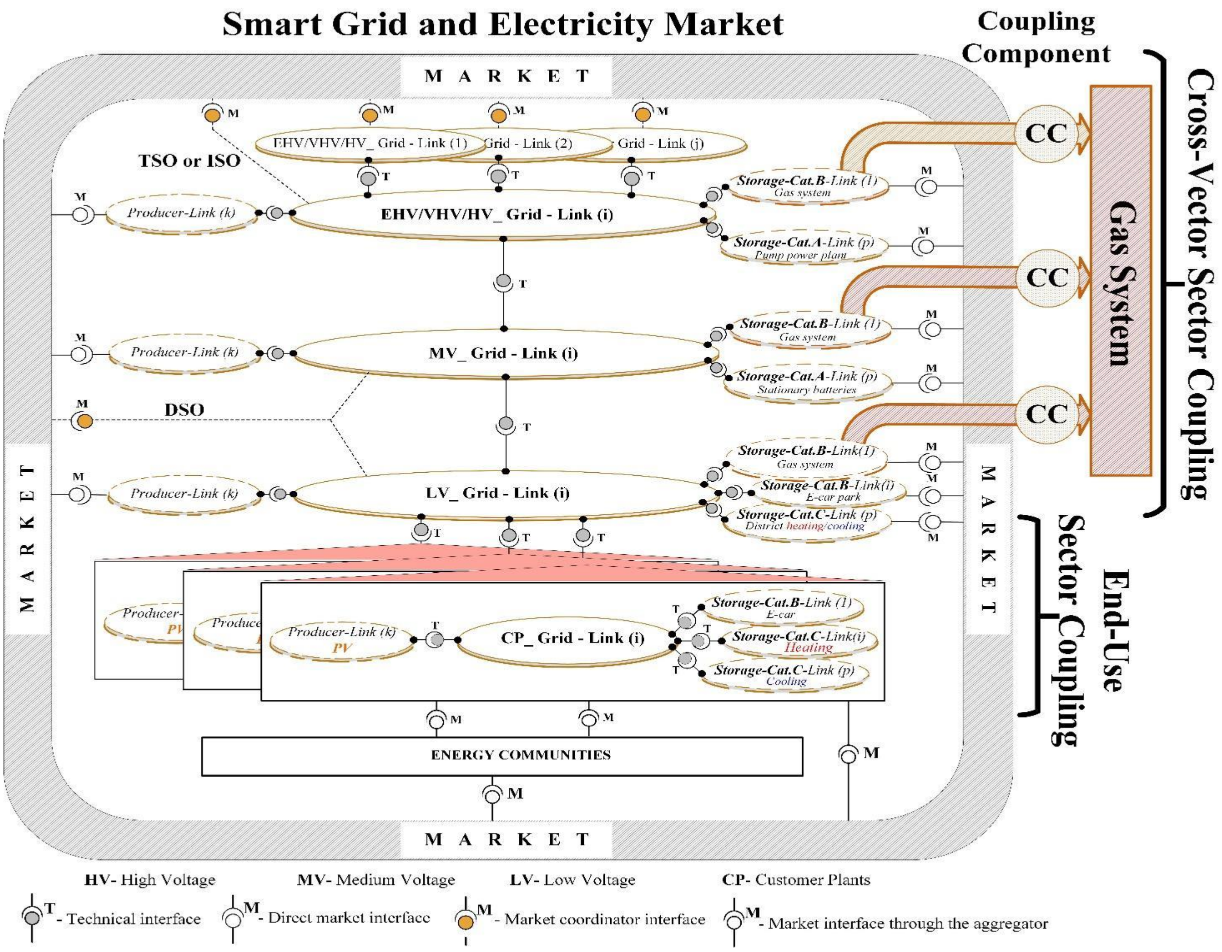


Figure 25. LINK-based holistic architecture coupled with the Gas System in the case of North-American type of power industry

The main principle of the *LINK*-Solution is the optimisation of the whole Smart Grids by coordinating and adapting the locally optimised Links. For the integrated energy systems gilt, the same principle as follows:

> *The optimisation of the electricity system and other sectors is realised by coordinating and adapting the locally optimised systems.*

Sector coupling may affect (in positive manner, if properly managed) the way ancillary services are provided and traded or valorised through market mechanisms. This is illustrated below using the process of price driven demand response.

C) Demand response in context of Sector coupling

The activation of residential, commercial and small business sectors, which join the real-time pricing demand response through already concluded contracts, may be triggered at any time. Their degree of participation in the demand response process may be different depending on the time of the day, duration interval, price value, etc. In the case of a surplus of electricity in the market, the electricity price decreases. All market participants and market operators will be notified to allow them the possibility to act on time. Fig. 26 shows the information flow during price driven demand response.

Each of the stakeholders participating in the demand response process have the possibility to perform sector coupling when the conditions are given. Some relevant use cases are discussed in Annex 10.2.3.

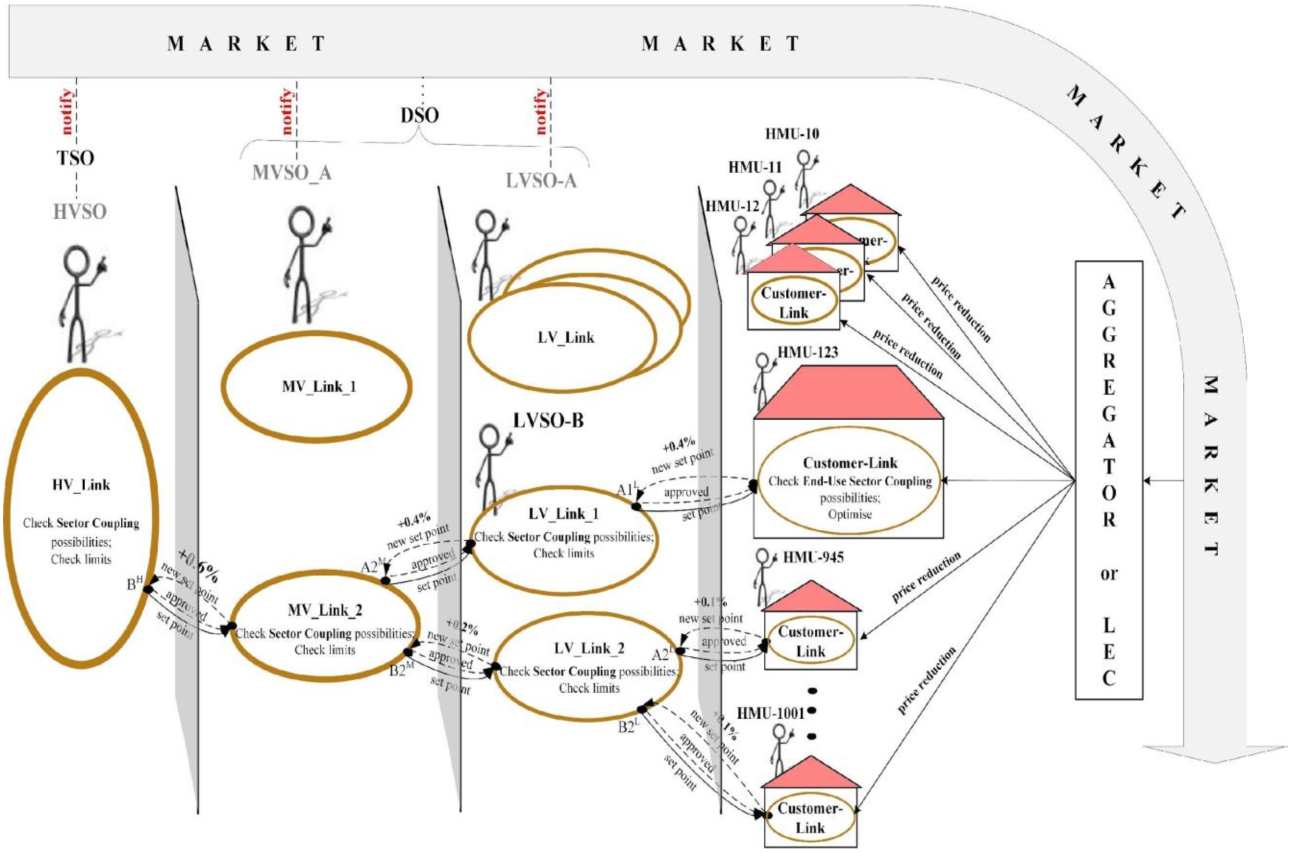


Figure 26. Unified modelling language (UML) diagram of the process price driven demand response

5.3 POSSIBLE BUSINESS MODELS FOR SECTOR INTEGRATION

Smart sector integration within the current context of accelerating the energy transition dynamics shall put all stakeholders of all sectors to be potentially coupled at the centre of a complex system of systems. Digital platforms will be key to manage this increasing complexity driving a sustainable energy transition, within evolving regulatory frameworks. These neutral platforms shall enable all participants to full data access, sharing and interoperability. National regulatory bodies shall define the rules for platform access and management (terms as proposed during the latest edition of the Florence Forum held in December 2020).

This "platformisation" business solution approach shall have many positive outcomes:

- Scale and efficiency are gained through re-use and ‘plug & play’ models which, in turn, reduce marginal costs.
- Customers are consumers and ‘prosumers’ at the same time; they buy innovative and sustainable energy solutions and services and they get access to shared value pools. Prosumers should be able to interact directly with these platforms through intermediary aggregator multi-sided platforms within the platforms concept approach.
- Innovation is boosted, thanks to an open, fast and inclusive approach, allowing multiple stakeholders to participate in the innovation process.

Digital platforms shall replace the traditional siloed sectoral approach, shaping a multi-layered digital architecture connecting data and solutions. This new platform-based market structure shall enable:

- The adoption of a platform operating model, flexible and modular by definition, which is “reuse” based, reducing marginal costs.

- The implementation of a platform business model, built as a service, such as demand response for large customers or the electrification of public transport for cities.
- Strict compliance with and increasing amount of regulation regarding all platform interactions.
- To address need to provide platform APIs to prosumer at the grid edge to facilitate participation of Distributed Energy Resources (DER) including the residential market.

Typically, industrial and commercial initiatives of sector coupling are private-based, where private investors set up a business case identifying their customer base, the products/services rendered to them, and the forecasted prices under a still changing regulatory environment. Public intervention is necessary in infrastructure planning (grids, generation, consumers plants), with a twofold perspective: in defining a scenario, bringing in due consideration to the large-scale sector integration initiatives, impacting grid planning objectives; for flexibility services, grid operators. These grid operators, that are public actors, are also the buyers of such services, so they shall develop the relevant technical requirements and carry out the purchase process, under the overarching set of despatching rules (network codes and ancillary service market rules). Moreover, at least for an initial transitory period, public incentives for sector integration projects shall be necessary, under different possible options (not only in monetary form), also for the deployment of demo & pilot projects.

6. ENABLERS AND FACILITATORS

6.1 EVOLVING MARKETS AND PLATFORMS

The upcoming new interfaces within sectors enabled by digital solutions will be facilitated by platforms through enhanced connectivity and within the context of the evolving markets.

6.1.1 EXAMPLE OF PLATFORM: EQUIGY USE CASE

The newly introduced EQUIGY platform constitutes the link between existing ancillary services markets and aggregators of distributed flexibility. It is in the form of Crowd Balancing Platform and is the tool to target the standardisation of processes and protocols to massively enable distributed flexibility resources, promoting pan-European cooperation between different stakeholders of the electricity value chain and leveraging the Block chain technology. The platform constitutes the link between existing ancillary services markets and aggregators of distributed flexibility.

The block chain technology facilitates the bidding, activation and settlement processes associated with the flexibility transactions of Virtual Power Plants guaranteeing quality, security and minimum transaction costs.

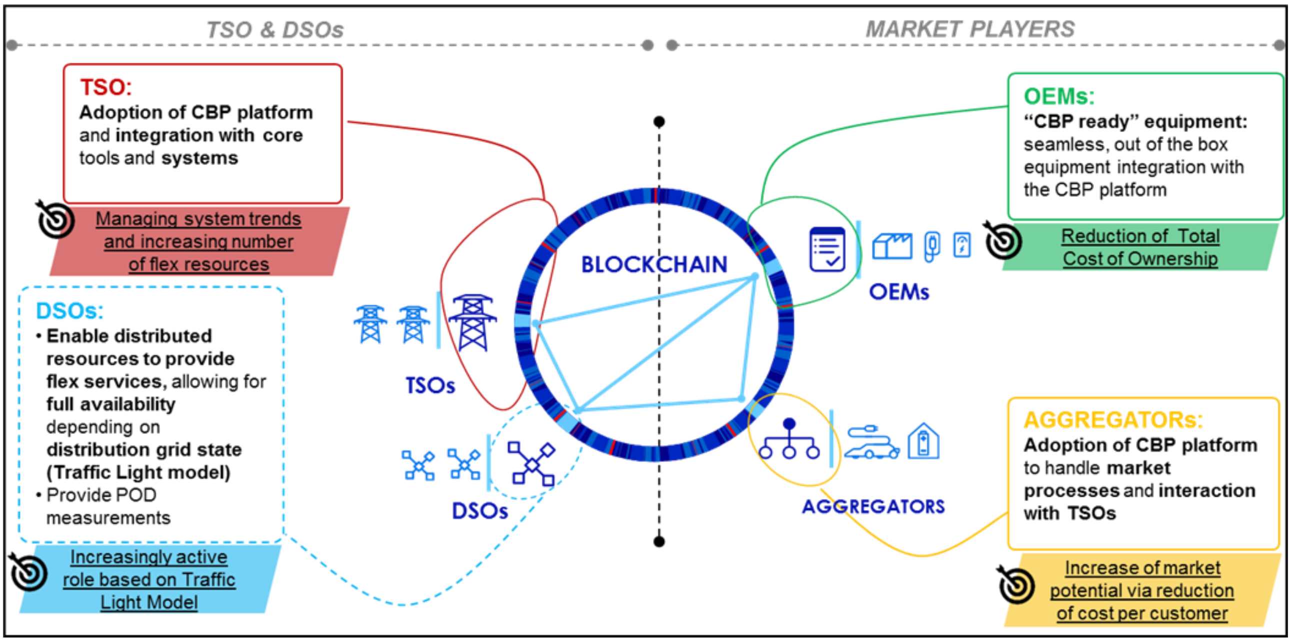


Figure 27. The blockchain technology facilitates platform transactions

6.2 DATA SHARING IN COMPLIANCE WITH GDPR

The exponential evolution of technology is transforming and influencing every aspect of our everyday life. The "Digital Transformation", is becoming an important goal for all organisations. Among the multiple challenges related to the digitalisation effort there is the issue of data protection and data security. For this reason, the European Commission updated the so-called General Data Protection Regulation[2] (GDPR), which became

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[2] GDPR Portal: https://www.eugdpr.org

applicable on May 25th, 2018, with the main purpose of protecting the individual subject concerning the treatment of personal data and its free circulation.

The GDPR has the objective to help Europe embracing the digital era, being an essential element of the Digital Single Market and of the European Union Agenda for Security. The main goal is to equalise the level of data protection in all European Union (EU) and eliminate the existing fragmentation in the EU. It harmonises the processing of personal data from data subjects residing in the Union, regardless of the location where the processing company is located, which is appreciable for the development of new data analytic solutions.

On the other side, the conditions for consent have been strengthened and the notification requirements on data breach have been increased. The new GDPR strengthens the right for data subjects to obtain from the data controller confirmation as to whether or not personal data concerning them is being processed, where and for what purpose. Further, the controller shall provide a copy of the personal data, free of charge, in an electronic format and also the right to be forgotten entitles the data subject to have the data controller erase their personal data, cease further dissemination of the data, and potentially have third parties halt processing of the data. GDPR introduces also data portability – the right for a data subject to receive the personal data concerning them, which they have previously provided in a “commonly used and machine-readable format” and have the right to transmit that data to another controller.

With the GDPR, companies will have to review their processes. Should a breach occur, the high penalties will reinforce the need to implement privacy by design and obligate companies to analyse deeply their methodology.

When addressing topics of digitalisation for smart sector integration, the role of data governance, availability and the related enabling infrastructures cannot be underestimated. “The European data strategy aims to make the EU a leader in a data-driven society”. Operations within the smart sector integration are enabled by data driven operations. European rules, in particular privacy and data protection, as well as competition law, are fully respected the rules for access and use of data are fair, practical and clear[3].

Reflecting on the Data Strategy and the White Paper on Artificial Intelligence (European Commission, 2020) which constitutes the first pillars of the new digital strategy of the Commission, the vertical context of smart sector integration requires special focus and analysis of data sharing architectures and the enabling platforms. The guiding principles within the “European Commission strategic pathway to leverage data in the best possible way for the sake of the European citizens and the Digital Single Market” will need to be integrated into the digital platforms and data spaces for smart sector integrations across the evolving services and marketplaces within verticals and across.

6.3 IMPACT OF CONNECTIVITY 5G

New Communication Technologies: considering lifetimes of 20-40 years new emerging technologies such as 5G, 6G and even 7G do not require a far stretching imagination considering evolving impacts on connectivity. Modular developments of exchanging or updating components parts in critical infrastructure environments or shared investments need to be considered, to benefit from these developments. The introduction of 5G, using an increased spectrum of 30-300 GHz has more bandwidth capabilities but cannot get around obstacles easily. This will need smart cells or femto cells, coordinating their smaller coverage through offering many more businesses an opportunity to share the infrastructure at the cost of not yet known cybersecurity impact. Allowing a sharing of infrastructure investment can be seen as a possible trigger for a speeding up of the digitalisation process in sector coupling participants.

Further challenges of sector integration in the field of cybersecurity include:

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[3] Gaia-X – A Federated Data infrastructure for Europe: https://www.data-infrastructure.eu/GAIAX/Navigation/EN/Home/home.html

- **There is a lack of a unified regulation** and certification framework at European level. Utilities often do not have the expertise to know what to require to be safe, and manufacturers do not see the market demand for high-effort developments. A sector specific "cybersecurity certification profile" can be developed by ENISA on demand of the European Commission. Such a profile would likely be based on international standards already adopted by the sector (e.g., IEC 62443 process and system level, IEC 62351 OT and equipment level, IEC 27001, -2, -19 on an organisational level).
- **Product life cycle** and online patching should be reconsidered. Most electrical devices (IEDs) are supported by Windows and/or Linux operating systems which should be updated and patched more frequently. Connected devices with a live cycle of 20 – 40 years are not secure from day 1.
- **How to secure legacy systems**. The sector coupled power grid is composed of millions of components based on obsolete hardware and software which does not incorporate any security measure. Securing these components is extremely expensive because of their numbers. The topics below are critical for consideration and evaluation.
- **Disaster response**. Greater coordination with other stakeholders and with other cybersecurity organisations (specific Computer Emergency Response Team - CERT for the sector).
- **Secure integration of smart devices and IoT**.
- **Stakeholder and user awareness**. As in many other sectors, infrastructure is only a part of the whole system. People continue to be one of the main sources of vulnerabilities.
- **Improving monitoring, detection & reaction capabilities** when coupling sectors – as specific sectorial threats may be able to propagate cross-sector if they are to be coupled
- **Building a global SOC gathering** technical information for all concerned sectors, in nominal and crisis situations.
- **Evaluate the opportunity of a "global" CSIRT** & pay attention to the complexification of interactions between CSIRTs (governmental/ private, national/wider)

6.4 CYBERSECURITY CONSIDERATIONS

The EU Security Union Strategy (European Commission, 2020c) introduce a proposal for strengthening the resilience and cybersecurity of critical energy infrastructure. The importance of this became apparent during the pandemic. The Commission announced in the recent report on the State of the Energy Union has also started work on a network code to ensure the cybersecurity of cross-border electricity flows (2020c).

Cybersecurity is a crosscutting issue in the SGAM for smart grids and will also be crosscutting every layer, domain and zone in an architecture model for sector coupling or sector integration.

Today, the cyber security level of equipment in use across the energy sectors is low. Intelligent Electronic Devices (IEDs) establish and reliably maintain connections across the most critical infrastructures across sectors: trains, public transport, electricity, water, gas, tunnels, and much more. But connecting is only half the battle. Most of the equipment today does not incorporate security measures that are required for connected electronic devices performing critical functions. Devices are created with software, are highly complex and never error-free. We must aim to create and maintain a home for every device, and every device needs to check for updates at that location now and in the future.

Recommendations and guidelines so far are very general, not binding, often waiting for legal implementation on national levels resulting in tough competition against global vendors. If there is no levelling priority, raising cybersecurity as a feature could be set to a minimum standard. For missed opportunities in commissioned systems now in 2020, a rollover is only expected 2040-2060. One of the most effective cybersecurity measures for organisations is the reputation of being ISO 27001 certified and the mandated risk management tool. The acquisition of these is often the first time the organisation is evaluated for cybersecurity. This has been adopted by some system operators and respective ICT component vendors and can serve as role models for sector coupling in general.

Evaluating interdependencies in heterogeneous environments, between multiple parties of critical infrastructure do have the cost of lives at stake in any stage. Taking necessary precautions of real-world testing requires teams of interdisciplinary experts working together during planning, implementation, and evaluation of every cascade. In fact, the process of defining in-depth measures in place that are tailored to every site cannot be automated and requires resources. Designing and building communication and control networks with cybersecurity in mind is not something former control-network-only personnel can individually accomplish.

The Directive on security of network and information systems (the NIS Directive), triggered nationwide CERTs for different sectors to actively pursue information and data sharing on cybersecurity issues. It offered bug bounties, fame for responsible disclosure, R&D/R&I projects for discovering flaws in critical infrastructure, creating a fund for most used open-source software to further their development, open protocol standards for interoperable components are further ideas to aid cybersecurity as collaborative topic and support working together with the professional cybersecurity community (academia, vendors, and operators alike).

Current developments on the power networks, such as digital communication between supplier and consumer, intelligent metering, and monitoring systems, will allow energy systems to improve the control over power consumption and distribution substantially to the benefit of consumers, suppliers, and grid operators. Moreover, not only advanced Information and Communication Technologies (ICT) are at the core of an effective, smart, and resilient sector coupled power grid. Also, Industrial Control Systems (ICS) and related Operational Technology (OT) need to be taken into account. All processes across the whole value chain are heavily based on these infrastructures and technologies. A smart sector coupling gives clear advantages and benefits to the whole society, but a dependency on ICT components (e.g., computer networks, IEDs), ICS (e.g. supervisory control and data acquisition systems, distributed control system), OT (e.g., firmware, operating systems) and the internet makes our society more vulnerable to malicious attacks with potentially devastating results on all interconnected sectors. This exploitation can happen in particular because vulnerabilities in telemetry, communication networks and information systems may be misused for financial or political motivation to hold large areas for ransom or directing cyber-attacks against power plants. The SGAM linked SGIS framework, for example, is an early mitigation tool to identify and visualise these risks pre-emptively.

