ETIP SNET

VISION 2050

Integrating Smart Networks for the Energy Transition:

Serving Society and Protecting the Environment

PLAN.

INNOVATE.

ENGAGE.

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Disclaimer

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Glossary

- **Energy systems:** electricity, gas, heating and cooling, liquid fuel systems, and other energy carriers (any system or substance that contains energy for conversion as usable energy later) are all considered ‘energy systems’.
- **Carbon-neutral:** situations where the energy system consumes as much CO_2 as it emits; the CO_2 balance is equal to zero.
- **Contingency:** an event (such as an emergency) that may but is not certain to occur. In power systems, a contingency is when an element such as a transmission line or a generator, of the electric grid fails.
- **Low-carbon:** situation where the CO_2 balance (i.e. emissions vs. sinks) is almost zero.
- **Prosumers:** consumers of all types (households, tertiary, industry, transport and agriculture sectors) who also produce energy. Prosumers can be active market participants by engaging in the real-time control of their energy-consuming and producing devices.
- **Power-to-Gas (PtG):** conversion of electrical power to a gas fuel. As an example of such conversion, electricity is used to split water into hydrogen and oxygen using the electrolysis principle, where hydrogen can then be converted to methane with CO_2 as input.
- **Power-to-Heat (PtH):** conversion of electrical power into heat/cooling. The conversion can be done for example by using conventional electric heaters or heat pump systems.
- **Power-to-Liquid (PtL**): conversion of synthetic gas (CO and H_2) into a mix of raw products, suitable for further processing at refineries or in the chemicals industry in view of the transformation into industrial products.
- **Gas-to-Power-and-Heat (GtP&H):** combustion of gases to generate at the same time and with high efficiency electricity and heat.
- **Gas-to-Heat (GtH):** combustion of gases to generate heat.
- **Adequacy:** A measure of the ability of a power system to meet the electric power and energy requirements of its customers within acceptable technical limits, taking into account scheduled and unscheduled outages of system components.
- **Resilience:** ability of the system with generating sources, transmission and distribution, conversion – to withstand high-impact, low-frequency events. This includes events that are natural, such as hurricanes or ice storms, as well as man-made, such as cyber or physical attacks on e.g. grid infrastructure.
- **Reliability:** all the measures of the ability of the system, generally given as numerical indices, to deliver electricity to all points of utilisation within acceptable standards and in the amounts desired.
- **Low voltage (LV):** usually refers to AC voltages from 50 to 1,000 volts.
- **Medium voltage (MV):** usually refers to AC voltages between 1,000 volts to 35,000 volts.
- **High voltage (HV**): usually considered any AC voltage over approximately 35,000 volts. This is a classification based on the design of apparatus and insulation.
- **Alternating current (AC):** an electric current which periodically reverses direction.
- **Direct current (DC):** is the unidirectional flow of electric charge.
- **Flexible AC Transmission Systems (FACTS**): is a system composed of static equipment used for the AC transmission of electrical energy. It is meant to enhance controllability and increase power transfer capability of the network. It is generally a power electronics-based system.
- **Digital twin:** refers to a digital replica of physical assets, processes and systems that can be used for various purposes. The digital representation provides both the elements and the dynamics of how an Industrial Internet of Things device operates and lives throughout its life cycle including continuous digital predictions through machine learning and artificial intelligence.

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FOREWORD

Miguel Arias Cañete

EU Commissioner for Climate Action & Energy (2014-2019)

It is in everyone's long-term interest to have a rapid and orderly transition towards a cleaner, more sustainable and less carbon intensive energy future.

Since 2014, the strategy of the European Union has been clear: we need to drive a clean, secure and efficient energy transition to face climate and energy challenges. This strategy has been reinforced by the strong commitment of the European Union towards the signature of the landmark 2015 Paris Agreement. This is also why the Commission proposed in November 2016 an ambitious "Clean Energy for All Europeans" package.

All relevant meetings, summits and measures started from a simple observation: "It is in everyone's long-term interest to have a rapid and orderly transition towards a cleaner, more sustainable and less carbon intensive energy future."

However, this simple observation requires us to look at a multifaceted challenge:

- Moving towards a low carbon energy sector
- Maintaining and extending global industrial leadership
- Creating a pan European integrated energy system
- Mobilising public and private sector towards the same objectives to finance the changes

The European Commission is working on a long-term decarbonisation strategy where these different thoughts will come together into one coherent strategy.

Therefore, by supporting the long-term decarbonisation strategy for the EU, this Vision 2050 elaborated and presented by the European Technology and Innovation Platform of Smart Networks for Energy Transition (ETIP SNET) is a useful tool to address these challenges and to achieve these common goals.

Thanks to the commitment of the research and industry experts, European and national public authorities, European associations and others, the platform has accomplished an exemplary job in gathering all actors from the energy sector to tackle the key aspects of a very complex issue. Indeed, the ETIP SNET Vision 2050 is an effective instrument that demonstrates to all in Europe and elsewhere that we have technical insights into our challenges, that our investments in human and financial capital will have an impact and an effective life-span well beyond 2050 for Europe to create a secure, sustainable and competitive energy system. It is also a remarkable reference publication for all actors having an interest in the energy sector.