6.4.1 OPERATIONAL TECHNOLOGY CYBERSECURITY VS. INFORMATION TECHNOLOGY CYBERSECURITY

The world of traditional Information Technology (IT) has morphed greatly over the years into non-traditional areas, such as supporting electricity management and control systems. This evolution has given rise to the need of cybersecurity within Operational Technology (OT). The OT role focuses on the process controls required to manage the operations side of the business. The differences between OT and IT can be confusing for those on either side when it comes to the specific roles each competency plays, but both types of security are necessary to ensure the protection of our critical infrastructure. The main principles behind a cyber-secure system can be defined using the CIA triad according to ISO/IEC 27001. CIA stands for Confidentiality, Integrity and Availability:

- Confidentiality: Protect data from unauthorised access or disclosure.
- Integrity: Protect the consistency of information ensuring the actual data is authentic, was sent, and that correctly.
- Availability: Ensure that the data and systems are available and that downtime is avoided or minimised.

In the IT world, the priority for these concepts is typically CIA, while in the OT world the priority is normally inverted as AIC. For example, take the case of a financial company. In the event of a cyber incident, it may be a normal practice to place their system offline to protect the confidentiality of their customers' data, whereas an electric utility would almost never consider taking their protection and control system offline. Doing so could potentially cause unsafe conditions for their personnel or leave a section of the grid in an outage condition. All security measures and maintenance practices are designed around maintaining this. Secondly, performance and reaction time are also very important. In the electrical grid, the time required to react needs to be in the range of tens of milliseconds. Lastly, OT systems use control methodologies and specialised protocols such as IEC 61850, which require specific domain expertise to both configure and secure.

6.4.2 CYBERATTACKS IN INDUSTRIAL CONTROL SYSTEMS

Industrial Control Systems (ICS) combine cyber- and physical layers (IT and OT) in order to perform a set of tasks within industrial environments. The latter can be composed of critical infrastructures as energy production and distribution (electricity, water, gas etc.). ICS are organised through a common architecture based on three hierarchical layers according to the processing capacity and decision-making power level. These layers are: the sensor/actuator layer that form the physical layer, the control layer composed of Human Machine Interfaces (HMI) and Programmable Logic Controller (PLC), and the supervision layer integrating the control room. In addition to these three layers, there are the communication networks that connect them together using analogue/discrete input/output (I/O) or proprietary protocols TCP/IP. ICS are vulnerable to cyberattacks because as previously explained (AIC vs. CIA), they are designed to solve issues of production and safety without taking into account security issues. These attacks can take different forms according to the affected layer as alteration of control flow by attacking the PLC in the supervision layer or communication removal between two layers impacting in both cases the IPS' availability, or spoofing data coming from sensors or orders sent to actuators impacting their integrity. ICS as an Operational Technology (OT) have specificities and constraints that make the use of classical security solutions used in Information Technology (IT) difficult. Indeed, ICS have strong real-time constraints, limited resources (memory), heterogeneous protocols and communication technologies, continuous production, and infrequent updates. Therefore, it is important to develop adapted solutions that take into account these aforementioned specificities and constraints in order to improve the security of ICS against cyberattacks. These solutions must generate models able to:

- Verify the consistency of each layer output (control commands, sensor outputs, SCADA/reports, etc.) according to the current functioning conditions;
- Determine online the prohibited or dangerous functioning modes (conditions) by observing the sequences (actions/sensor outputs etc.);
- Communicate using an independent and secured network in order to limit the cyberattack size;
- Operate in non-intrusive manner without the need to install new probes in the production system;
- Adapt online their inference engine to new cyberattacks (new prohibited and dangerous modes);
- Operate in decentralised decision structure in order to be consistent with the ICS distributed nature and to limit the computation complexity. These objectives can be fulfilled by combining approaches and technologies from interdisciplinary domains, ranging from analytical/physical model-based communities through Artificial Intelligence communities.

7. REGULATORY CHALLENGES AND POSSIBLE WAYS FORWARD

7.1 REGULATORY CHALLENGES

For the purpose of this paper, sector coupling is seen as a progressive integration of several energy carriers, such as electricity, gases and heat, by connecting and enhancing the EU electricity and gas markets and assets. This overall smart sector integration perspective shall help to accelerate Europe's decarbonisation path, adding synthetic and renewable gases to natural gas, and adding flexibility and interoperability to energy markets of and amongst all European countries, strengthened also by enhanced energy exchanges with neighbouring continents, such as with Africa for renewable power sources.

The role of policy in steering these expected outcomes is crucial. Policies, funding, and regulatory flexibility and responsiveness shall determine how fast and to which extent gas, electricity infrastructure and storage shall evolve towards the ever more flexible interoperability with a high degree of operational security and systemic resilience, to allow for more, and more flexible energy uses within the EU. Furthermore, continuous innovation in still less mature technologies has to be facilitated.

A more dynamic and cross-sector regulation should allow to create a level playing field not only cross border, considering that regulation is by its very nature primarily a regional or national competence, but also within each sector for the development and integration of new technologies and uses. One example is the introduction of renewable and low-carbon gases, which shall be transported in existing gas grids, requiring an adaptation of the current gas infrastructure regulation, which is focused on natural gas. Another example is the adaptation of the electricity transmission and distribution grids to an ever-higher penetration of renewable power sources, both on- and off-shore, ranging from large plants to small individual prosumer installations such as rooftop solar, while facing additional demand and flexibility requirements from e-mobility and V2G too.

Energy system operation and planning shall thus require a high degree of coordination to cope with intertwined energy carriers, transmission and distribution systems, and potentially different regulatory and technological approaches from country to country. Again, interoperability, functioning markets and dynamic regulation shall be decisive to allow Europe to reach its clear ambition of becoming a global leader in decarbonisation.

7.2 REGULATORY BARRIERS TO SECTOR COUPLING

Sector coupling faces potential barriers when the development and integration of new technologies or the level playing field amongst different sectors and technologies are being jeopardised. Both regulatory gaps and inadequacies contribute to these potential barriers and have to be identified and gradually removed to allow for Europe's smart sector integration. Regulation is set at EU and country level, by sector-specific regulatory agencies and public administration, i.e. at European, Member State, and local scale and level.

For the scope of this paper many existing studies on the regulatory frameworks of Member States as well as recommendations from stakeholders have been taken into account. Accordingly, four main categories of regulatory barriers or gaps can be identified:

- Sectorial barriers arising from regulation "per sector" rather than "cross sector"
- Infrastructural barriers from challenges to the existing energy market grids and assets
- Interoperability barriers to the expected transition and interaction of energy markets
- Innovation barriers for the development and integration of new technologies

Sectorial barriers

Each sector (power, gas, storage, transportation, heating, buildings) faces specific end-user tariffs (for its regulated business), taxes, and levies, then again with significant regional and national differentiation.

Furthermore, these expenses borne by the customer are not exclusively cost-reflective, since they include systemic costs, often arising from the past, that distort the playing field for sector coupling.

Examples of such cost distortions, not exclusively cost-reflective for operations and forward-looking infrastructure investment costs, are cost-recoveries for incentives schemes of the past, such as for supporting the development of renewable energy sources or sunk and dismantling costs from assets that are underused, or dismissed. Indeed, sunk investment costs from former nuclear power generation development and plants, as well as underused coal and/or gas-fired power plants are weighing significantly on the electricity bill of many customers in the EU as of today. The same applies to long term RES funding schemes through tariffs, causing sometimes extremely severe regulatory assets (systemic debts to be borne by the entire sector), as for Spain which reached a national total debt exposure of its power sector of 25bn€ in December 2015 (Informe CNMC 2017).

Consequently, any development of Power-to-Gas production chains shall be potentially hampered by these additional systemic costs inherited from the past, as well as the implementation of synthetic gases that require electricity for their production.

Infrastructural barriers

Sector coupling targets and relies on a least cost and interconnected infrastructure of both power and gas transmission and distribution grids, considering and incentivising the development and future injection of synthetic and renewable gases into the gas pipelines, while giving clear rules and solutions for storage, flexibility and congestion management requirements.

Consequently, grid planning should follow a holistic systemic approach, coordinated amongst all power and gas transmission and distribution operators, possibly at EU level rather than only at national level. Furthermore, adequate planning shall require valid forecasts of future demand for both power and gas, including new gases such as hydrogen or new electricity needs as those arising from e-mobility and heat sectors, also in order to create satisfactory storage, flexibility and congestion management conditions for the systemic operational feasibility and optimisation.

Currently, these predictions are difficult to make for both future demand and offer, since the development of new technologies and energy carriers itself also faces uncertainty as to access (injection technology) and blending with the existing (natural) gas transportation and storage infrastructure. Developers still face uncertainty as for the technical feasibility of new gases injection, except for biomethane, which starts to dispose of respective norms in many European countries, since quality standards were historically established for natural gas, so far. The European Gas Directive does not yet cover specific operator incentives or provisions for the use of low-carbon gases, creating uncertainty for their respective development and future commercialisation. The future injection of low-carbon gases into the existing gas grid might also create congestion issues at the distribution level not yet faced in the gas system, requiring additional infrastructural investments not yet planned or considered. Nor does the Gas Directive tackle the tariffs or third-party access rules for new gases such as hydrogen, which may jeopardise its respective development and deployment ambitions within the EU.

Interoperability barriers

Power and, even more so, gas markets and infrastructure are being developed and optimised at national level, which is not necessarily an optimal scenario at EU level. Interoperability between markets and member states may be jeopardised by the lack of grid enhancements and/or decommissioning of (sunk) assets that might result useful at Member State level but detrimental to both cross-border interoperability and the respective sunk cost tariff component impeding a level playing field, as mentioned before. Furthermore, the introduction of new energy carriers, such as, but not limited to hydrogen, shall potentially enhance the regional fragmentation of products and markets, a challenge to a European-wide interoperability and cost optimisation.

Innovation Barriers

New energy carriers such as renewable and low-carbon gases face significant infrastructural costs for the initial (first of a kind) pilots, as well as regulatory uncertainty as to tariffs and systemic costs to be borne when interacting with the existing (natural) gas markets. This uncertainty may delay or hinder the technological progress and infrastructural investment needed for their desired respective deployment.

7.3 POTENTIAL SOLUTIONS TO REGULATORY BARRIERS

Regulatory and financial support for innovation is required at all four stages of project development, from initial Research and Development (R&D) to pilots and field demonstration projects and, finally, to the phase 4 roll-out projects at larger regional scale (see figure 28 below).

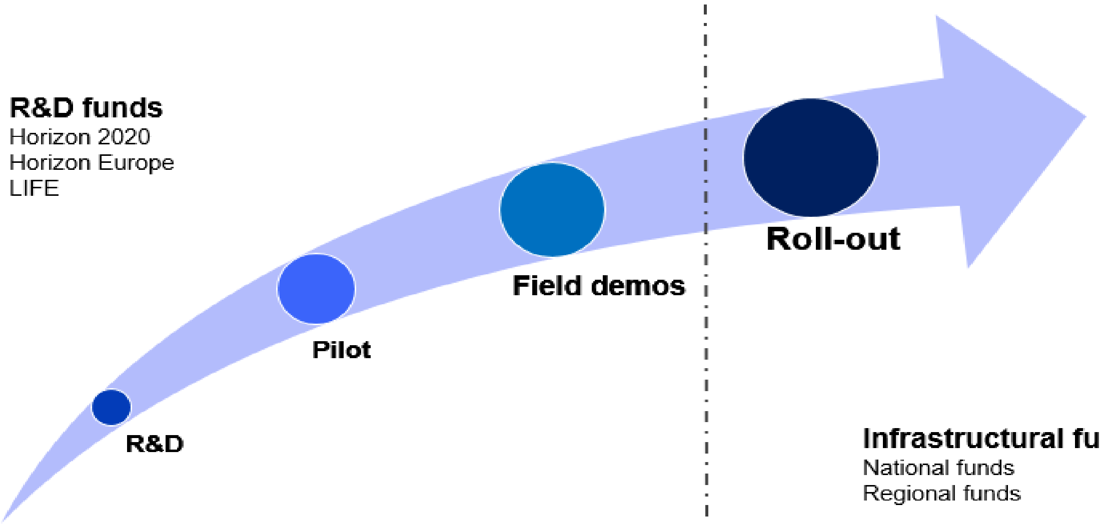


Figure 28. Project stages and funds characterisation

Continuity of state aid from one stage to the next should be ensured and possibly addressed specifically by the EU's energy market legislation in order to support the transition phase from R&D to roll-out, in particular for renewable and low-carbon gas technologies.

It could be beneficial for overcoming coordination barriers to consider network operator involvement up to (partial) ownership at the early R&D or pilot project stages, in particular for power-to-gas projects. Always subject to the unavailability of any respective market-based investment and with thorough supervision by Regulatory Authorities in order to check the overall systemic benefits of any project with (initial) market signal scarcity.

When sector coupling pilots involve several technologies with unlevelled playing fields caused by diverging specific cost recovery mechanisms for either or both policy support and infrastructural assets regulatory sandboxes should be considered in order to address cost recovery issues. This shall be the case, for example, when existing gas infrastructure is to convey renewable and low-carbon gases. Distortions arising from sunk infrastructural assets costs are more difficult to address. It could be envisaged to either partially redirect these costs from users to taxpayers, or by balancing them out between different sectors (power, gas, heat).

New services and processes, such as flexibility services for grid stability, sector coupling or energy storage, require speeding up the reconfiguration of the energy system through real-world applications. Experimental space to trial processes, services and business innovations in a real-world environment is conceded through regulatory sandboxes, which help analyse the impact of regulatory changes. Such regulatory sandboxes are considered by regulatory bodies to test solutions not necessary or thought of previously when facing new challenges arising not only from sector coupling, but also within an energy carrier sector, such as, for example, for the development of flexibility services for power grid stability, the energy storage integration, or the management of final customer clusters grouped as local energy communities. These sandboxes are already being implemented in the power sector, for example, to address innovative solutions for new energy services (e.g., peer to peer exchange of energy and flexibility services), platform solutions (e.g., TSO/DSO, distributed ledger technologies with block chains), new tariff models (e.g., grid tariffs reshaped for innovation purpose) or new business models (e.g., local energy community).

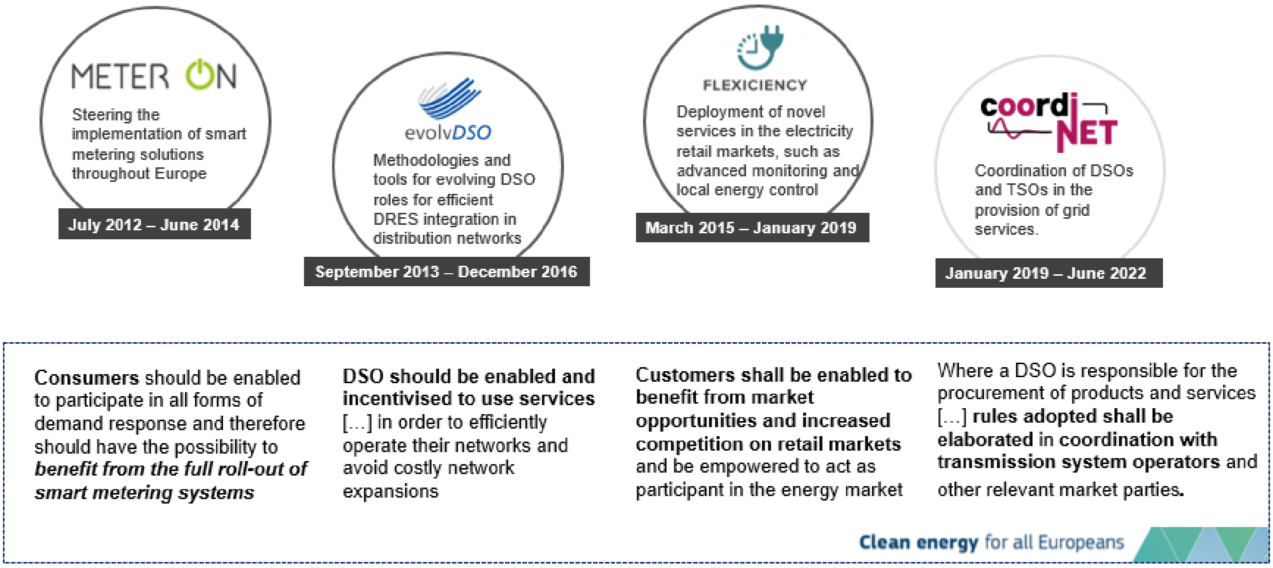
In 2019, as many as 13 countries already have regulatory sandbox programs on smart grids on-going or about to start (ISGAN), amongst which Germany, Italy, the Netherlands and the United Kingdom, with sufficient regulatory autonomy to experiment in place.

Regulatory sandboxes could also be envisaged for the natural gas market design also, in order to address the future injection of renewable and low-carbon gases.

Asset planning and decommissioning should also be coordinated cross-sector (between transmission and distribution level, and between electricity and gas networks) and cross-border (circumscribing the decommissioning of assets beneficial to neighbouring Member States) in order to foster interoperability across markets and borders and to reach a common vision as to how to satisfy future demand supply balances.

Storage needs have to be assessed and addressed, both for the power and gas sectors, since flexibility shall condition grid stability and investments (power), as well as the feasibility of the injection of renewable gases and low-carbon gases into the natural gas market.

Several funded European projects successfully address the need to follow project stages gradually (see Figure 29 below on Horizon2020 projects regarding DSOs), as well as barrier removal and full value chain perspective when addressing new projects (such as ETIP SNET's "big idea" Digital Twin concept for Electricity Distribution grids in Europe – see Figure 30).



Steering the implementation of smart metering solutions throughout Europe

July 2012 – June 2014

Methodologies and tools for evolving DSO roles for efficient DRES integration in distribution networks

September 2013 – December 2016

Deployment of novel services in the electricity retail markets, such as advanced monitoring and local energy control

March 2015 – January 2019

Coordination of DSOs and TSOs in the provision of grid services.

January 2019 – June 2022

Consumers should be enabled to participate in all forms of demand response and therefore should have the possibility to ***benefit from the full roll-out of smart metering systems***

DSO should be enabled and incentivised to use services [...] in order to efficiently operate their networks and avoid costly network expansions

Customers shall be enabled to benefit from market opportunities and increased competition on retail markets and be empowered to act as participant in the energy market

Where a DSO is responsible for the procurement of products and services [...] **rules adopted shall be elaborated in coordination with transmission system operators** and other relevant market parties.

Figure 29. Value of H2020 funded projects experience

- The main purpose of the program is to create the conditions for a digitalisation of the full value chain in energy.
- Main driver of the process is to create the right conditions for a customer-centric grid
- On the practical side this means that traditional barriers are removed: operation vs market, operation vs planning
- The concept of digital twin is a key element behind this vision and one of the main technology enablers. The concept was inspired by the Enel Network Digital Twin ® initiative.

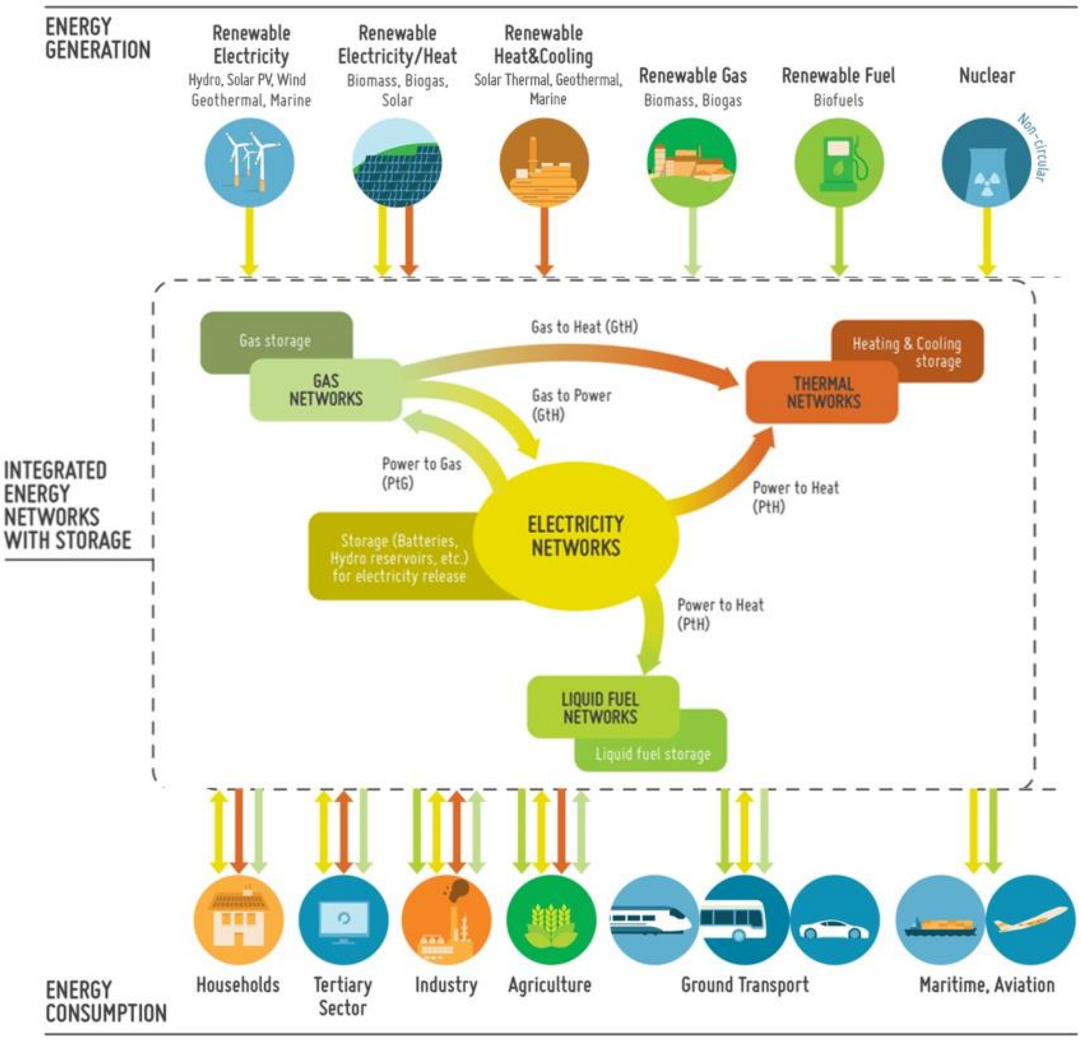


Figure 30. ETIP SNET "Big idea": digital twin of the European Energy Ecosystem towards Vision 2050

7.4 POLICY RECOMMENDATIONS

The urgency of Europe's Clean Energy Transition requires speeding up the innovation processes and the regulatory flexibility of the energy sector itself both cross-sector and cross-border. The regulatory framework must become more dynamic, conceding regulatory flexibility for testing new solutions and approaches, such as the regulatory sandboxes mentioned above. Indeed, large scale regulatory sandboxes with flexible time frames of up to several years should be envisaged, with consequent review of their outcomes by all stakeholders concerned, in order to create level playing fields and fair interoperability solutions.

Also, clear price signals should be given, since they trigger the reaction of producers and consumers according to their own interest and for the energy system overall. Limitations from tariffs, incentives or taxation that privilege any single energy carrier or member state above others should be avoided, in order to allow energy conversions across carriers and countries. Different conversion and storage facilities should face equivalent cost categories in terms of tariffs and taxes, as well as equivalent compensation for environmental and quality of supply performance.

This could be more easily achieved by establishing such a new dynamic regulation of the energy sector at EU level, possibly coordinating interventions at national or regional level amongst the respective National Regulatory Agencies and the European Association of Regulators (CEER/ACER). This could be facilitated through EU sandbox pilots that cover more than one sector and more than one country.

Decarbonised and renewable gases, as well as new gases or respective technologies, should be allowed to integrate the existing gas markets, facilitated by a clear European legislative framework, covering all aspects from gas categories, blending, storage and carbon capture to hydrogen networks, possibly with third party access. The gas sector should benefit from equal network code governance improvements as delivered to the electricity sector with the Clean Energy Package.

Last but not least, and as a key provider of flexibility, energy storage has to be enabled and adequately valued. Again, this requires clear price signals to guide the investment decisions of private actors and aggregators, since competitive and monopoly activities need to be clearly differentiated. Even sector coupling can be seen as a storage solution, since it can potentially help to meet seasonal flexibility needs. Policy makers should provide an enabling environment and level playing field by harmonising tariff practices across Member States, eliminating double imposition of grid tariffs on both storage charge and discharge. Another barrier is constituted by net metering which should, ideally, be abolished altogether.

Consequently, Europe's smart sector integration shall rely on the following main recommendations:

- Foster cross-sector and cross-countries level playing fields, removing unnecessary or double taxation on electricity, incentivising Power-to-X solutions (e.g. Gas, district heating, hydrogen generated from RES, and new flexibility solutions such as demand-side response including V2G). Decarbonisation and carbon-free electrification are to become the pillars of the European Smart Sector Integration Strategy.
- Provide cross sectorial decarbonisation incentives while striving to achieve real-time auditing of carbon footprints from primary energy down to end use.
- Encourage development of interoperable interfaces of relevant sectorial market platforms to ensure implicit interactions across clearing platforms.
- Encourage stakeholder cooperation for platformisation (TSO-DSO-aggregator cooperation on flexibility and storage) and a revamped EU Emission Trading Scheme, possibly extended to sectors such as fossil fuelled heating and transportation, which would set the right signals and back Europe's sector coupling and decarbonisation ambitions.
- Boost the imminent electricity and gas sector coupling for new products, but not limited to, such as electrolytic hydrogen and renewable gases to become market-based solutions on a revised, functional and transparent European gas market.

8. IMPACT CRITERIA AND ECONOMIC ASSESSMENT

8.1 ECONOMIC EVALUATION THROUGH CBA

A preliminary proposal of a benchmark economic assessment is described, i.e. a Cost Benefit Analysis (CBA), which needs to be specifically tailored to sector coupling projects as well as an outline of a use case, complemented by real examples.

There is currently no unique way to approach a CBA for a sector coupling project: given the positioning of these projects at the intersection of different value chains, where different methodologies might apply thus defining a standard is not straightforward. In particular, assessing the economic or welfare benefits deriving from a specific project might present difficulties given by:

- The blending of regulated activities (due to the role of transmission and transport networks operating as natural monopolies) and non-regulated businesses open to competition;
- The objective complexity in insulating economic and welfare effects generated by the innovation;
- The low level of comparability, given the potential issues in replicating the same conditions in different contexts.

To outline a simplified approach in this contribution, we rely on the best practice methodology of the EU Guide to Cost-Benefit Analysis of Investment Projects (EC, 2014), paired with the insights provided by the ENTSO-E (ENTSO-E, 2018) and corroborated by the comments by ACER (ACER-CEER, 2019).

The EU Guide suggests addressing in the CBA five key objectives by 2020, specifically mentioning Employment, Innovation and Climate Change. For the latter, Table 5 below reports the recommendations in terms of measures to be added.

Climate change	The responses to climate change are assessed by estimating costs and benefits of integrating: • Climate change mitigation measures, by measuring the economic value of greenhouse gas (GHG) emissions emitted in the atmosphere and the opportunity cost of the energy supply savings; • Climate change adaptation measures, resulting from the assessment of the project's risk exposure and vulnerability to climate change impacts.

Table 5. CBA key objectives in term of Climate change

General concepts to be included in a CBA usually comprise:

- Opportunity Cost, defined as the potential gain from the best alternative investment, when a choice needs to be taken between different mutually exclusive alternatives. The opportunity costs factors in externalities and social benefits alike. In particular, in sector coupling the projects could be competing with each other, either when they serve the same purpose or provide comparable net benefits. A competing project exists when i) it is in the same stage of development and/or ii) would not be carried out in case the project under evaluation would be realised.
- Long-term perspective, ranging from a minimum of 10 to a maximum of 30 years or more, depending on the sector of intervention. Sector coupling envisages the association and/or hybridisation of technologies with different time spans and it is therefore pivotal to define a consistent duration.
- Use of economic performance indicators expressed in monetary terms, by assigning a monetary value to all the positive (benefits) and negative (costs) welfare effects of the investment. These values are discounted and then added in order to calculate a net total benefit. The project overall performance is measured by indicators expressed in monetary values, see below.

- Scenario modelling, i.e. the comparison of a scenario with-the-project to a counterfactual benchmark scenario without-the-project. Generally, the benchmark scenarios include a Business-as-Usual scenario (basic functionality of assets) and a Do-Minimum (including some adaptation investments). The ENTSO-E Guidelines, given the focus on the modernisation and expansion of the power grid, suggest the opportunity to differentiate between a “Take Out One at the Time” (TOOT) and a “Put IN one at the Time” (PINT) approach. In the former, the reference scenario reflects a future target grid situation in which all interventions are made, and projects under evaluation are removed from the forecasted network structure, one at the time, to evaluate changes of load or other indicators. In the latter, the reference scenario is the current state of the grid, and projects under evaluation are added to the scenario, one at the time. A similar approach might also be considered in sector coupling projects involving the electricity and/or gas networks, though the definition of the benchmark scenario might result more complex, due to the greater variety of technology options at disposal.

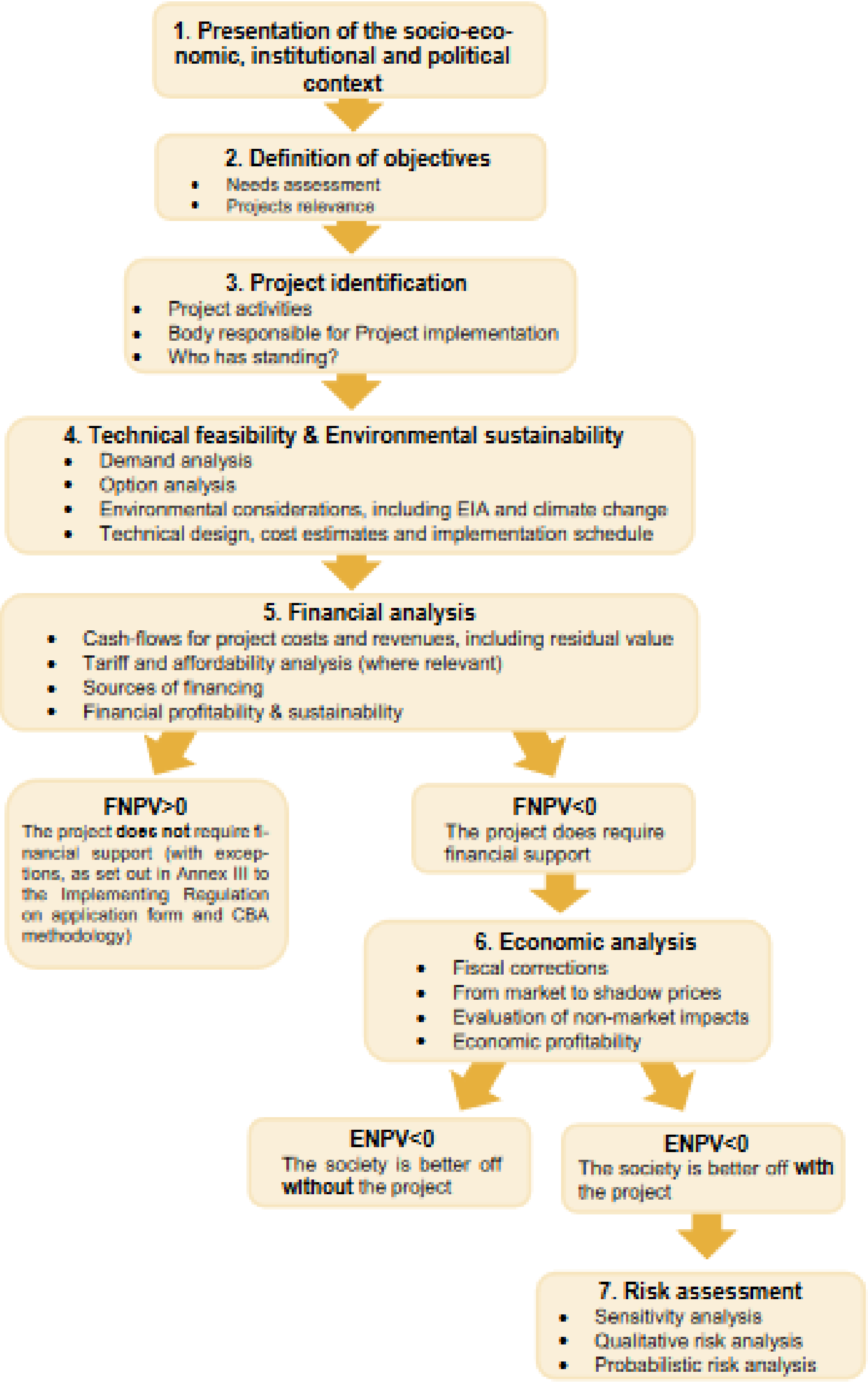


Figure 31. EU Guide to Cost-Benefit Analysis of Investment Projects

Financial analysis is carried out by identifying all the costs related to the investment, including capital and operating costs (fixed and variable). According to the EU Guide, revenues from energy projects are generally divided into three categories (EC, 2014):

- Energy or fuel sales: a tariff or a unit price, paid by consumers of the energy supplied by the project, usually consisting in a combination between a fixed and a variable component. Also, the tariff could include an incentive component (e.g. feed-in tariff), usually targeting the rewarding of renewable energy projects;
- Transport or other service sales: a tariff or a price, paid by users of the project infrastructure for the transport of electric energy through a grid, or heat and gas through a pipeline network. Similarly, a price can be paid for other types of network and ancillary services;
- Sale of energy allowances: if ETS allowances or similar certificates compensating for the reduced production of GHG emissions are sold on the national or European market, the resulting revenues must be included among the project inflows.

Cash inflows and outflows must be included in the analysis, and the Discounted Cash Flow (DCF) is the preferred methodology to assess financial feasibility. The ENTSO-E Guidelines recommend the selection of an appropriate discount rate, which must be unique even in cross border projects and consistent with the assessed cash flows (real or nominal). The EU Guide suggests the use of real prices and cash flows only, to avoid the incorporation of forecasted inflation or CPI in the calculation. Moreover, in sector coupling projects, it is relevant to highlight how discount rates might vary between regulated and non-regulated competitive sectors, and it is therefore necessary to select or derive a unique rate.

The economic lifetime must be consistent with the underlying technologies (including full depreciation and substitution of assets) and ENTSO-E recommends to consider a zero-residual value at the end of the project period, to avoid inconsistencies. The ENTSO-E Guidelines recommend studying at least two-time horizons, one mid-term and one-long term (ENTSO-E, 2018).

Project performance indicators, such as financial and economic net present value (NPV), internal rate of return (IRR), benefit/cost (B/C) ratio or payback time are then calculated, providing insight over the financial viability.

To carry out the economic analysis, market prices are converted into economic or shadow prices, to better reflect the social opportunity benefits and costs of the investment. This is done by removing transfer payments such as taxes and subsidies, by quantifying positive and negative externalities not already included in the financial analysis and, when possible, monetising them.

Economic benefit	Type of effect	Examples of typical projects
Increase and diversification of energy supply to meet increasing demand	Direct	Construction of a new energy production plant Increase of production capacity of an energy facility Construction/expansion of energy storage facilities Construction of an interconnector or LNG regasification facilities to expand the volume of imported energy
Increase of security and reliability of the energy supply	Direct	Construction of a new energy production plant Construction/modernisation of energy supply systems within the country Integration of electricity and natural gas networks into EU electricity and gas supply systems Construction/expansion of energy storage facilities Development of a smart distribution system (smart grids)

		Integration of renewable energy sources in the power network
Reduction of energy costs for substitution of the energy source	Direct	Construction of a new energy production plant displacing existing ones Construction/modernisation of energy supply systems within the country Development of a smart distribution system (smart grids)
Market integration	Direct	Construction/expansion of storage facilities Development of new cross-border transmission lines
Improved energy efficiency	Direct	Modernisation of energy facilities to improve production efficiency Modernisation of an energy distribution system to reduce losses
Variation of GHG Emissions	Externality	All types of energy projects
Variation of air pollutant emissions	Externality	All types of energy projects

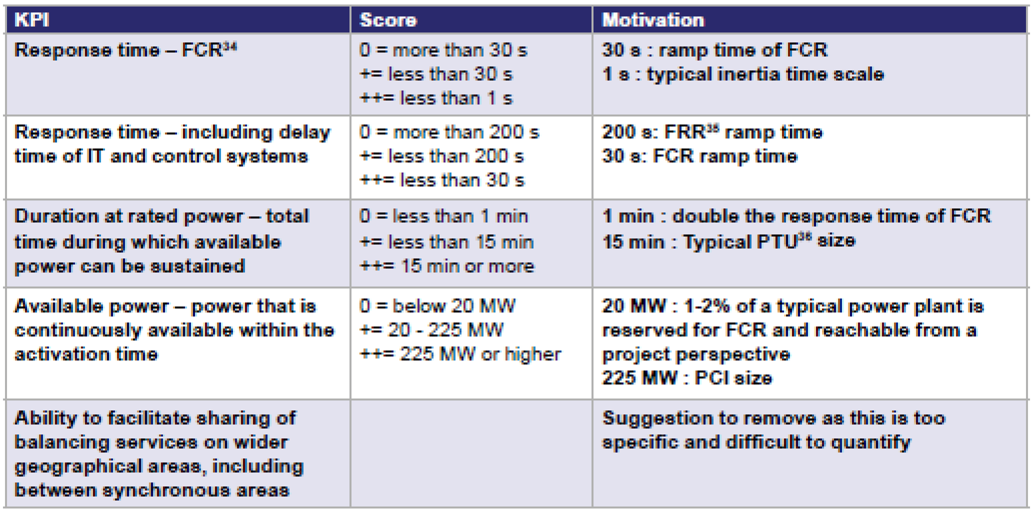
Table 6. EU Guide to Cost-Benefit Analysis of Investment Projects

In particular, the Increase of Security of Supply may be divided into two subcategories: System Adequacy, i.e. the capacity of the system to meet demand at any moment in time, and System Stability, i.e. the capacity to quickly adapt to fast and deep changes in demand, with high RES injection and frequent ramp-up and ramp-down requirements. Both parameters pertain to sector coupling and are quantifiable in non-monetary terms.

The ENTSO-E Guidelines propose additional benefit categories that are also relevant to a sector coupling project:

- Societal Well Being as a result of RES Integration and Change in CO2 emissions, i.e. the residual, not directly monetised, effects of RES integration and decrease in GHG emissions, such as the impacts on global warming mitigation. The indicator is in free format.
- RES Integration, to be separately considered into two parameters, the Connection of RES to the main power system, i.e. the share and quality of RES connected to the system, and the Avoided RES spillage, both quantifiable in monetary terms.

Storage projects follow the same approach and categories of other energy projects, but the ENTSO-E Guidelines propose to add a qualitative, non-monetary assessment to measure the benefits in terms of system flexibility, based on the technology features and response time (ENTSO-E, 2018), summarised in Table 7 below.



KPI	Score	Motivation
Response time – FCR[34]	0 = more than 30 s += less than 30 s ++= less than 1 s	30 s : ramp time of FCR 1 s : typical inertia time scale
Response time – including delay time of IT and control systems	0 = more than 200 s += less than 200 s ++= less than 30 s	200 s: FRR[35] ramp time 30 s: FCR ramp time
Duration at rated power – total time during which available power can be sustained	0 = less than 1 min += less than 15 min ++= 15 min or more	1 min : double the response time of FCR 15 min : Typical PTU[36] size
Available power – power that is continuously available within the activation time	0 = below 20 MW += 20 - 225 MW ++= 225 MW or higher	20 MW : 1-2% of a typical power plant is reserved for FCR and reachable from a project perspective 225 MW : PCI size
Ability to facilitate sharing of balancing services on wider geographical areas, including between synchronous areas		Suggestion to remove as this is too specific and difficult to quantify

Table 7. ENTSO-E CBA guidelines

The economic analysis allows for the calculation of indicators such as the Economic Net Present Value (ENPV) and the Economic Rate of Return (ERR).

It is also recommended to perform a sensitivity analysis to assess the main risks and uncertainties, in vase modelled parameters might vary within a specific range. ENTSO-E suggests the following:

- Fuel and CO2 prices;
- Discount rate;
- Commissioning date;
- Climate Year, i.e. the use of climate data related to different years (also my relying in interpolation techniques) to include the variability of RES infeed;
- Load, which is steered by two drivers: energy efficiency, decreasing system load, and electrification;
- Technology phase-out, within the project lifespan, a technology might be phased out and lead to a transition within the energy system.

For sector coupling projects, a suitable sensitivity might be on energy conversion indicators across the different technologies, to factor in improvements or degradation.

8.2 ECONOMIC ASSESSMENT CRITERIA AND METHODOLOGIES FOR USE CASES

According to the definition presented in ETIP SNET's "White Paper: Sector Coupling: Concepts, State-of-the-art and Perspectives", sector coupling consists of an energy conversion process towards an adjacent industrial sector, where the converted energy (net of conversion losses) can follow different paths:

- be stored more easily outside than inside the electric system, for time-shifted, successive re-conversion to electricity: shift in time and in some cases also in space;
- be consumed in another sector, if cheaper/cleaner than other energy sources typical of that sector, either temporarily (operational optimisation) or permanently (electrification);

- be transported (in form of heat or gas/liquid), in some cases where transport performances can be higher than for transmitting and distributing electricity, or faster to realise considering societal constraints (building authorisations, environmental permits, public acceptance);
- be re-converted for final use, incurring multiple energy losses (conversion + reconversion + transport + storage losses).

The schematic presented in Figure 31 outlines a systematic representation of possible rationale and goals underpinning sector integration projects.

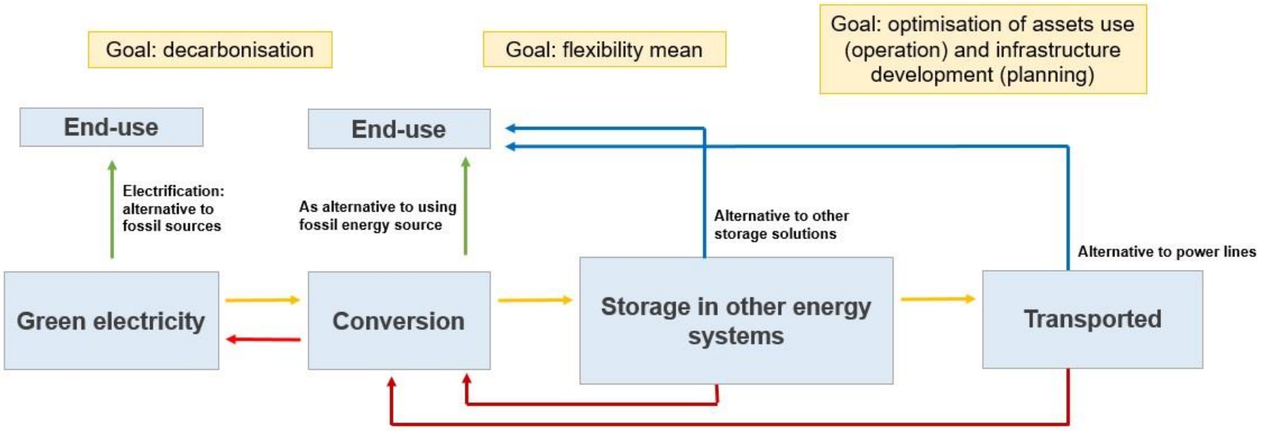


Figure 32.Possible rationale and components of Sector Integration projects.

Any combinations of the above options are also possible, which add further complexity to the assessment, as the potential energy path might be neither immediately evident nor mutually exclusive. Therefore, assessing sector coupling projects is a complex multi-variables optimisation problem, with the objective of achieving the minimisation of costs and constraints represented by current or state-of-the-art technology, and whose goal is to deliver a decarbonisation impact and/or a more efficient use of energy assets.

Any proposed project/initiative must be assessed for costs and performances versus the best alternative available to reach the same results. In addition to the CBA analysis framework described in paragraph 8.1, a Template for a Use Case Analysis is proposed below.

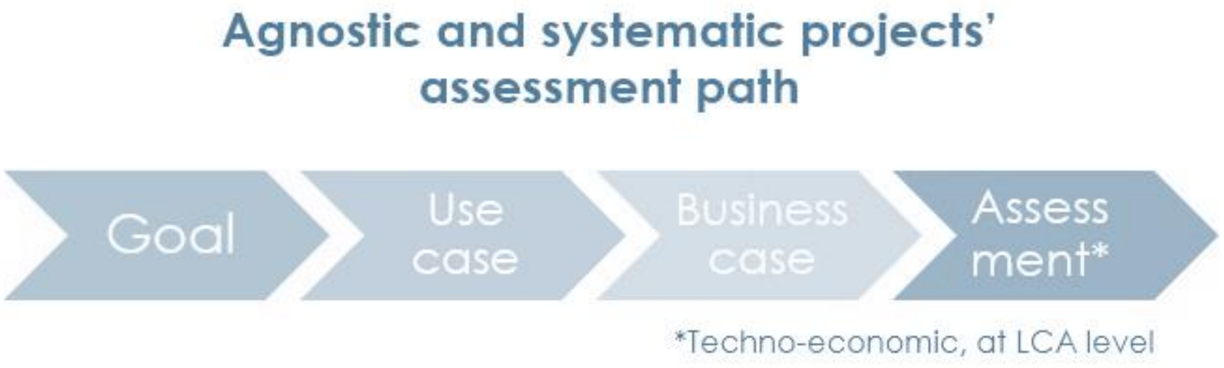


Figure 33. Agnostic and systematic project's assessment path

An "agnostic", technologically unbiased way to assess projects across their full life cycle can ideally follow the pattern represented in the following section see Figure 32.

The first step is to clearly define the Goal the project is pursuing. Potential, not mutually exclusive, reasons to undertake a new sector coupling project and/ or technology might be the following:

- Reduce emissions, in terms of GHGs or pollutants;
- Improve efficiency or performance across different energy vectors;
- Improve reliability, back-up solutions or safety of the system;
- Deliver new services or attend new customers.

At this stage, it is therefore relevant to define clear metrics, mostly quantitative, and a suitable time frame and/or lifecycle to assess the impact of the project. The definition of a set of Key Performance Indicators (KPIs) might be useful. Qualitative goals are also applied, when there is evidence that future benefits are not immediately measurable in quantitative terms.

A suggested approach is to include at least one benchmark or reference model scenario (e.g. Business-as-Usual, Without-Project, Do-Something).

As more information is built in, the Use Cases include a more detailed and descriptive definition of the goals, the adopted technology and the markets impacted by the project (see 7.3 and Template for a Use Case Analysis). Use Cases also comprise external elements such as technology boundaries and regulatory conditions, often requiring a more descriptive approach.

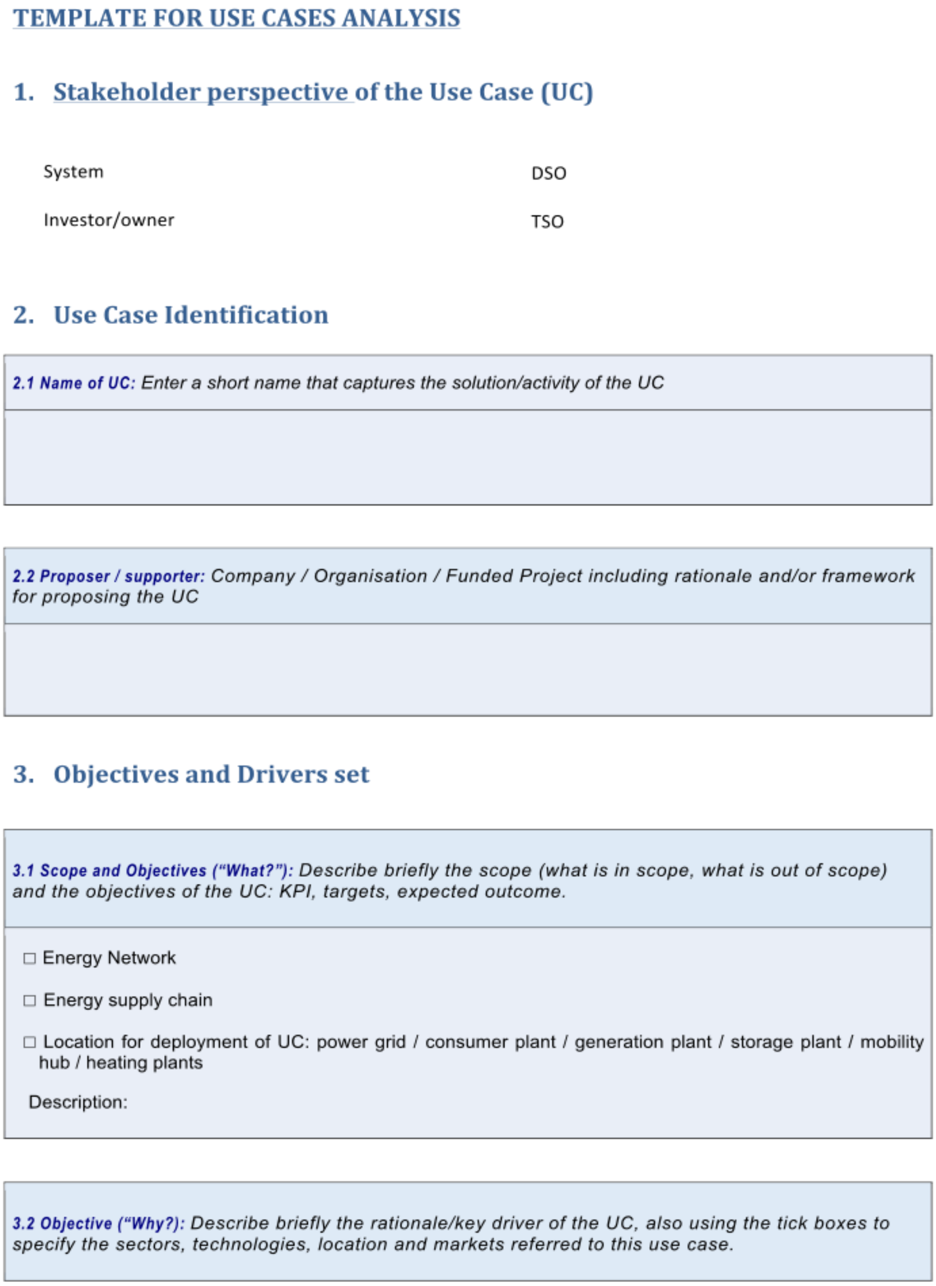
The full Business Case provides all the relevant information related to the project, by incorporating elements of the CBA and pairing economic and financial feasibility to the Use Case description. As detailed in the previous paragraph, the Business Case:

- Include expected impacts in terms of job creation and positive / negative welfare effects;
- Detail the time horizon of the entering into operations;
- Provide information about the financial structure of the project, including financial performance indicators (NPV, IRR, Payback Period, etc.).

Finally, the Assessment phase must:

- Consider all technical aspects, such as conversion (double conversion if back to electricity and multiple if logistic is included) costs and losses in realistic duty cycles as well as proper valorisation of the performance, impacts on safety and reliability of the system.
- Include externalities (positive and negative, not only reduction of CO2 and/or pollutants) possibly on lifetime horizon, from raw materials supply to dismissal/disposal (Life Cycle Assessment).

8.3 APPLICATION TO USE CASES – TEMPLATE



TEMPLATE FOR USE CASES ANALYSIS

1. Stakeholder perspective of the Use Case (UC)

System	DSO
Investor/owner	TSO

2. Use Case Identification

2.1 Name of UC: *Enter a short name that captures the solution/activity of the UC*

2.2 Proposer / supporter: *Company / Organisation / Funded Project including rationale and/or framework for proposing the UC*

3. Objectives and Drivers set

3.1 Scope and Objectives ("What?"): *Describe briefly the scope (what is in scope, what is out of scope) and the objectives of the UC: KPI, targets, expected outcome.*

☐ Energy Network

☐ Energy supply chain

☐ Location for deployment of UC: power grid / consumer plant / generation plant / storage plant / mobility hub / heating plants

Description:

3.2 Objective ("Why?): *Describe briefly the rationale/key driver of the UC, also using the tick boxes to specify the sectors, technologies, location and markets referred to this use case.*

Main rationale:

☐ Decarbonisation
☐ Energy Optimisation
☐ Infrastructures Optimisation
☐ Flexibility provision

Sectors to be coupled:

Technologies deployed:

Impacted markets:

☐ EHV
☐ HV
☐ MV
☐ LV Day Ahead Energy Market
☐ Day Ahead Balancing Market
☐ Intraday Energy Market
☐ Intraday Balancing Market
☐ Flexibility Market
☐ Distribution Constraints Market
☐ Capacity Market
☐ Other

4. Boundary conditions and pre-requisites

4.1 External conditions: *List and assess the main conditions to be in place for realising the UC, commenting on their reasons, expectations, impact (show-stopper or simply reducing the UC feasibility), actors / decision makers behind such conditions; elaborate on ways to de-risk or secure such conditions.*
4.2 Regulatory issues: *List and describe* main regulatory issues impacting and conditioning the feasibility of the use case.

5. Business case (optional, only not confidential info)

5.1 Business model: *Short but comprehensive description of value chain flow: who invests, who sells/earn the UC product /service, who purchase/pays it, if there are pass-through or pass-over of costs to other stakeholders, if tariffs (or other regulated economic flows) are involved.*
5.2 Economic assumptions: *List main implicit and explicit assumptions on economic values to be used for assessing feasibility of UC; include list of externalities (positive or negative); include CO2 role and values.*
5.3 Base case for reference: *Describe and quantify the best alternative(s) to reach same goal, traditional or other competing innovative solution, to be used as reference for comparing the economics of UC against such base case.*
5.4 Sensitivities and key parameters: *List and shortly describe which are the few main parameters affecting the feasibility of UC, and which can determine the need of subsidies; in particular the parameters on which future evolution is expected. On such parameters break-even analysis should be made, to determine the break-even point for deployment without subsidies.*

6. Achieved results and impacts (for finished projects)

6.1 Benchmark between set goals and achieved results
6.2 Shareable impacts
6.3 Policy contributions

9. CONCLUSIONS AND RECOMMENDATIONS

9.1 FRAMEWORK AND ETIP-SNET ROLE

The future energy system will require more integrated and enhanced dynamics between all value chains of the energy sectors addressing energy transition and decarbonisation goals, optimally linking the various energy resources and networks to the consumption sectors. This brings a System of Systems vision, where electricity becomes the leading energy carrier (up to 60%), and the power grids are the backbone for the decarbonisation of all energy sectors.

Smart sector integration is expected to deliver a scalable solution to improve overall system efficiency, resiliency, allowing greater integration of renewables whilst enabling flexible consumption and deeper consumer empowerment.

ETIP-SNET Vision 2050 and Roadmap 2020-2030

The Functionalities needed from the ETIP SNET roadmap are F2 on cross-sector integration, F3 on Integration and the subsidiarity principle, F5 on Integration of the local markets, F6 of Integration of digital services, F8 Energy systems business models, F9 on Simulation tools for electricity and energy systems, F10 on integrating flexibility in generation, demand, conversion and storage technologies, F11 Efficient heating and cooling for buildings and industries in view of systems integration and flexibilities as well as F12 Efficient carbon-neutral liquid fuels and electricity for transport in view of system integration of flexibilities. Moreover, the research areas are expected to be contributing to the achievement of the functionalities.

9.2 DEFINITIONS AND RATIONALE OF SECTOR INTEGRATION PROJECTS

There is no unique and generally accepted definition of sector integration. There is wide consensus on the underlying concept: plan and operate the electricity system and several mutually interacting systems in a co-optimised manner. However, different terms are sometimes used as synonyms and reversely, the same term is used to indicate or include different processes.

A possible set of consistent definitions has been proposed, under several viewpoints (energy flows, processes, semantic meaning) for sector coupling, sector integration, Power-to-X and Multi Energy Systems.

The rationale for sector integration projects coupling sectors, and even more integrating them, under common planning and/or operation framework may derive from different drivers, which can also co-exist and reinforce each other. The three main rationales, which have been analysed in this Paper, are energy efficiency/decarbonisation, asset & networks optimisation, and improving system flexibility/reliability.

9.3 BUILDING BLOCKS

Electric RES is a major building block of a climate-neutral energy system due to their maturity and intrinsic efficiency advantage; energy efficiency and electrification are the low hanging fruits, to be exploited first and foremost. The remaining energy demand (heavy industry, high-temperature heat, air- and sea-borne transport, etc.) will be covered by low-carbon liquid and gaseous fuels “molecules”. P2G will support this, both to supply green molecules and by adding flexibility and long-term storage, complementary to electrochemical storage. A taxonomy of true green molecules is needed. Producing hydrogen from electricity implies an increase in primary energy demand, and its cost also depends on solving the trade-off between high utilisation rates and using cheap surplus electricity.

It is recommended for ETIP-SNET to form an interface with the evolving new partnership within the Horizon Europe Cluster 5 on Clean Hydrogen and consider additional interfaces after all partnerships are launched.

Smart sector integration fosters cross-sector and cross-countries level playing fields development, removing unnecessary or double taxation on electricity, incentivising cost-effective Power-to-X solutions: CO2-free gas, district heating, hydrogen generated from RES, and new flexibility solutions based on demand-side response including V2G. As decarbonisation and carbon-free electrification are becoming the pillars of the European Smart Sector Integration Strategy greater integration and interfaces development will be needed based on the market approach. New products such as electrolytic hydrogen (green hydrogen) and renewable gases are to become market-based solutions under a revised, functional and transparent European gas market.

Smart sector integration will encourage further stakeholder cooperation for “platformisation” based on advancements of TSO-DSO-aggregator cooperation on flexibility and storage and a revamped EU Emission Trading Scheme, possibly extended to sectors such as fossil-fuelled heating and transportation, which would set the right signals and scale-up Europe’s sector coupling and decarbonisation ambitions.

9.4 ARCHITECTURES AND ENABLERS

An integrated approach requires streamlined System of Systems vision to overcome existing barriers. Holistic architectures need to take the many-to-many interfaces and integrations into consideration. ICT and other enabling technologies could facilitate integration in a faster way while avoiding barriers, such as interoperability, lack of seamless interfaces or fragmentation.

The holistic approach transforms experts’ perspectives to perceive the power system in ways that are more extended, creating increasingly more flexibilities and opportunities to decarbonise the entire economy. The “LINK” holistic architecture, which is designed for power systems and electricity market, actually creates a respectable foundation for the cross-sector and end-consumer sector coupling; the holistic approach also of other industry vectors such as natural gas will be required to cover all energy systems as a whole. These developments enable efficient interfaces to all three silos: electricity (bidirectional), gas (bidirectional) and heat by promoting an extremely flexible new kind of CHP technology.

The evolving ecosystems will require close collaboration at all levels, starting from the creation of a repository of evolving use cases and a monitoring observatory as a format; dedicated task forces across stakeholders’ communities should jointly tackle barriers and foster deployment of state-of-the-art innovative applications. The format, goals and parameters of such set up are subject to further considerations. Various formats were already successfully implemented within the EU for single sectors, while cross-sectorial ones could play an accelerator role.

The ICT backbone and the enabling technologies as well data related considerations are of high importance. The approach that takes all of the components forming cyber-physical and considerations for smart sector integration necessitates this dual approach, as well as close collaboration with the evolving EU-wide initiatives, focused on data management, security and governance topics. The Smart Grid Architecture Model (SGAM) and associated reference standards and APIs offers the necessary toolbox to analyse necessary APIs to be built between the central electricity backbone and peripheral sectors.

9.5 ASSESSMENT CRITERIA AND REGULATION

Recommendations for the consistent economic assessment of sector integration projects include a proper allocation of resources, particularly when public funding is involved, requires a structured and schematic assessment of sector coupling projects. This can be achieved through the Use Case approach, where the following criteria are utilised:

- Declare if KPIs and metrics are used from the perspective of investor/proponent or system/social one;
- Scope is stated (“What?”), in terms of coupled sectors, technologies, location in the value chain (power grid / consumer plant / generation plant / storage plant / mobility hub / heating plants), impacted markets;

- Objective ("Why?"): rationale (Decarbonisation, Energy Optimisation, Infrastructures optimisation, Flexibility provision), KPI, targets, expected outcome;
- Boundary conditions and prerequisites, external conditions and their decision-makers;
- Base case for reference, i.e. the best alternative to reach the same objective to be used as a baseline for comparing the economics of the project;
- Business model, economic assumptions, externalities; key parameters for sensitivity and break-even analysis, especially if subsidies are requested to achieve economic feasibility.

To proceed to smooth deployment of smart sector integration, the regulation should rely on the following main recommendations:

- Foster cross-sector and cross-member states level playing fields, removing unnecessary or double taxation on electricity, incentivising Power-to-X solutions (e.g. Gas, district heating, hydrogen generated from RES, and new flexibility solutions such as demand-side response including V2G models and beyond). Decarbonisation and carbon-free electrification are to become the pillars of the European Smart Sector Integration Strategy.
- Encourage stakeholder cooperation for platformisation (TSO-DSO-aggregator cooperation on flexibility and storage) and a revamped EU Emission Trading Scheme, possibly extended to sectors such as fossil-fuelled heating and transportation, which would set the right signals and back Europe's sector coupling and decarbonisation ambitions.
- Boost the imminent electricity and gas sector coupling for new products such as electrolytic hydrogen and renewable gases to become market-based solutions on a revised, functional and transparent European gas market.

10. ABBREVIATIONS

ACER	European Union Agency for the Cooperation of Energy Regulators
AI	Artificial Intelligence
ANM PtW	Active Network Management - Power-to-Water
B/C	Benefit/Cost ratio
BEV	Battery EVs
B2B	Business-to-Business
CAPEX	Capital Expenditure
CAES	Compressed Air Energy Storage
CBA	Cost Benefit Analysis
CC	Coupling Component
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilisation
CEER	The Council of European Energy Regulators
CERT	Computer Emergency Response Team
CHP	Combined Heat and Power
CIA	Central Intelligence Agency
CO2	Carbon Dioxide
CO2eq	Carbon Dioxide Equivalent
COP	Coefficient of performance
COP21	21st Conference of the Parties, referring to the countries that have signed up to the 1992 United Nations Framework Convention on Climate Change
CP	Customer Plant
CSIRT	Computer Security Incident Response Team
CSP	Concentrated Solar Power
DC	Direct Current
DCF	Discounted Cash Flow
DH	District Heat
DSO	Distribution System Operator
EC	European Commission
ECH2A	European Clean Hydrogen Alliance
EEA	European Economic Area
EHV	Extra High Voltage
EHPs	Electric heat pumps
ENPV	Economic Net Present Value
ERR	Economic Rate of Return
ENTSO-E	European Network of Transmission System Operators for Electricity
ENTSO-G	European Network of Transmission System Operators for Gas
ES	Energy Storage
ESI	Energy Systems Integration
ETIP SNET	European Technology and Innovation Platform Smart Networks for Energy Transition
EU	European Union
EVs	Electric Vehicles
FCR	Frequency Containment Reserve
FRR	Frequency Restoration Reserve
FP7 7th	Research Framework Programme
GAMES	General-purpose Architectural model for multi-energy systems
GasO	Gas System Operator
GDPR	General Data Protection Regulation
GHG	Greenhouse Gas
GriLiO	Operator of the Grid-Link
GW	Gigawatt
GWh	Gigawatt-hour
H2	Hydrogen
HEVs	Hybrid Electric Vehicles
HESS	Hydrogen Energy Storage Systems
HMI	Human Machine Interfaces
HMU	House Management Unit
HP	Heat pump
HW/SW	Hardware/Software
HV	High Voltage
H2O	Water
ICT	Information and Communications Technology
ICS	Industrial Control Systems
IEA	International Energy Agency
IDE4L	Ideal Grid for All
IEDs	Improvised Explosive Devices
I/O	input/output
IoT	Internet of Things

IPS	In-Plane Switching
IRENA	International Renewable Energy Agency
IRR	Internal Rate of Return
ISGAN	International Smart Grids Action Network
IT	Information Technology
KIP	Key Impact Pathways
KPIs	Key Performance Indicators
kg	Kilogram
kW	Kilowatt
kWh	Kilowatt-hour
LAES	Liquid Air Energy Storage
LEC	Local Energy Communities
LV	Low Voltage
m	meter
MES	Multi-Energy System
MJ/kg	Megajoules per kilogram
MV	Medium Voltage
MW	Megawatt
MWh	Megawatt-hour
NPV	Net Present Value
O2	Oxygen
OPEX	Operational Expenditure
OEM	Original Equipment Manufacturer
OT	Operational Technology
pan-EU	Pan-European
PINT	Put IN one at the Time
PLC	Programmable Logic Controller
PLN	Polish zloty
PtC	Power-to-Cooling
PtH	Power-to-Heat
PtX	Power-to-X
PV	Photovoltaic
P2B	Power to Battery
P2L	Power to Liquid
P2G	Power to Gas
P2G2P	Power to Gas to Power
P2H&C	Power to Heating and Cooling
P2W	Power to Water
RD&I/RDI	Research, Development and Innovation
RES	Renewable Energy Sources SAE Society of Automotive Engineers
SC	Sector Coupling
SCADA	Supervisory Control And Data Acquisition
SGAM	Smart Grid Architecture Model
SO	System Operator
SOC	State of Charge
SysML	System Modelling Language,
TCP/IP Internet Protocol	Transmission Control Protocol /
TES	Thermal Energy Storage
TOOT	Take Out One at the Time
TOTEX	Total Expenditure
TRL	Technology Readiness Level
TSO	Transmission System Operation
TW	Terawatt
TWh	Terawatt-hour
TYNDP	Ten Year Network Development Plan
UC	Use case
UML	United Modelling Language
UK	United Kingdom
UN's	United Nations
WG1	ETIP SNET Work Group 1 Reliable, economic and efficient smart grid system
WPPO	Water Power Plant
vRES	Variable Renewable Energy Sources
V2G	Vehicle to Grid

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12. ANNEXES

12.1 ANNEX 1 USE CASES

12.1.1 USE CASES SUMMARY

Name	Sector	Type of sector integration	More info
ANM4L **Active Network** **Management For All**	Grid Services	Power and water: The project focuses on innovative active network management (ANM) solutions for the integration of renewable energy sources (RES) in electricity distribution networks. A water desalination plant is intended to be used to provide flexible demand, increasing the water production in high wind situations thus coupling the power and the water sectors.	EC fiche: https://cordis.europa.eu/project/id/775970 Website: https://anm4l.eu/
Energy Community: **Energy Cluster Michałowo Energy Region**	Renewable Heat Generation	Energy and Heat: the project aims at supplying heat to larger customers in the town of Michałowo with network heat generated by a local biogas plant. As part of the scenario, two biogas plants will be built, each with an installed electrical capacity of 600 kW and heating capacity of 595 kW, and a heat network with a total length of 5000 m.	Website: https://klastermichalowo.pl/
EQUIGY	Grid services	Energy, Transport, Domestic consumptions. The project consists in a Crowd Balancing Platform at pilot stage for DER active participation in ancillary services market, through smart aggregation. The platform constitutes the link between existing ancillary services markets and aggregators of distributed flexibility. The Blockchain technology facilitates the bidding, activation and settlement processes associated to the flexibility transactions of Virtual Power Plants guaranteeing quality, security and minimum transaction costs.	Website: https://equigy.com/

Energy for water sustainability	Energy optimisation, flexibility	Energy and water. The project analyses the evolution of water energy nexus, with the aim of presenting proposals to optimise the joint management of water and energy resources. Starting from the assumption that the electricity sector could contribute to water sustainability, the paper proposes the creation of a shared water management plan to optimise the benefits of multiple water uses. It highlights the benefits of efficient use of infrastructure in relation to drinking water, agricultural and energy uses.	Cooperation Enel-Arera
FutureGas	Energy and gas sector	Energy and gas: The main purpose of the FutureGas project is to contribute to growth and green transition through interdisciplinary and coordinated research across the gas sector. The goal is to stimulate; 1) an efficient and economical supply of gas – including gas based on renewable sources, 2) an appropriate and flexible use of these gases, and 3) an optimal integration of gas in the overall energy system, including an energy and economic efficient interaction with heat, electricity, industry and transport sectors. The FutureGas project is mainly focusing on Denmark.	Website: https://futuregas.dk/

12.1.2 FCH JU SECTOR INTEGRATION USE CASES

Acronym	EC fiche	Name	Website	Sector	Type of sector integration
H2Future	https://cordis.europa.eu/project/id/735503	HYDROGEN MEETING FUTURE NEEDS OF LOW CARBON MANUFACTURING VALUE CHAINS	https://www.h2future-project.eu/	Steel Industry	6MW PEM electrolyser to produce Hydrogen and electricity for the steel industry. This project brings together energy suppliers, the steel industry, technology providers and research partners, all working hand in hand on the future of energy. Six partners, one goal: green hydrogen from green electricity.
REFHYNE	https://cordis.europa.eu/project/id/779579	Clean Refinery Hydrogen for Europe	http://www.refhyne.eu/	Oil refinery	REFHYNE will install and operate the world's largest hydrogen electrolyser the Shell Rhineland Refinery in Wesseling, Germany. The electrolyser has a peak capacity of 10 MW (megawatts) and will be able to produce approximately 1,300 tonnes of hydrogen per year. This decarbonised hydrogen can be fully integrated into refinery processes including the desulphurisation of conventional fuels. The project will use the hydrogen produced for: 1.Processing and upgrading products at the Wesseling refinery site. 2. Testing the PEM technology at the largest scale achieved to date. 3. Exploring applications in other sectors including: industry, power generation, heating for buildings, and transport.
DEMO4GRID	https://cordis.europa.eu/project/id/736351	Demonstration of 4MW Pressurised Alkaline Electrolyser for Grid Balancing Services	https://www.demo4grid.eu/	Grid services	commercial setup and demonstration of a technical solution using the Pressurised Alkaline Electrolyser (PAE) technology for providing grid balancing services under real operational and market conditions and the production of Green Hydrogen for industrial energy services
GRINHY2	https://cordis.europa.eu/project/id/826350	Green Industrial Hydrogen via steam electrolysis	https://www.green-industrial-hydrogen.com/	Steel Industry	By the end of 2022 it is expected to have been in operation for at least 13,000 hours, producing a total of around 100 tonnes of high-purity (99.98 %) hydrogen. This will be used for annealing processes in the integrated steelworks as a replacement for hydrogen produced from natural gas.

DJEWELS	https://cordis.europa.eu/project/id/826089	Joint Development of green Water Electrolysis at Large Scale	https://djewels.eu/	Green fuels production	Demonstrate the operational readiness of a 20 MW electrolyser for the production of green fuels (green methanol) in real-life industrial and commercial conditions
GREEN HYSLAND	https://cordis.europa.eu/project/id/101007201	Deployment of a H2 Ecosystem on the Island of Mallorca	Not available	fully-integrated and functioning H2 ecosystem	The project brings together all core elements of the H2 value chain i.e. production, distribution infrastructure and end-use of green hydrogen across mobility, heat and power.

12.1.3 ANM4L

Stakeholder perspective_of the Use Case (UC)

☐ System

☐ Investor/owner

x DSO

☐ TSO

Use Case Identification

2.1 Name of UC: *Enter a short name that captures the solution/activity of the UC*
Active Network Management - Power-to-Water (**ANM PtW**)
2.2 Proposer / supporter: *Company / Organisation / Funded Project including rationale and/or framework for proposing the UC*
ANM4L (ERA NET project) – there is a need for active network management solutions to cope with distribution grid congestions and voltage issues due to excessive distributed RES generation.

Objectives and Drivers set

3.1 Scope and Objectives ("What?"): *Describe briefly the scope (what is in scope, what is out of scope) and the objectives of the UC: KPI, targets, expected outcome*

☐ Energy Network

☐ Energy supply chain

X Location for deployment of UC: power grid / consumer plant / generation plant / storage plant / mobility hub / heating plants

Description: A water desalination plant is intended to be used to provide flexible demand, increasing the water production in high wind situations. Thus coupling the power and the water sectors.

3.2 Objective ("Why?): *Describe briefly the rationale/key driver of the UC, also using the tick boxes to specify the sectors, technologies, location and markets referred to in this use case.*

Main rationale:

☐ Decarbonisation

☐ Energy Optimisation

☐ Infrastructure optimisation

X Flexibility provision

Sectors to be coupled: Water & Power

Technologies deployed: Measurements, communication, integrated toolbox for DSO control room

Impacted markets:

- EHV
- HV

X MV

- LV Day Ahead Energy Market
- Day Ahead Balancing Market
- Intraday Energy Market
- Intraday Balancing Market
- Flexibility Market

X Distribution Constraints Market

- Capacity Market
- Other

Boundary conditions and prerequisites

4.1 External conditions: *List and assess the main conditions to be in place for realising the UC, commenting on their reasons, expectations, impact (show-stopper or simply reducing the UC feasibility), actors / decision makers behind such conditions; elaborate on ways to de-risk or secure such conditions.*

The size of the water supply system is a limiting factor needed to be considered during high wind and low water demand situations. Several types of flexible resources (from load and generation) will contribute to the total flexibility needed for the distribution grid.

4.2 Regulatory issues: *List and describe* main regulatory issues impacting and conditioning the feasibility of the use case.

Today, TOTEX based regulation demotes alternative non-capital “agile” investment solutions.

Business case (optional, only not confidential info)

5.1 Business model: *Short but comprehensive description of value chain flow: who invests, who sells/earns the UC product /service, who purchases/pays it, if there are pass-through or pass-over of costs to other stakeholders, if tariffs (or other regulated economic flows) are involved.*

DSO is the main stakeholder for this. The detailed CBA for investment planning needs to consider the various alternative solutions, and their individual life-expectancy (which is typically shorter than conventional grid investments). Increased uncertainties in both the scenarios as well as in the investments in new technologies are challenges.

5.2 Economic assumptions: *List main implicit and explicit assumptions on economic values to be used for assessing feasibility of UC; include list of externalities (positive or negative); include CO2 role and values.*

5.3 Base case for reference: *Describe and quantify the best alternative(s) to reach the same goal, traditional or other competing innovative solution, to be used as reference for comparing the economics of UC against such base case.*

Conventional grid expansion to cope with increased RES deployment.

5.4 Sensitivities and key parameters: *List and shortly describe which are the few main parameters affecting the feasibility of UC, and which can determine the need of subsidies; in particular the parameters on which future evolution is expected. On such parameters break-even analysis should be made, to determine the break-even point for deployment without subsidies.*

Achieved results and impacts (for finished projects)

6.1 Benchmark between set goals and achieved results
6.2 Shareable impacts
6.3 ***Policy contributions***

12.1.4 ENERGY CLUSTER MICHAŁOWO

Stakeholder perspective of the Use Case (UC

☐ System

✓ Investor/owner

☐ DSO

☐ TSO

Use Case Identification

2.1 Name of UC: *Enter a short name that captures the solution/activity of the UC*

Decarbonisation - heat supply to Michałowo town from a biogas cogeneration unit, together with the construction of a municipal heat network.

2.2 Proposer / supporter: *Company / Organisation / Funded Project including rationale and/or framework for proposing the UC*

Energy Community: *Energy Cluster Michałowo energyRegion,* address: ul. Białostocka 78, 16-050 Michałowo

- Michałowo municipality, ul. Białostocka 11, 16-050 Michałowo - owner of the heat transmission infrastructure, main customer of heat energy, organiser of municipal transport;
- Zielona Energia Michałowo sp.z o.o., ul. Białostocka 78, 16-050 Michałowo - owner of the manufacturing infrastructure.
- IEN Energy sp.z o.o., ul. Kolady 3, 02-691 Warsaw - Energy Cluster Coordinator.

Objectives and Drivers set

3.1 Scope and Objectives ("What?"): *Describe briefly the scope (what is in scope, what is out of scope) and the objectives of the UC: KPI, targets, expected outcome*

✓ Energy Network

✓ Energy supply chain

✓ Location for deployment of UC: power grid / consumer plant / generation plant / storage plant / mobility hub / heating plants

Description:

The scenario assumes supplying heat to larger customers in the town of Michałowo with network heat generated by a local biogas plant. As part of the scenario, two biogas plants will be built, each with an installed electrical capacity of 600 kW and heating capacity of 595 kW, and a heat network with a total length of 5000 m.

The purpose of implementing the projects described in the scenario in the environmental and ecological dimensions is to improve air quality and reduce emissions by basing heat generation on renewable energy sources and increasing the efficiency of heat use. Implementation of activities in the economic dimension is to bring cheaper heat, first of all for public utility facilities, and after the end of the durability period, also for multi-family and single-family housing, as well as for trade, services and industry. A significant social effect is to be achieved by basing the generation of heat and electricity on local fuel suppliers - the basic substrate for the biogas plant is maize silage grown in the immediate vicinity of Michałowo. Cheap heat with assured stable supplies is also to be an important factor of competitive advantage when attracting investors to the city. After introducing regulations for energy communities, electricity can be advantageously distributed in the area of the cluster - not only to the facilities of local government units, but also to companies, which may create cost advantages and encourage investment in the commune belonging to the energy cluster.

Stage 1: construction of biogas plant No.1, completed in 2015. KPI:

- Increase in new electricity generation capacity of 600 kW,
- Electricity production: 4,360 MWh,
- Increase in new heat generation capacity: 595 kW,
- Thermal energy production: 13,995 GJ.

Stage 2: construction of the heat network (part one) - completed in 2015. KPI:

- Number of connections to the district heating network: 2,
- Length of the constructed heat network: 1100 m,

Stage 3: construction of the heat network (part two) - completed in 2020. KPI:

- Number of connections to the district heating network: 6,
- Length of the constructed heat network: 2900 m,
- Heat supply to public utility buildings: 100%.

Stage 4: construction of biogas plant No. 2 - planned for implementation in 2021. KPI:

- Increase in new electricity generation capacity of 600 kW.
- Electricity production from the new unit: 4,360 MWh.
- Increase in new thermal energy production capacity of 595 kW.
- Heat production from the new unit: 13,995 GJ.

Stage 5: construction of the heat network (part three) – planned for implementation in 2022-2024. KPI:

- Length of the constructed district heating network: 1000 m,
- Number of connections to the district heating network: 5.

Stage 6: construction of the heat network (part three) – planned for implementation after 2025. KPI:

- Number of connections to the district heating network: 30.

Stages 1-3 are completed, stage 4 is planned for implementation in 2021 (design work has been completed and funding has been obtained). Stages 5-6 are in the concept phase.

3.2 Objective ("Why?): *Briefly describe the rationale/key driver of the UC, also using the tick boxes to specify the sectors, technologies, location and markets referred to in this use case.*

Main rationale :

- ✓ Decarbonisation
- ✓ Energy Optimisation
- ✓ Infrastructures optimisation
- ☐ Flexibility provision

Sectors to be coupled:

Energy, Heat

Technologies deployed:

Biogas, cogeneration, high-efficiency heating networks

Impacted markets:

- EHV
- HV
- MV
- LV Day Ahead Energy Market
- Day Ahead Balancing Market
- Intraday Energy Market
- Intraday Balancing Market
- Flexibility Market
- Distribution Constraints Market
- Capacity Market
- Other

Boundary conditions and prerequisites

4.1 External conditions: List and assess the main conditions to be in place for realising the UC, commenting on their reasons, expectations, impact (show-stopper or simply reducing the UC feasibility), actors / decision makers behind such conditions; elaborate on ways to de-risk or secure such conditions.

The main conditions for the existence of the described UC (heating network for the Michałowo town powered by thermal energy from two biogas plants) are the involvement and cooperation of the business (production sources) and local government units - the Michałowo municipality (heat network and heat recipients). Thanks to delineating the boundary conditions (the approximate cost of heat supplied from the biogas plant ensuring higher profitability of the biogas plant, and lower costs of heating public utility buildings for the city), it was possible to create business plans for both projects - construction of a biogas plant and a heat network. The deepening of this cooperation was the creation of the Michałowo Energy Cluster (energy community), which became a platform for constant dialogue between the interested parties. The cluster also made it possible to engage in the dialogue with other local government units interested in investments in energy efficiency, renewable energy and thermal modernisation combined with the replacement of high-emission heat sources.

While private actors are primarily motivated by financial issues, institutional actors, in this case the municipality of Michałowo, also take into account the social and environmental context. Cooperation with a biogas plant and purchase of heat allows not only to reduce the operating costs of the municipality, but also significantly contributes to the improvement of air quality in the town. Basing energy production on local resources in a closed cycle of values affects the development of the municipality. Heat bills are credited to the account of the local company, which pays taxes to the municipality, at the same time leases fields from farmers or buys biogas feedstock from them, which allows the farms to grow and increase employment. Access to cheap heat in the municipality with investment land at a competitive price is also a great asset attracting investors, as evidenced by the opening in 2020 of a production plant of a company producing gypsum stucco and prefabricated elements requiring active drying.

A threat to the implementation of UC are regulatory changes related to the purchase of electricity from biogas plants. Experience shows that the beginnings of biogas plant operation in Poland were difficult and the newly built installations were a victim of legislative uncertainty and many of them suffered huge losses. It seems that at present this risk is low, and the existing support systems have a rigid framework that ensures financial return on existing and newly commissioned installations.

Another threat to the owner of a biogas plant is the strong fluctuations in the price of maize silage, which is the main component of the substrate.

This risk is mitigated by ensuring a significant proportion of supplies from the fields leased by the biogas plant owner, which reduces the sensitivity to price fluctuations. Additionally, the increase in the cost of obtaining one of the co-substrates for biogas plants may be compensated to some extent by changing the substrate mixture and increasing the share of periodically cheaper substrates.

An important factor ensuring the stability of the operation of a biogas plant is heat reception. In the case of the UC in question, it was important to establish cooperation with the municipality that decided to build a heat network. Due to the provisions of the program regulations, from which this construction was co-financed, it is not possible to connect private recipients in the 2nd and 3rd stage of the expansion of the network of private consumers during the project durability period. However, it is in the well-understood interest of the local community to shorten the durability of the project and connect multi-family buildings to the network first, and later also companies. In the case of single-family houses, only after the audits have been conducted, it is possible to determine the most optimal path to eliminate the problem of low emissions in the city to minimise the phenomenon of energy poverty. This requires the connection of deep thermal modernisation with the selection of cost-effective and environmentally optimal heat sources.

On the part of the municipality and other heat recipients, there is a risk of an increase in heat prices imposed by the owner of the generating source. This risk is minimised by long-term heat supply contracts and the fact that without selling heat, the biogas plant faces the risk of losing financial liquidity.

Risks affecting the implementation of the last stages of the scenario include limiting the investment possibilities of the commune. Polish local governments are extremely financially burdened in 2020 due to the reduction of revenues to their budgets due to fiscal changes and the crisis caused by the COVID-19 epidemic

4.2 Regulatory issues: List and describe main regulatory issues impacting and conditioning the feasibility of the use case.

Support systems for biogas plants in the field of electricity sales (FIT / FIP / auction system / system of certificates of origin)

From 2018, producers of electricity in biogas plants can take advantage of the new support system for renewable energy sources based on feed-in tariffs (FIT) or subsidies to the market price (Feed in premium - FIP). These were new solutions, apart from the possibility of biogas plant participation in auctions and the extinguished, ineffective system of certification of energy produced with certificates of origin. The FIT / FIP support systems along with the parallel auction system create a good legislative environment for the financial operation of a biogas plant.

Obligation to have a license for the production and distribution of heat and to approve the tariff for heat from biogas plants

In accordance with the applicable regulations, the generation of heat in the biogas plant in Michałów does not require a license, because its total installed thermal capacity, nor the size of the power ordered by customers, does not exceed 5MW. Therefore, neither the heat producer nor the owner of the heating network need a license to generate / trade heat. However, any possible legislative changes in this respect should not affect the financial results of both actors due to the obligations imposed on the regulator (the Energy Regulatory Office), which is to ensure a justified return on capital employed.

Business case (optional, only not confidential info)

5.1 Business model: Short but comprehensive description of value chain flow: who invests, who sells/earns the UC product /service, who purchases/pays it, if there are pass-through or pass-over of costs to other stakeholders, if tariffs (or other regulated economic flows) are involved.

The investor and owner of the production installations is Zielona Energia Michałowo. The company also leases fields and grows maize, ensuring the supply of maize silage, which is the basic component of the substrate used. The remaining co-substrates are obtained on the open market. The company sells the generated electricity by participating in the auction system. Heat is sold to commercial customers and the Michałowo community - to collection points located in public buildings. The price of heat is regulated on the free market.

The investor and owner of the transmission network is the Michałowo community. For the purposes of this multi-stage investment, a grant was obtained from the Regional Operational Program of the Podlaskie Voivodeship.

The community remains the main recipient of heat. Fees for heat distribution are regulated by tariffs.

Commercial heat consumers and suppliers of the substrate for biogas plants - mainly maize silage, also participate in the closed cycle

5.2 Economic assumptions: List main implicit and explicit assumptions on economic values to be used for assessing feasibility of UC; include list of externalities (positive or negative); include CO2 role and values.

Assumed indicators:

Length of the constructed heat networks: 5000 m.

Number of district heating connections: 20 (2020), 30 (2025), 50 (2030).

Number of biogas plants: 2.

Total electric power of the biogas plant: 1.2 MW.

Total thermal power of biogas plants: 1.19 MW.

Annual electricity production in biogas plants: 8.7 GWh.

Annual heat production in biogas plants: 7.8 GWh.

CO2 reduction: 9307 tonnes of CO2 equivalent.

Assumed investment outlays:

Biogas plants: PLN 20.5 million net, including co-financing of PLN 10 million.

Heat network with connections: PLN 12 million gross, including co-financing of PLN 10 million.

Electromobility in the Michałowo municipality: PLN 6.5 million gross, including co-financing of PLN 5.2 million.

5.3 Base case for reference: Describe and quantify the best alternative(s) to reach the same goal, traditional or other competing innovative solution, to be used as reference for comparing the economics of UC against such base case.

The reference price for 2020 for installations with a total installed electrical capacity of not less than 500kW and not more than 1MW, using only agricultural biogas to generate electricity from high-efficiency cogeneration, is PLN 700 / MWh. The average price at which energy was sold in the AZ / 4/2019 auction for agricultural biogas plants with a capacity not exceeding 1MW was PLN 652.

Estimated price of district heating for customers in the municipality of Michałowo:

1 kWh = 0.18-0.22 PLN

The cost of heating with fuel oil: 1 kWh = 0.26-0.35 PLN

Natural gas heating cost: 1 kWh = 0.23-0.24 PLN

The cost of heating with a pellet boiler: 1 kWh = 0.19-0.22 PLN

Hard coal heating cost: 1 kWh = 0.16-0.18 PLN

Heat pump heating cost: 1 kWh = PLN 0.14

Large facilities in the municipality are mainly heated with outdated oil or coal fired boilers with low efficiency rates. The result is an increase in costs and their high emissivity

In terms of the price of 1 kWh only, the most cost effective solution for single-family houses is to install individual heat pumps. It is worth noting, however, that pumps may require an additional heat source, and are also associated with very high investment costs. District heating may also be more expensive than from a coal-fired boiler house, however, one should take into account the maintenance of an individual boiler room, its servicing, coal storage, sensitivity to price changes, as well as introduced or planned legislative restrictions - e.g. extending zones where heating with solid fuel boilers (all or more emission classes) is prohibited.

An alternative to generating electricity from RES is building a PV installation. To achieve a similar productivity as in the case of two biogas plants with a total installed capacity of 1.2 MW and planned production of 8.7 GWh, it would be necessary to build an installation with a capacity of approx. 8.7 MW. In this case, investment outlays for net would reach 18-20 million. The reference price for 2020 for installations with a total installed electrical capacity of more than 1MW, using only solar energy to generate electricity, is PLN 340 / MWh.

In the case of the scenario discussed here, one should take into account the cost of producing 1 MWh in an agricultural biogas installation, which can be estimated at PLN 350-400, assuming a high content of high-quality co-substrates in the substrate, mainly maize silage. In the case of obtaining a subsidy of 90% of the reference price for electricity, i.e. PLN 630 per 1 MWh less co-financing, this means an income of about PLN 30-80 per 1 MWh. The biogas plant in Michałowo operates in the auction system, hence its income is similar and should be in the range of PLN 40-90 / MWh. Additionally, the income from heat is PLN 180-220 per 1 MWh. This allows for an annual income from sales of energy in the amount of PLN 1.7-2.4 million before deduction of fixed costs (including personnel costs) and taxation. An additional income for biogas plants can be the sale of digestate used to cultivate fields. It can also be used on crops administered by the biogas plant.

In the case of PV installations, the price obtained at the auction for installations above 1 MW ranges from PLN 162.83 / MWh to PLN 233.29 / MWh. This means that the annual income from the sale of energy, reduced by the level of co-financing, would amount to approximately PLN 1.7-2 million.

In the case of biogas plants and PV compared in terms of electricity production capacity, we can show similar investment outlays and income from energy sales. However, it is worth noting that a biogas plant is a source of a different type. First of all, it can work in a continuous mode, it is a controllable source with production control and the possibility of energy storage in a biogas warehouse. This allows us to adjust the production profile and dispose of the power. Moreover, thanks to the utilisation of some of the by-products from agricultural production, it is possible to obtain negative emission results from biogas plants. Contrary to PV installations, a biogas plant in connection with a heat network contributes significantly to the reduction of low emissions and the phenomenon of energy poverty. The costs of energy production in a biogas plant can also be reduced by changing the content of the substrate and shifting the focus to by-products in agricultural production: fruit pulp, potato or tomato peel, slaughter waste. However, it should be remembered that the biogas plant in the analysed UC is located close to urban developments. As a result, the costs of building a heat network and losses in this network were significantly reduced. However, it is connected with the need to rigorously minimise the environmental impact and to maintain good neighbourly relations.

5.4 Sensitivities and key parameters: List and shortly describe which are the few main parameters affecting the feasibility of UC, and which can determine the need of subsidies; in particular the parameters on which future evolution is expected. On such parameters break-even analysis should be made, to determine the break-even point for deployment without subsidies.

Estimated price of district heating for customers in the Michałowo municipality 1 MWh: PLN 180-220

The cost of generating 1MWh of electricity in a biogas plant: PLN 350-400.

The cost of production is high due to the inability to use cheap and environmentally harmful co-substrates such as slurry or animal slaughter by-products.

Average price of electricity on the wholesale market: PLN 245.

Price of electricity from a biogas plant after taking into account the selling price in the auction system and the degree of investment aid: PLN 430.

Lowering the subsidies in the form of FIT / FIP tariffs or significantly lower prices in the biogas auction basket may render the sale of energy unprofitable. For biogas plants located at meat processing plants, certificates for negative emissions achieved could be a significant incentive.

Biogas plant income from 1 MWh of electricity: PLN 30-80.

Achieved results and impacts (for finished projects)

6.1 Benchmark between set goals and achieved results

For the completed stages 1-3, the project achieved the assumed results.

6.2 Shareable impacts

The project of a heat network based on an agricultural biogas plant is part of the practical implementation of a circular economy in an urban-rural municipality of an agricultural nature with the problem of low emissions. The biogas plant makes use of the agricultural potential of the region for the production of zero-emission electricity and heat. Applying subsidies to the production of electricity from biogas makes the operation of a biogas plant economically justified, which allows for the development of solutions for the management of heat generated in cogeneration. The availability of district heat in areas with cheap investment land is an important factor attracting a non-burdensome industry with high heat demand - e.g. dryers (both food and industrial). Locating a biogas plant near the economic zone may also be an element of the project of including this zone with an independent distribution network with a directly connected generation source, which will result in cheaper energy for local customers. A biogas plant with a cogeneration unit may become an important element in the development of the local community by creating a demand for co-products (also difficult to manage production by-products), creating new jobs (thanks to competitively priced energy), increasing local administration revenues (indirectly - from taxes and directly - by reducing energy expenditure for public utility facilities), reducing low emissions and energy poverty (by replacing ineffective and emitting heat sources and increasing the income of residents, which will allow them to improve housing conditions, including deep thermal modernisation of their own buildings).

6.3 Policy contributions

The current system of subsidies provides biogas plants with relative financial security in the field of electricity production. The management of heat from cogeneration units can provide a significant yield for a biogas plant and at the same time constitute a strong development impulse for local communities. In order to increase the efficiency of biogas plants, it is possible to consider linking support systems from heat management or creating additional systems supporting the creation and operation of local heat systems powered by RES.

12.1.5 EQUIGY PROJECT FROM TERNA

Stakeholder perspective of the Use Case (UC)

☐ System

✓ TSO

☐ DSO

☐ Investor / Owner

Use Case Identification

2.1 Name of UC: *EQUIGY*

Crowd Balancing Platform: Tool at pilot stage for DER active participation to ancillary services market, through smart aggregation

2.2 Proposer / supporter: *Company / Organisation / Funded Project including rationale and/or framework for proposing the UC*

Terna, Tennet, SwissGrid, TSOs respectively of Italy, Netherlands, Switzerland

Aggregators and Open Software providers

Objectives and Drivers set

3.1 Scope and Objectives ("What?"): *Describe briefly the scope (what is in scope, what is out of scope) and the objectives of the UC: KPI, targets, expected outcome*

✓ Energy Network

Energy supply chain

✓ Location for deployment of UC: <u>power grid</u> / <u>consumer plant</u> / <u>generation plant</u> / <u>storage plant</u> / mobility hub / heating plants

Description:

The Crowd Balancing Platform is the tool to target the standardisation of processes and protocols to massively enable distributed flexibility resources, promoting pan-european cooperation between different stakeholders of the electricity value chain and leveraging the Blockchain technology.

The platform constitutes the link between existing ancillary services markets and aggregators of distributed flexibility.

The Blockchain technology facilitates the bidding, activation and settlement processes associated to the flexibility transactions of Virtual Power Plants guaranteeing quality, security and minimum transaction costs

3.2 Objective ("Why?): *Describe briefly the rationale/key driver of the UC, also using the tick boxes to specify the sectors, technologies, location and markets referred to in this use case.*

Main rationale:

Decarbonisation

Energy Optimisation

Infrastructure optimisation

Flexibility provision

Sectors to be coupled:

Energy, Transport, Domestic consumptions

Technologies deployed:

Blockchain, innovative platform for transactions, smart metering

Impacted markets:

EHV

HV

MV

LV Day Ahead Energy Market

Day Ahead Balancing Market

Intraday Energy Market

Intraday Balancing Market

Flexibility Market

Distribution Constraints Market

Capacity Market

Other

DSR is a success story in many countries but a real, substantial aggregation of small, distributed resources is still hindered by meaningful barriers.

If not properly managed, EVs charging can have relevant impacts on residual load ramp management.

Smart Charging and V2G can:

- contribute to reduce the Total Cost of Ownership for final users

- provide Flexibility to the grid

Boundary conditions and prerequisites

4.1 External conditions: *List and assess the main conditions to be in place for realising the UC, commenting on their reasons, expectations, impact (show-stopper or simply reducing the UC feasibility), actors / decision makers behind such conditions; elaborate on ways to de-risk or secure such conditions.*

Strategic integration of EVs can transform a threat into a system wide opportunity establishing synergies and generating distributed benefits along the value chain.

New platforms and tools are needed.

Standardisation and interoperability are fundamental to enable massive adoption of V2G technologies.

DSO involvement is crucial.

4.2 Regulatory issues: *List and describe* main regulatory issues impacting and conditioning the feasibility of the use case.

Market Design to be adjusted.

Facilitate flexibility market access in order to increase value proposition to customers.

Business case (optional, only not confidential info)

5.1 Business model: *Short but comprehensive description of value chain flow: who invests, who sells/earns the UC product /service, who purchases/pays it, if there are pass-through or pass-over of costs to other stakeholders if tariffs (or other regulated economic flows) are involved.*

The platform constitutes the link between existing ancillary services markets and aggregators of distributed flexibility.

The Blockchain technology facilitates the bidding, activation and settlement processes associated with the flexibility transactions of Virtual Power Plants guaranteeing quality, security and minimum transaction costs.

5.2 Economic assumptions: *List main implicit and explicit assumptions on economic values to be used for assessing feasibility of UC; include list of externalities (positive or negative); include CO2 role and values.*

European TSOs together for digitalisation, standardisation and promotion of DERs flexibility.

Not for profit NewCo owned by TSOs but driven by stakeholders' needs: Aggregators, OEMs, DSOs.

Market prices shall apply, since flexibility products are transacted on the existing power markets

5.3 Base case for reference: *Describe and quantify the best alternative(s) to reach the same goal, traditional or other competing innovative solution, to be used as reference for comparing the economics of UC against such base case.*

The reference case would be to procure more reserve and flexibility from traditional fossil fuel plants, with detriment to decarbonisation.

5.4 Sensitivities and key parameters: *List and shortly describe which are the few main parameters affecting the feasibility of UC, and which can determine the need of subsidies; in particular the parameters on which future evolution is expected. On such parameters break-even analysis should be made, to determine the break-even point for deployment without subsidies.*

Number of end-users enabled to the platform

Number of Electric Vehicles in national fleets

Achieved results and impacts (for finished projects)

6.1 Benchmark between set goals and achieved results

Potentially available flexibility: 1,3 GW present DER enrolment, to become 70 GW in 2030 (Italy, National Plan scenario), in terms of qualified power; but a derating of 90% is applied by TSO to be considered as firm capacity

Contributors to flexibility through Equigy are Heat Pumps, Water Heaters, EV, distributed storage.

6.2 Shareable impacts

Increase the pool of active resources to guarantee grid stability and to foster the coordination between value chain stakeholders.

Increase the know-how on distributed resources and on innovative technology solutions to manage them.

The platform is designed for being able to integrate with already existing TSO processes, achieving standardisation and minimising activation and transactions certification costs

6.3 Policy contributions

Creation of a positive and mutually beneficial multi-stakeholder ecosystem.

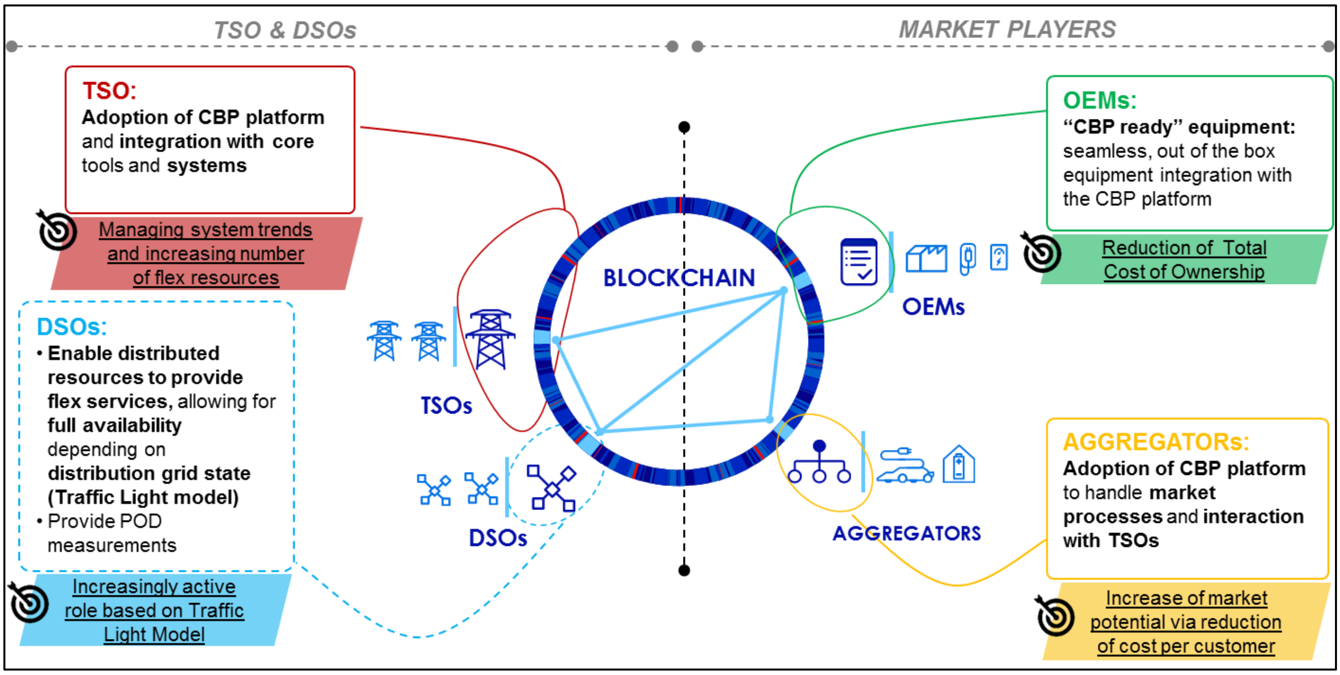

Figure 34. EQUIGY Block chain technology

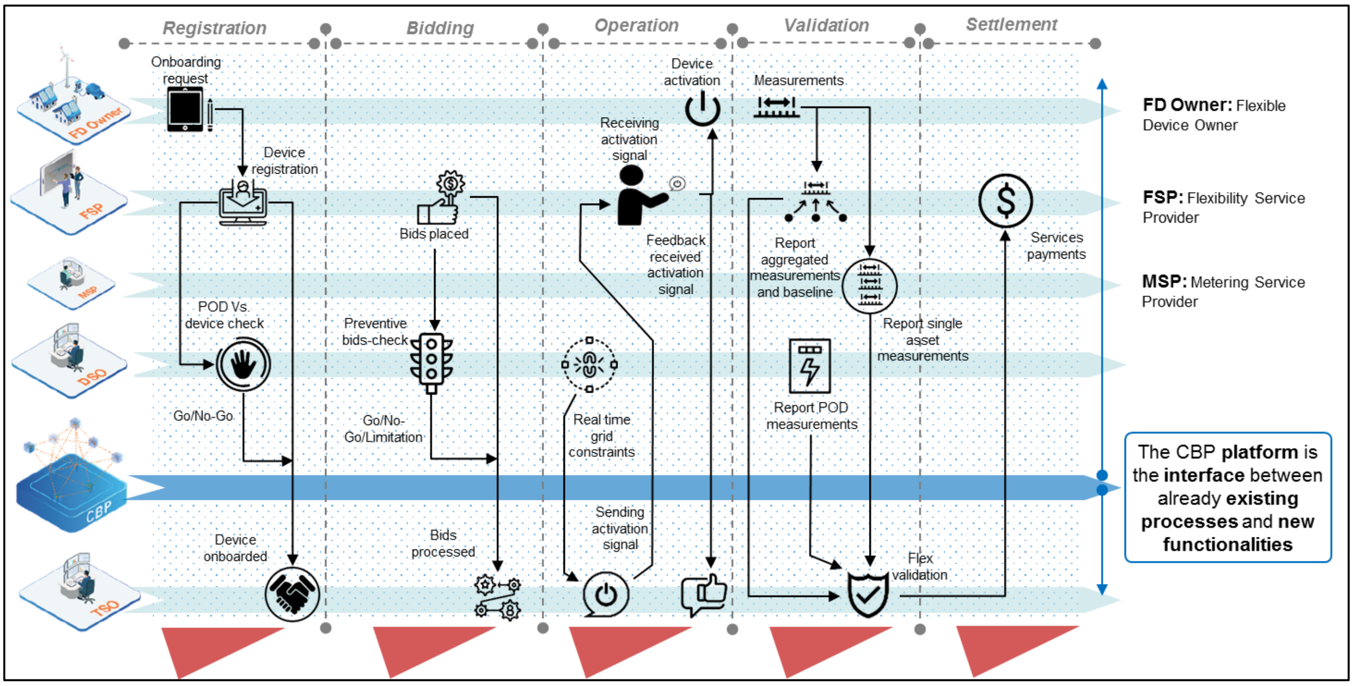

Figure 35. EQUIGY Crowd Balancing Platform

12.1.6 ENERGY FOR WATER SUSTAINABILITY

Stakeholder perspective of the Use Case (UC)

✔ System

☐ Investor / Owner

☐ TSO

☐ DSO

Use Case Identification

2.1 Name of UC: Energy for water sustainability
Analyse the evolution of water energy nexus, with the aim of presenting proposals to optimise the joint management of water and energy resources.

2.2 Proposer / supporter: *Company / Organisation / Funded Project including rationale and/or framework for proposing the UC*

Enel and Arera

Objectives and Drivers set

3.1 Scope and Objectives ("What?"): *Describe briefly the scope (what is in scope, what is out of scope) and the objectives of the UC: KPI, targets, expected outcome*

- ✓ Energy Network
- ✓ Energy supply chain
- ✓ Location for deployment of UC: power grid / consumer plant / generation plant / storage plant / mobility hub / heating plants

Description:

The electricity sector could contribute to water sustainability. The paper proposes the creation of a shared water management plan to optimise the benefits of multiple water uses. It highlights the benefits of efficient use of infrastructure in relation to drinking water, agricultural and energy uses.

3.2 Objective ("Why?): *Describe briefly the rationale/key driver of the UC, also using the tick boxes to specify the sectors, technologies, location and markets referred to this use case.*

Main rationale :

Decarbonisation

X Energy Optimi sation

Infrastructures optimisation

Flexibility provision

Sectors to be coupled:

Energy and water

Technologies deployed:

Blockchain, water-energy nexus

Impacted markets:

EHV

HV

MV

LV Day Ahead Energy Market

Day Ahead Balancing Market

Intraday Energy Market

Intraday Balancing Market

Flexibility Market

Distribution Constraints Market

Capacity Market

Other

Even if the production of energy from hydroelectric sources has some environmental impacts that can still contribute to the reduction of emissions, it can also allow the integration of non-programmable renewable sources in the fuel mix.

The production of hydroelectric power is a resource of great potential. It doesn't contribute to consumption of water as the withdrawals are fully returned and can carry out a series of additional services for the community compared to generation stand alone.

In terms of supply security and multipurpose solutions, a contribution to the management of reserves water can come from widespread storage systems.

Boundary conditions and prerequisites

4.1 External conditions: *List and assess the main conditions to be in place for realising the UC, commenting on their reasons, expectations, impact (show-stopper or simply reducing the UC feasibility), actors / decision makers behind such conditions; elaborate on ways to de-risk or secure such conditions.*

Management of water reserves shared with the Public and private stakeholders can offer multi-purpose services such as flood control, water and irrigation, fire prevention, the management of river waste blocked by retaining works.

4.2 Regulatory issues: *List and describe* main regulatory issues impacting and conditioning the feasibility of the use case.

Within the programs of the Green New Deal, interventions for the protection and increase of availability of water should be included. It would be opportune measures of exclusion from the calculation of the budget deficit of the public investments in relevant water infrastructures aimed at environmental protection and / or the land security. Specific financial instruments, such as green bonds, dedicated funds and investor intervention institutional as infrastructural fund

Business case (optional, only not confidential info)

5.1 Business model: *Short but comprehensive description of value chain flow: who invests, who sells/earns the UC product /service, who purchases/pays it, if there are pass-through or pass-over of costs to other stakeholders, if tariffs (or other regulated economic flows) are involved.*

Even if the production of energy from hydroelectric sources has some environmental impacts that can still contribute to the reduction of emissions, it can also allow the integration of non-programmable renewable sources in the fuel mix.

The production of hydroelectric power is a resource of great potential. It doesn’t contribute to consumption of water as the withdrawals are fully returned and can carry out a series of additional services for the community compared to generation stand alone.

In terms of supply security and multipurpose solutions, a contribution to the management of reserves water can come from widespread storage systems.

additional sources may be larger installations : recovery of abandoned sites and structures, such as disused quarries, can also contribute to face water crises and in some regions interventions of this type are being studied. Rolling tanks and exploitation of the aqueduct pipelines are other possible multifunctional configurations that could contribute to water supply security.

Other renewable sources, such as wind and solar power, could contribute to reducing water consumption in energy production.

As far as technological development is concerned, important innovations are expected in the production of ocean energy from the waves or tides.

Another sector in which it is possible to have a useful combination of the two sectors is represented by desalination plants

5.2 Economic assumptions: *List main implicit and explicit assumptions on economic values to be used for assessing feasibility of UC; include list of externalities (positive or negative); include CO2 role and values.*

s

5.3 Base case for reference: *Describe and quantify the best alternative(s) to reach the same goal, traditional or other competing innovative solution, to be used as reference for comparing the economics of UC against such base case.*

5.4 Sensitivities and key parameters: *List and shortly describe which are the few main parameters affecting the feasibility of UC, and which can determine the need of subsidies; in particular the parameters on which future evolution is expected. On such parameters break-even analysis should be made, to determine the break-even point for deployment without subsidies.*

Achieved results and impacts (for finished projects)

6.1 Benchmark between set goals and achieved results

Overall, the configurations identified could increase electricity production by 5.8 TWh/year (and water storage capacity for 2.8 billion cubic meters, equal to 20% of the reservoir capacity of the great Italian dams.

6.2 Shareable impacts

The interventions, recovery and management of the facilities must be part of strategies to combine environmental and energy objectives, aimed at maximising the benefits multiple use of water due to the different configurations analysed in the study

6.3 Policy contributions

The interventions (recovery and management of the facilities) should be part of an organic strategy at the national level able to provide for concrete measures that can bring results even in a relatively short term.

12.1.7 USE CASES ANALYSIS - FUTUREGAS

Stakeholder perspective of the Use Case (UC)

✓ **System**

☐ **TSO**

☐ **DSO**

☐ **Investor / Owner**

Use Case Identification

2.1 Name of UC: *FutureGas*

FutureGas analyses the gas chain from supply to regulation: efficient production and use of green gases including potential conditioning to natural gas quality, flexible use of gas also for transport, system integration, as well as the application of measures to ensure an economically efficient use of gas.

2.2 Proposer / supporter: *Company / Organisation / Funded Project including rationale and/or framework for proposing the UC*

Technical University of Denmark, Aarhus University, Danish Energy Association, Energinet, Evida, Danish Gas Technology Centre, Brintbranchen/Hydrogen Denmark, Chalmers University of Technology, Florence School of Regulation, Delft University of Technology, University of Exeter, NGF Nature Energy Holding A/S, RAM-Løse EDB, EA Energy Analysis, PlanEnergi, Danish Energy Agency, Ørsted

Funded by Innovation Fund Denmark

Objectives and Drivers set

3.1 Scope and Objectives ("What?"): *Describe briefly the scope (what is in scope, what is out of scope) and the objectives of the UC: KPI, targets, expected outcome*

✓ Energy Network

✓ Energy supply chain

☐ Location for deployment of UC: power grid / consumer plant / generation plant / storage plant / mobility hub / heating plants

Description:

The main purpose of the FutureGas project is to contribute to growth and green transition through interdisciplinary and coordinated research across the gas sector. The goal is to stimulate; 1) an efficient and economical supply of gas – including gas based on renewable sources, 2) an appropriate and flexible use of these gases, and 3) an optimal integration of gas in the overall energy system, including an energy and economic efficient interaction with heat, electricity, industry and transport sectors.

The FutureGas project is mainly focusing on Denmark.

3.2 Objective ("Why?): *Describe briefly the rationale/key driver of the UC, also using the tick boxes to specify the sectors, technologies, location and markets referred to in this use case.*

Main rationale :

- ✓ Decarbonisation
- ✓ Energy Optimisation

Infrastructures optimisation

Flexibility provision

Sectors to be coupled:

Gas, Electricity, Heat, Transport

Technologies deployed:

Mainly modelling and analysis, as well as tests on gas components and operation of biological methanation plant

Impacted markets:

EHV

HV

MV

LV Day Ahead Energy Market

Day Ahead Balancing Market

Intraday Energy Market

Intraday Balancing Market

Flexibility Market

Distribution Constraints Market

Capacity Market

Other

Boundary conditions and prerequisites

4.1 External conditions: *List and assess the main conditions to be in place for realising the UC, commenting on their reasons, expectations, impact (show-stopper or simply reducing the UC feasibility), actors / decision makers behind such conditions; elaborate on ways to de-risk or secure such conditions.*

The use case considers various technologies and systems, however, the power to gas (PtG) technology is highlighted in the following.

Power to gas (PtG): The deployment of PtG technologies is expected to increase in the future. However, to realise these expectations some external conditions might be in place. Costs of PtG technologies have to come down to be competitive with other alternatives. Producing PtG technologies on a larger scale is a next step to decrease costs. Market designs have to be uniformed and regulatory frameworks might be used to boost the production in the initial phase, and should not hinder the deployment.

4.2 Regulatory issues: *List and describe* main regulatory issues impacting and conditioning the feasibility of the use case.

A coherent regulatory framework needs to be developed and in place to ensure increasing production of PtG technologies. The electricity price is a determining factor for the feasibility of the PtG technologies and thereby also the electricity tariffs. Another example is that excess heat might be generated from the PtG technologies, and by having the availability to larger heating consumers (e.g. through district heating), an additional income for the PtG technology can be generated, and thus having a positive impact on the business case. However, some development of new markets like using excess heat might be further developed, as well as the flexible PtG units potential future participation in various electricity markets.

Business case (optional, only not confidential info)

5.1 Business model: *Short but comprehensive description of value chain flow: who invests, who sells/earns the UC product /service, who purchases/pays it, if there are pass-through or pass-over of costs to other stakeholders, if tariffs (or other regulated economic flows) are involved.*

5.2 Economic assumptions: *List main implicit and explicit assumptions on economic values to be used for assessing feasibility of UC; include list of externalities (positive or negative); include CO2 role and values.*

The main economic assumptions related to the feasibility of PtG technologies include, among others:

CAPEX, OPEX, lifetime, discount rate, electricity price, heat price, other revenue streams such as O2, and green value of the renewable gas.

5.3 Base case for reference: *Describe and quantify the best alternative(s) to reach the same goal, traditional or other competing innovative solution, to be used as reference for comparing the economics of UC against such base case.*

5.4 Sensitivities and key parameters: *List and shortly describe which are the few main parameters affecting the feasibility of UC, and which can determine the need of subsidies; in particular the parameters on which future evolution is expected. On such parameters break-even analysis should be made, to determine the break-even point for deployment without subsidies.*

The main sensitivity and key parameters for feasibility of the PtG technologies:

Costs (CAPEX, OPEX) of the technology

Electricity price (including tariffs)

Achieved results and impacts (for finished projects)

6.1 Benchmark between set goals and achieved results

The project has entailed detailed energy system modelling as well as supplementary analyses and tests in labs, and the achieved results correspond to the goals set before the project.

6.2 Shareable impacts

The project has many impactful and shareable results, (see www.futuregas.dk)

The most important findings from the FutureGas project, given the project assumptions, are summarised here:

It is still feasible to distribute a significant amount of gas through the current gas system in the future. Thus it is recommended that the overall gas grid is maintained.

The most important sectors for gas supply will be industry, but also to a certain degree households as well as the power and district heating sectors.

In individual heating, hybrid heat pumps combining an electric heat pump with a gas boiler show up to be an interesting option, however with a high sensitivity to costs.

Carbon Capture and Storage (CCS) has potential to become an economically viable option in 2050 and paves the way for more use of natural gas, especially in the part of the industry, where electrification isn't feasible.

Existing regulation should be reconsidered to bring the energy system more in accordance with the socio economic results. Current regulation may lead to a higher use of biomass and a lower use of especially wind power and natural gas than what is seen to be socio-economically viable.

Support to renewable gas production should be technology neutral, with fair accounting of externalities including negative GHG emissions, but also fertilising benefits etc.

6.3 Policy contributions

Support to renewable gas production should be technology neutral, with fair accounting of externalities including negative GHG emissions, but also fertilising benefits etc.

Existing regulation should be reconsidered to bring the energy system more in accordance with the socio economic results. Current regulation may lead to a higher use of biomass and a lower use of especially wind power and natural gas than what is seen to be socio-economically viable.

12.2 ANNEX 2 *LINK*-SOLUTION

12.2.1 RELATIONSHIP OF LINK-SOLUTION TO ENERGY SYSTEMS INTEGRATION

The main goal of the Energy Systems Integration (ESI) is the decarbonisation of the economy.

> *Energy Systems Integration is the process of coordinating the operation and planning of energy systems across multiple pathways and/or geographical scales to deliver reliable, cost-effective energy services with minimal impact on the environment (O'Malley et al. 2016).*

ESI covers the entire economy of a country. The economy is divided into sectors to determine the proportion of a population involved in various activities (Rosenberg, 2020). Although many economic models divide the economy into only three sectors, others divide it into four or even five. In our discussion, we will focus in the three first sectors: Primary[4]-, Secondary[5]-, and Tertiary[6] Sector, because the last two sectors: Quaternary- and Quinary Sector are closely linked with the services of the tertiary sector, which is why they can also be grouped into it. Additionally, both last sectors are not directly associated with energy resources.

ESI is categorised into three opportunity areas: Streamline, Synergise, and Empower (Fig. 20). These categorisations help to identify how various ESI approaches can offer solutions to problems related to climate change.

Streamline refers to improvements made within the existing energy system of different sectors by restructuring, reorganising, and modernising current energy systems through institutional levers (i.e., policies, regulations, and markets) or in-vestment in infrastructure. *LINK*-Solution modernises the electricity or power system in such a way that ESI can be realised.

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[4] The **primary sector** of the economy extracts or harvests products from the earth such as raw materials and basic foods. Activities associated with primary economic activity include agriculture (both subsistence and commercial), mining, forestry, grazing, hunting and gathering, fishing, and quarrying. The packaging and processing of raw materials are also considered to be part of this sec-tor.

[5] The **secondary sector** of the economy produces finished goods from the raw materials extracted by the primary economy. All manufacturing, processing, and construction jobs lie within this sector. Activities associated with the secondary sector include metalworking and smelting, automobile production, textile production, the chemical and engineering industries, aerospace manufacturing, energy utilities, breweries and bottlers, construction, and shipbuilding.

[6] The **tertiary sector** of the economy is also known as the service industry. This sector sells the goods produced by the secondary sec-tor and provides commercial services to both the general population and to businesses in all five economic sectors. Activities associated with this sector include retail and wholesale sales, transportation and distribution, restaurants, clerical services, media, tour-ism, insurance, banking, health care, and law.

Synergise describes ESI solutions that connect energy systems

- of various vectors within the second sector (ex. Cross different Vectors of the energy utilities such as electricity, heat, gas and so on);

Cross-Vector Sector Coupling involves the integrated use of different energy infrastructures and vectors, in particular electricity, heat and gas.

- between the electricity and End-Users (ex. electricity and transport, agriculture, industry, households and so on) to take advantage of benefits in efficiency and performance (Van Nuffel, Dedeca, Smit, & Rademaekers, 2018).

End-Use Sector Coupling involves the integrated use of different infrastructures within the Customer-Plants such as electricity or power, heat and cooling infrastructures, and the modernisation of energy demand while reinforcing the interaction between electricity supply and end-use, such as electricity or power to chemistry and so on.

LINK-Solution describes and enables the Cross-Vector and End-Use Sector Coupling.

Empower refers to ESI actions that include the consumer, whether through their investment decisions, their active participation, or their decisions to shift energy modes (e.g. through Energy Communities). *LINK*-Solution enables the creation and operation of Energy Communities.

Growing customer awareness regarding the various possibilities of their participation in the energy market clearly translates into their activity. This leads to the creation of new forms of activity that, in line with the expectations of the active customer, will bring measurable benefits not only at individual scale, but also at global scale. The changing role of the individual customer in the energy system is an important element in the transformation of the existing energy market model towards its decentralisation. The emerging new initiatives in which citizens organise to establish their own rules of activity at the local level prove that regardless of the existing theories, concepts or forms defined in the scientific literature, the process of changes in the energy market is progressing rapidly and its main leverage are active customers within Energy Communities.

In the context of sector coupling, Energy Communities could be seen from two perspectives:

1. The first one that fits into the concept of perceiving it as an important element of system integration, which, thanks to the involvement of active customers, who are members of the community, will significantly determine the directions of the future, vector-based connection of various elements of the energy system (production of energy for own needs, also related to heat pumps or charging electric cars).
2. The second perspective defines the activities undertaken by community members, A wide range of possibilities of using energy (both electricity and heat) contributes to the activation of the entire community, which, consequently, may also be a service provider for the entire system, ensuring its stable operation (flexibility services provider).

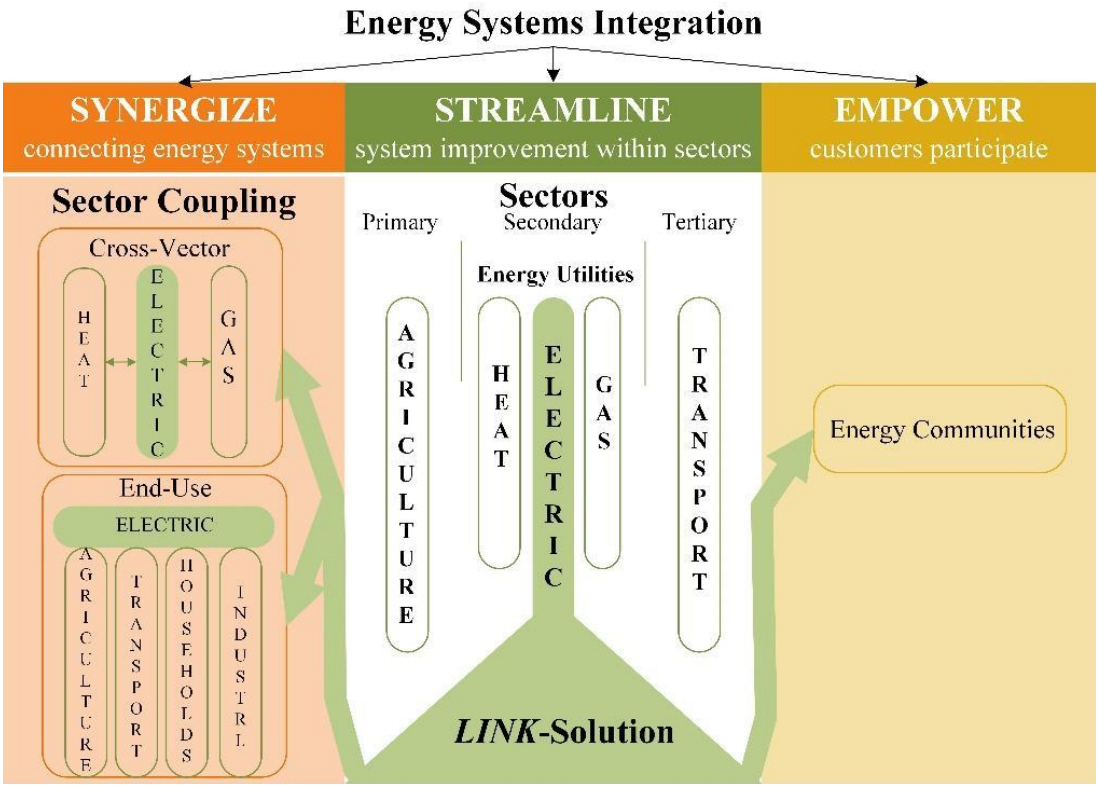

Figure 36. LINK-Solution in context of Energy Systems Integration based on (O'Malley et al. 2016)

12.2.2 NORTH AMERICAN TYPE OF POWER INDUSTRY

Figure 36 shows the LINK-based holistic architecture coupled with the Gas System in the case of North-American type of power industry. DSOs operate only the medium- and low voltage levels of the grid, This kind of organisation of power industry exists also in some countries in Europe e.g. Italy. In all cases, Sector Coupling takes place via the Coupling Components, CC.

Electricity Storage in the era of integrated energy systems takes on a new meaning. The traditional understanding of the storage that it injects electricity back at the charging point does not apply to all cases. Therefore, the storage is categorised as follows:

- Cat. A - the stored energy is injected at the charging point of the grid such as pumped hydroelectric energy storage, stationary batteries, etc.
- Cat. B - the stored energy is not injected back at the charging point on the grid such as Power-to-Gas (P2G), batteries of EVs, etc.
- Cat. C – the virtual stored energy reduces the electricity consumption at the charging point in the near future such as cooling and heating systems (consumer devices with energy storage potential) or chemical industry.

LINK-Architecture spreads over the whole power grid including extra high-, very high-, high-, medium- and low voltage levels, customer plants, and the market. Storage in each voltage level splits in Cat. A, B and C according to the categorisation given above. The cross coupling between the electricity and gas vector may be realised in high-, medium- and low voltage level through the storage of category B, Cat. B.

In Sector Coupling conditions the use cases for the electricity storage process are classified in traditional, and in Cross-Sector and End-Use Sector Coupling.

12.2.3 *LINK*-BASED USE CASES

In the following is described a generalised use case, which refers to more abstract relationships, and some more specialised cases.

The term power-to-X refers to technologies that convert surplus electricity into alternative products. The "X" may stand for fuel (e.g. hydrogen, methane, and so on), ammonia, chemicals, and heat among others. These products can be used directly, or may be converted back to electricity in power-to-power applications, making this option a flexible way to link power and fuel networks and an effective way to integrate intermittent renewable resources into energy systems and services (Hanna & al, 2018).

Fig. 25 shows the generalised use case for the price driven P2X response. It has four main players:

1.1 The market agent;
2.1 The Grid-Link operator (GriLiO) that may be a TSO, DSO or customer;
3.1 The operator of the electrolysing system: most of Sector Coupling systems use electrolysis to produce hydrogen, methane and so on. It may contribute as a storage of category Y (where Y can be A, B or C); and
4.1 The operator of the respective sector X (where X can be Gas, Chemical industry and so on)

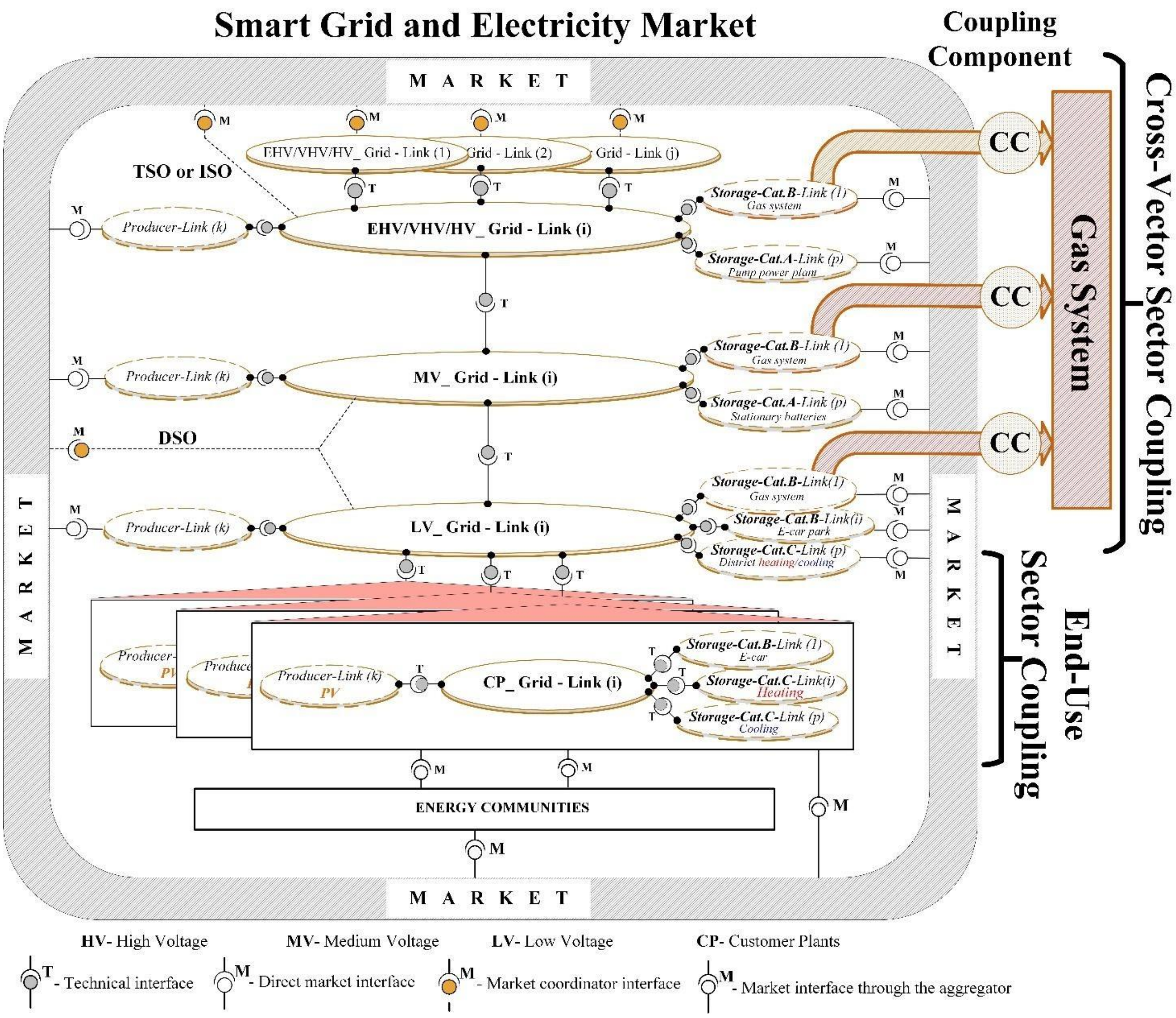

Figure 37. LINK-based holistic architecture coupled with the Gas System in the case of North-American type of power industry

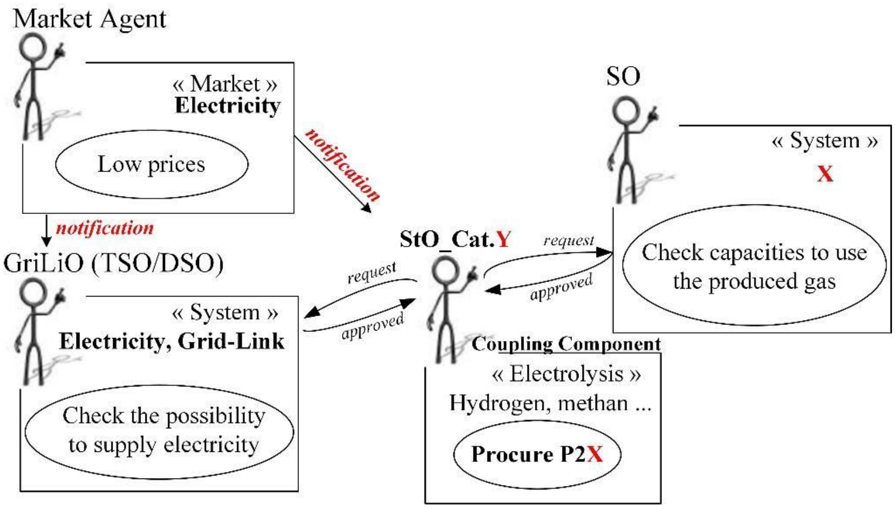

Figure 38. Generalised use-case: Price driven P2X response

In case of a surplus in electricity production, the prices in the market decreases and the Market Agent notifies the St.O_Cat.Y and the GriLiOs. St.O_Cat.Y send a request to increase the production of the gas (hydrogen, methane and so on) to the SO of System X. The latter, having checked the capacities in its own system, approves the action. StO_Cat.Y also checks the possibility of increasing the electricity consumption at the connection point with the grid by sending the relevant request to the corresponding GriLiO. The latter authorises the increase in consumption after checking the limits in its own grid. Finally, the StO_Cat.Y procures the P2X. Specific use-cases are described in Annex 10.2.

End-Use Sector Coupling happens in Customer Plant levels. The three main elements of the LINK-Architecture are also contained in this level. The End-Users consist of the primary and tertiary sectors of economy including agriculture, transport, industry, households, services, and so on. The main coupling in the Customer Plant level happens between the electricity and the heating and cooling equipment available in the End-User premises.

B.1 Use cases for the traditional storage

Storage facilities that behave traditionally are part of the electricity energy vector and inject the electricity at the charging point of the grid, Cat. A.

➢ Power to Hydrogen Energy Storage System (StO_Cat.A)

Hydrogen Energy Storage Systems (HESS) are a combination of an electrolyser unit, which produces hydrogen by consuming cheap electricity, and fuel cells that produce electricity by using hydrogen. It has normally one operator. Therefore, the “Electrolyses” and “System” blocks of generalised use cases are merged in the unique block “Storage System”. HESS is a storage of category A, because the electricity used to produce hydrogen is injected at the same point of the grid.

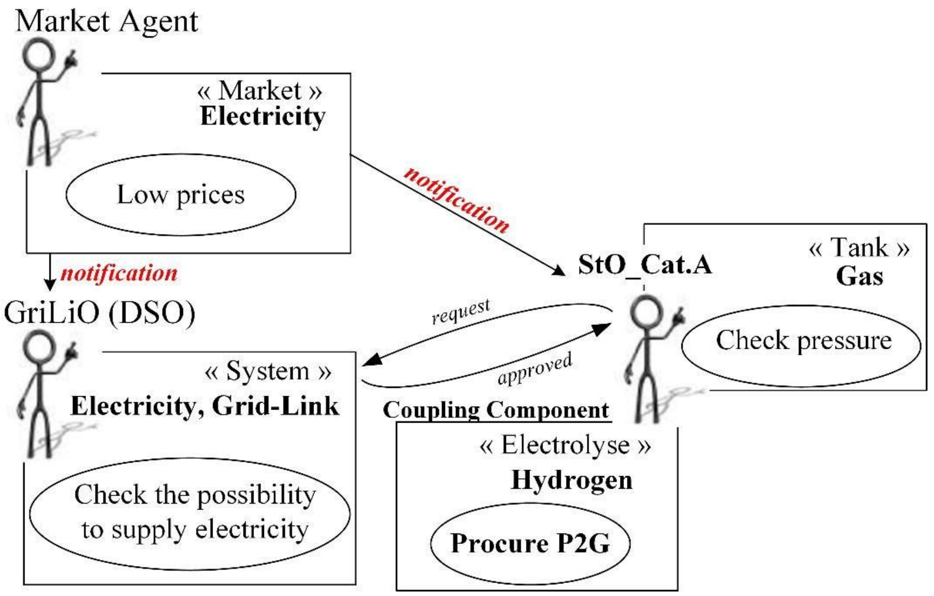

Figure 39. Use case: Price driven P2H response

➢ Power to Batteries (StO_Cat.A)

Nowadays, large batteries are experimentally connected in some distribution networks to increase network flexibility. They consist of many electrochemical cells that store chemically the electricity and vice versa transform the chemical energy to electricity (electricity-energy → chemical-energy → electricity-energy). The all energy transformation happens in one device, "Storage_System" Battery. The latter is a storage of category A, because the electricity used to produce hydrogen is injected at the same point of the grid

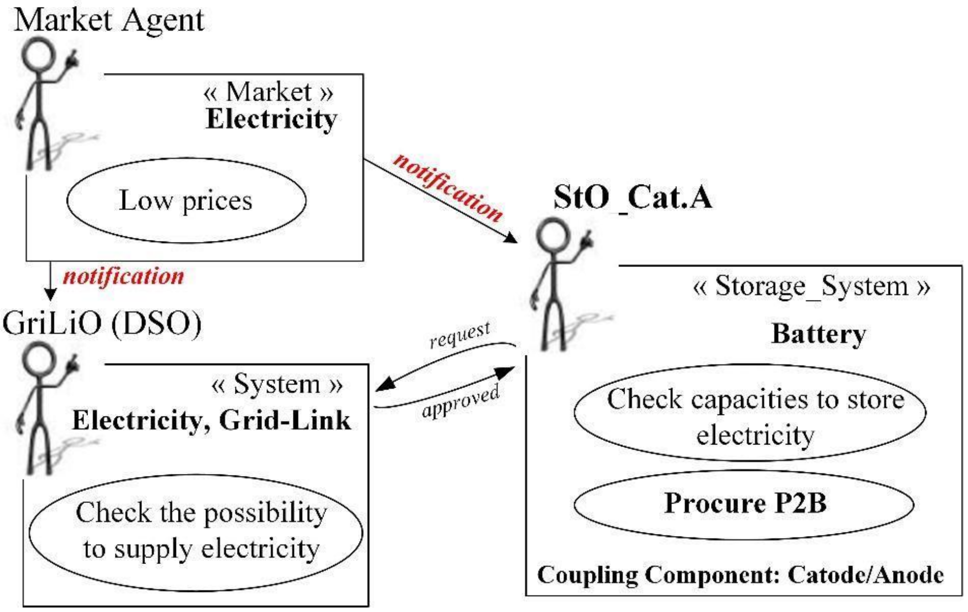

Figure 40. Use-case: Price driven P2B response

➢ Power to Water (StO_Cat.A)

Figure 20 shows the use case: Price driven P2W response. P2W is classified in the Cat. A of the storage. In this case, the StO_Cat.A also operates the Water Power Plant (WPPO). After being informed by the market agent about the low electricity prices, WPPO sends a request to the GriLiO (TSO) to increase the electricity consumption. After having verified the effectiveness of this action in its own Link, the TSO approves the request and the WPPO procures the P2W.

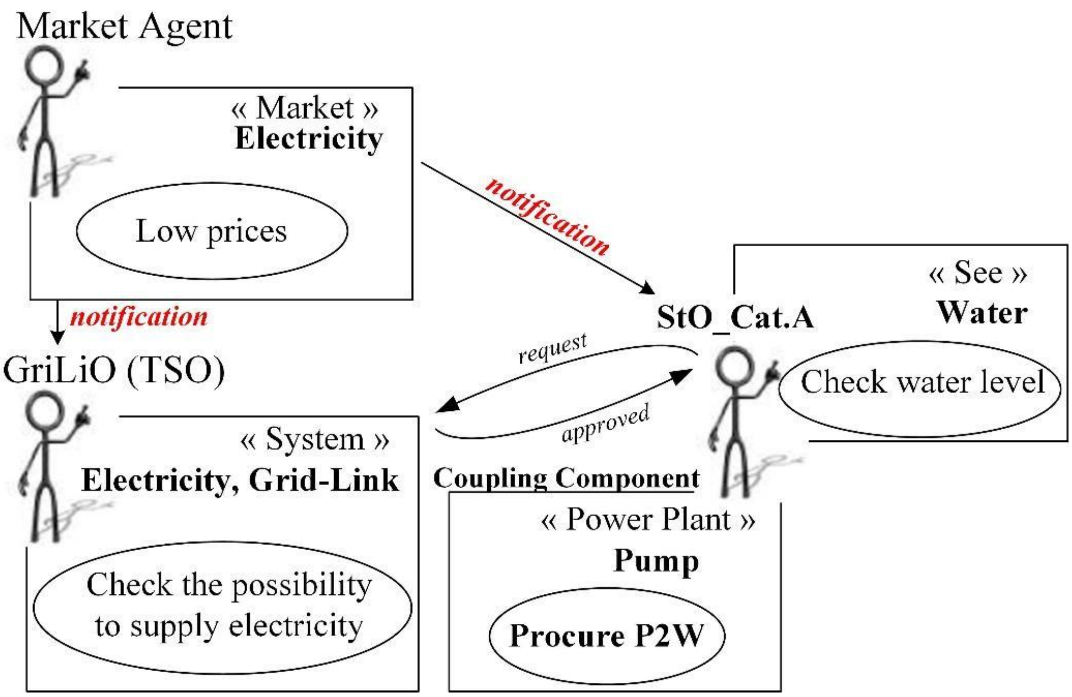

Figure 41. Use-case: Price driven P2W response

B.2 Use cases for the Cross-Vector Sector Coupling

Cross-Vector Sector Coupling takes place between the various vectors of the secondary economic sector. It takes place between the networks of the electric utilities and the networks of other utilities such as gas, fuel, heating and so on. In this case, the stored energy is not injected back at the charging point on the grid, Cat.B.

➢ Power to Gas (StO_Cat.B)

The interaction between different players is described by means of the use case: Price driven P2G response, P2G is classified in the Cat. B of the storage. The operator of the storage Cat.B, who for ex. is responsible for H_2 production, receives from the Market Agent a notification for low electricity price. Consequently, he sends a request to the operator of the Gas System (GasO) to increase for e.g. the H_2 production. After having checked the availability in the Gas System, SO approves the request of StO_Cat.B. The latter sends a request to the operator of the Grid-Link (GriLiO) where the charging point is located. After having verified the effectiveness of this action in its own Link, the GriLiO approves the request and the StO_Cat.B procures the P2G.

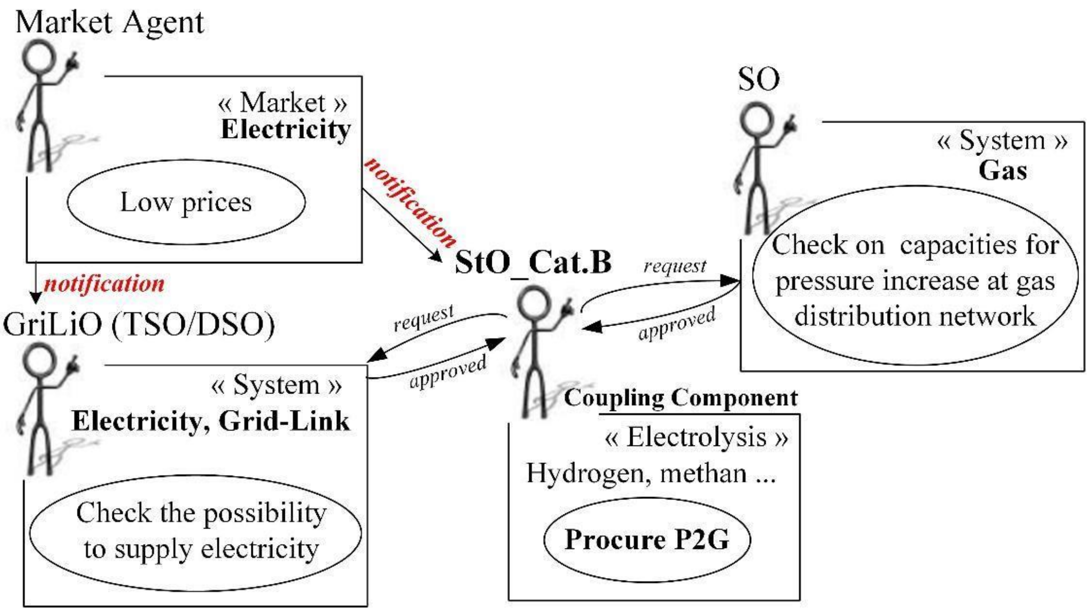

Figure 42. Use-case: Price driven P2G response

B.3 Use cases for the End-Use Sector Coupling

End-Use Sector Coupling happens in Customer Plant levels. The End-Users consist of the primary and tertiary sectors of economy including agriculture, transport, industry, households, services, and so on. The stored energy reduces the electricity consumption at the charging point in the near future, Cat.C.

From the perspective of the grid, Customer Plants in *LINK*-Solution act as black boxes. Within the Customer Plants or End-Users facilities, there may be the potential to implement different types of Storage-Links.

➢ Power to Households (StO_Cat.C)

Combined Heat and Power, CHP, typically developed for residential heating, can provide ancillary services for the power grid through the Prosumer/Customer Plant. It is the task of the secondary control, set up through the CP_Grid-Link, to find the optimum operating point of all available devices within the Customer Plant and the actual Grid circumstances. shows a typical use case of the End-Use Sector Coupling: Price driven P2H/C response. The GriLiO is the customer, who should have installed the House Management Unit (HMU). The latter takes over the coordination and the optimisation of the processes within the customer plant.

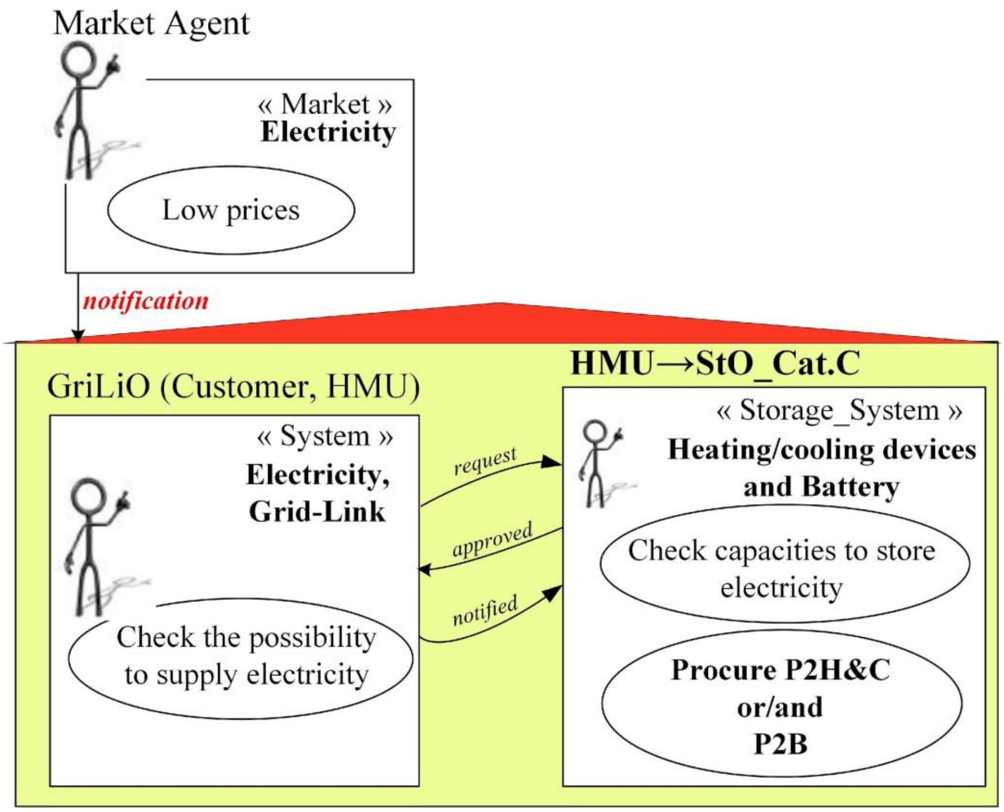

Figure 43. Use case: Price driven P2House response

Power to Chemicals (StO_Cat.C)

Power-to-Chemicals refers to a process the electrical energy is used via water electrolysis and other downstream steps to manufacture chemical raw materials. In this way, the production of the latter can also be decarbonised. The products produced by electrolysis are not used for direct energy storage. However, it deals with a virtual stored energy, which reduces the electricity consumption at the connection point in the near future, storage category C,

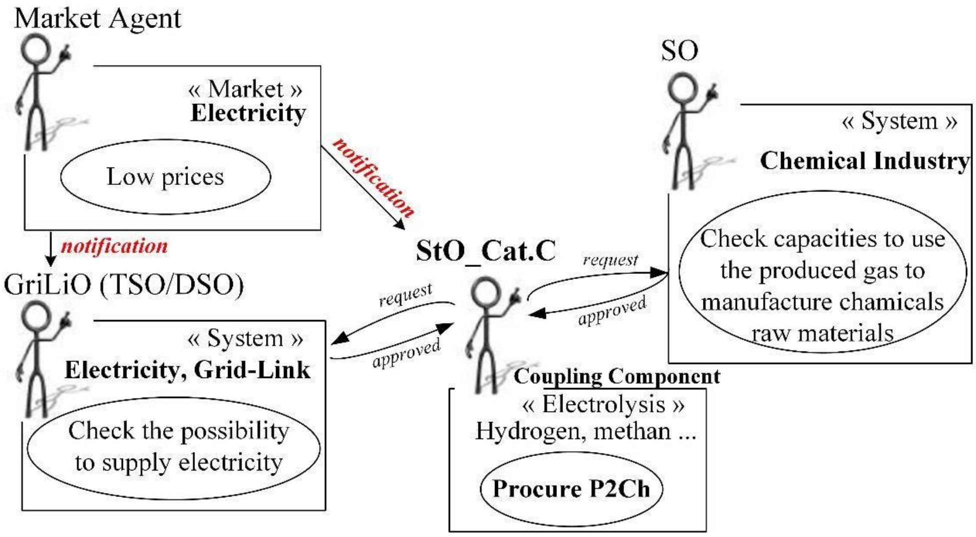

Figure 44. Use case: Price driven P2Ch response

12.3 ANNEX 3

National Hydrogen plans/Strategies [7]:

NATIONAL HYDROGEN PLANS/STRATEGIES					
Country	Document	Pages	Data	Foreseen investments	Website
Published in Europe					
France	Plan Hydrogene	26	June 2018	100 + 90M€ (in 2019)	https://www.ecologique-solidaire.gouv.fr/plan-hydrogene-outil-davenir-transition-energetique
Germany	The National Hydrogen Strategy	32	June 2020	250 + 481M€ (in 2019)	https://www.bmbf.de/files/bmwi_Nationale%20Wasserstoffstrategie_Eng_s01.pdf
Italy	Piano Nazionale di Sviluppo – Mobilità Idrogeno Italia	163	2019	418M€ (in 2021-2025)	https://www.h2it.it/wp-content/uploads/2019/12/Piano-Nazionale_Mobilita-Idrogeno_integrale_2019_FINALE.pdf
Portugal	Estratégia Nacional para o Hidrogénio (EN-H2)	81	August 2020	7-9bn€ (until 2030)	https://dre.pt/home/-/dre/140346286/details/maximized
Netherlands	Government Strategy on Hydrogen	14	2019	17,5-2,5bn€ (until 2030)	https://www.government.nl/binaries/government/documents/publications/2020/04/06/government-strategy-on-hydrogen/Hydrogen-Strategy-TheNetherlands.pdf
Being prepared in Europe					
Czech Republic	There is no H2 National Strategy, but the National Plan on energy and climate 2030 mentions the role of H2	442	November 2019		https://ec.europa.eu/energy/sites/ener/files/documents/cs_final_necp_main_en.pdf

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[7] Partly sourced from https://www.fchobservatory.eu/observatory/policy-and-rcs/National-policies/other-relevant-policies

Greece	There is no H2 National Strategy, but the National Plan on energy and climate 2030 mentions the role of H2	307	2019		-
Ireland	There is no H2 National Strategy, but a private report was produced to support a national strategy	135	October 2019		http://hydrogenireland.org/wp-content/uploads/2019/10/HMI_report_final_Oct3rd2019-2.pdf
Latvia	There is no H2 National Strategy, but the National Plan on energy and climate 2030 mentions the role of H2	214	2018		https://ec.europa.eu/energy/sites/ener/files/documents/ec_courtesy_translation_lv_necp.pdf
Spain	"Hoja de Ruta del Hidrógeno: una apuesta por el hidrógeno removable	72	Roadmap closed public consultation on 11 September 2020		https://energia.gob.es/_layouts/15/HttpHandlerParticipacionPublicaAnexos.ashx?k=16826
UK	There is no H2 National Strategy, but mounting pressures calling for one				https://hydrogenstrategynow.co.uk/
International					
Australia	Australia's National Hydrogen Strategy	136	2019		https://www.industry.gov.au/sites/default/files/2019-11/australias-national-hydrogen-strategy.pdf
Chile	Estrategia Nacional Hidrógeno Verde	25	June 2020		https://www.energia.gob.cl/sites/default/files/mini-sitio/estrategia-nacional_hidrogeno-verde_vdef.pdf

China	The first Hydrogen Fuel Cell Vehicle Technology Roadmap was released in 2016, and later that year H2 new energy vehicles & hydrogen infrastructure were added to the 14th Five-Year Plan outlining targets for mass application of hydrogen in the transport sector		article September 2019		https://www.cleantech.com/hydrogen-in-china/
Japan	Basic Hydrogen Strategy	5	2017		https://www.meti.go.jp/english/press/2017/pdf/1226_003a.pdf
US	Hydrogen Strategy – Enabling a Low-Carbon Economy	24	July 2020		https://www.energy.gov/sites/prod/files/2020/07/f76/USDOE_FE_Hydrogen_Strategy_July2020.pdf

Reference projects

acronym	EC fiche	name	website	sector	type of sector integration
H2Future	https://cordis.europa.eu/project/id/735503	HYDROGEN MEETING FUTURE NEEDS OF LOW CARBON MANUFACTURING VALUE CHAINS	https://www.h2future-project.eu/	Steel Industry	6MW PEM electrolyser to produce Hydrogen and electricity for the steel industry. This project brings together energy suppliers, the steel industry, technology providers and research partners, all working hand in hand on the future of energy. Six partners, one goal: green hydrogen from green electricity.
REFHYNE	https://cordis.europa.eu/project/id/779579	Clean Refinery Hydrogen for Europe	http://www.refhyne.eu/	Oil refinery	REFHYNE will install and operate the world's largest hydrogen electrolyser the Shell Rhineland Refinery in Wesseling, Germany.The electrolyser has a peak capacity of 10 MW (megawatts) and will be able to produce approximately 1,300 tonnes of hydrogen per year. This decarbonised hydrogen can be fully integrated into refinery processes including the desulphurisation of conventional fuels. The project will use the hydrogen produced for: 1.Processing and upgrading products at the Wesseling refinery site. 2. Testing the PEM technology at the largest scale achieved to date. 3. Exploring applications in other sectors including: industry, power generation, heating for buildings, and transport.

DEMO4GRID	https://cordis.europa.eu/project/id/736351	Demonstration of 4MW Pressurised Alkaline Electrolyser for Grid Balancing Services	https://www.demo4grid.eu/	Grid services	commercial setup and demonstration of a technical solution using the Pressurised Alkaline Electrolyser (PAE) technology for providing grid balancing services under real operational and market conditions and the production of Green Hydrogen for industrial energy services
GRINHY2	https://cordis.europa.eu/project/id/826350	Green Industrial Hydrogen via steam electrolysis	https://www.green-industrial-hydrogen.com/	Steel Industry	By the end of 2022 it is expected to have been in operation for at least 13,000 hours, producing a total of around 100 tonnes of high-purity (99.98 %) hydrogen. This will be used for annealing processes in the integrated steelworks as a replacement for hydrogen produced from natural gas.
DJEWELS	https://cordis.europa.eu/project/id/826089	Delfzijl Joint Development of green Water Electrolysis at Large Scale	https://djewels.eu/	Green fuels production	demonstrate the operational readiness of a 20 MW electrolyser for the production of green fuels (green methanol) in real-life industrial and commercial conditions

12.4 ANNEX 4

12.4.1 LIST OF REFERENCE PROJECTS

SOLAR ENERGY - POWER-TO-X - SUSTAINABLE INDUSTRY

PECSYS's goal is to develop a scalable integrated device, using breakthrough materials and technology, for direct hydrogen production from sunlight, and to test it under industrial settings. This solar generated hydrogen stores solar energy in a chemical form and releases it, as required for example at night, via a fuel cell.

REGULATION – CERTIFICATION

CERTIFHY marked the start of a new green hydrogen market by launching the first-of-its-kind EU-wide “guarantees of origin” pilot scheme for green and low carbon hydrogen. Environmentally sustainable hydrogen is essential to decarbonise the energy system

AVIATION

HEAVEN will allow zero-emissions long range flights thanks to the high power fuel cell and cryogenic hydrogen storage technology. It will have an autonomy range of >800 kilometres for up to 19 passengers.

SUSTAINABLE INDUSTRY - STEEL PRODUCTION - HEAVY INDUSTRY

H2FUTURE uses excess electricity from renewables to split water molecules via electrolysis, the resulting green hydrogen can be stored in fuel cells to supply power as needed. The project has focussed particularly on deploying a large-scale electrolysis system operated for steel manufacturing. It demonstrated the increasing power of electrolysers, highlighting their suitability for energy-intensive heavy industries.

REFUELLING STATIONS - HYDROGEN CARS – MOBILITY

H2ME helped to significantly expand the number of hydrogen vehicles and the refuelling network. H2ME deployed 29 hydrogen refuelling stations and 325 vehicles, while its follow-up project, H2ME2, is adding 20 hydrogen refuelling stations and over 1100 vehicles in Europe. Altogether, these projects are kick-starting a pan-European hydrogen fuelling station network.

PUBLIC TRANSPORT - SUSTAINABLE CITIES - BUSES – MOBILITY

JIVE and JIVE2 contribute to the increase of hydrogen buses in Europe to almost 400. Hydrogen fuel cell buses provide multiple benefits and are popular with both the public and transport operators. They contribute to cleaner air in urban areas, and are much quieter than buses running on fuel. Their ability to travel up to 400 kilometers without refueling also makes them a strategic choice for sustainability seeking city councils.

MARITIME - PORT – INFRASTRUCTURE

H2PORTS aims to boost the transition of the European port industry towards an effective low-carbon/zero-emission and safe operating model with fuel cell technologies oriented to increase energy efficiency, decarbonisation and safety of port terminals. It will demonstrate and validate two innovative solutions based on fuel cell technologies and a hydrogen mobile supply station in real port operations.