The European Commission would like to pay tribute to all efforts made by the stakeholders of the platform to produce this Vision 2050 that advances a more unified Europe based on a:

> *low-carbon, secure, reliable, resilient, accessible, cost-efficient, and market-based pan-European integrated energy system supplying the whole economy and paving the way for a fully CO_2-neutral and circular economy by the year 2050, while maintaining and extending global industrial leadership in energy systems during the energy transition.*

Vision 2050 is a document of crucial importance to accompany the ambitious objectives of a clean, secure and efficient energy transition.

I am confident that Vision 2050 will be taken up by all relevant entities and encourage the ETIP SNET to continue its research and innovation development efforts by contributing with its expert knowledge and scientific experience to making the energy transition a reality.

INTRODUCTION

Nikos Hatziargyriou

Chairperson of the European Technology and Innovation Platform of Smart Networks for Energy Transition (ETIP SNET)

Chairman & CEO of the Hellenic Electricity Distribution Network Operator (HEDNO S.A.)

> In this document, the ETIP SNET stakeholders present their vision of a longer time horizon (2050) with a particular focus on low-carbon energy systems' integration needs for all involved users.

European citizens are central actors in the transition from the present single-carrier, fossil-based energy systems towards an integrated, low-carbon, secure, reliable, resilient, accessible, cost-efficient and market-based energy system by the year 2050. This system will pave the way for a fully CO_2 neutral and circular economy, while maintaining and extending global European industrial leadership in energy systems during the energy transition.

In 2006, the European Technology Platform (ETP) for Smart Grids (SG) presented its Vision for 2020 and beyond. In 2017, the European Technology and Innovation Platform for Smart Networks for the Energy Transition (ETIP SNET) was established with the support of the European Commission, building on the previous activities of the ETP SG and the EEGI (European Electricity Grid Initiative), while expanding its scope to the entire energy system, integrating and optimising all sources and vectors. With this document, the ETIP SNET stakeholders present their vision of a longer time horizon (2050) with a particular focus on low-carbon energy systems' integration needs for all involved users.

Distribution System (DSOs) and Transmission System (TSOs) operators, storage technology and services providers, energy and information system equipment manufacturers and suppliers, information and communication technology and software providers, research centres and academia are core stakeholders of the ETIP SNET. Representatives from renewable energy sources, flexible thermal generation, and from other energy carrier networks interfacing with the electricity networks, such as gas, heating and cooling and the transport sector are active participants of the Platform. Regulators and national representatives are also key contributors to the ETIP SNET, ensuring full coordination between European and national energy system policies.

Members of this very wide stakeholder group see electricity distribution and transmission grids as the "backbone" of the future low-carbon energy systems with a high level of integration among all energy carrier networks, by coupling electricity networks with gas, heating and cooling networks, supported by energy storage and power conversion processes. Such energy systems will be fully-digitalised, with a high level of automation. Efficient markets supported by digital platforms, from wholesale to retail, will allow all stakeholders of the energy system to trade energy, including prosumers selling their excess energy to the neighborhood in peer-to-peer transactions. Digital solutions will be interoperable, certified and cyber-secure.

The ETIP SNET Vision 2050 presents consolidated and qualitative ETIP SNET stakeholders' views for the energy system of 2050 and the associated high-level research, development and innovation (RD&I) challenges. It also indicates the framework in which RD&I efforts should be pursued in the decades to come. Within this framework, the upcoming ETIP SNET roadmaps and ETIP SNET implementation plans will elaborate further on the necessary steps, and actions to be taken.

The content of this document accumulates the views and knowledge of many experts. I would like to thank all contributors, more specifically the members of the ETIP SNET Governing Board whose intensive discussions led to this consensually-agreed vision document. More than 200 dedicated experts from five ETIP SNET working groups and the National Stakeholder Coordination Group have contributed to this work by providing valuable inputs in several workshops, interactive discussions and webinars.

I would also like to thank all stakeholders and individuals who commented upon the various versions of this vision through ETIP SNET internal and public consultation processes. The ETIP SNET support team (Horizon 2020 project INTENSYS4EU) and in particular the Vision 2050 Core Team who took the responsibility for editing and laying out this document and figures deserve the highest acknowledgement. Finally, and most importantly, special thanks to the representatives of the European Commission for their advice and facilitation.

On behalf of the ETIP SNET, I hope that this Vision 2050 will provide the essential inspiration and will contribute to a more robust and faster transition to a sustainable future.

EXECUTIVE SUMMARY

A low-carbon, secure, reliable, resilient, accessible, cost-efficient, and market-based pan-European integrated energy system supplying all of society and paving the way for a fully carbon-neutral circular economy by the year 2050, while maintaining and extending global industrial leadership in energy systems during the energy transition.

Vision 2050 by ETIP SNET

A low-carbon, secure, reliable, resilient, accessible, cost-efficient, and market-based pan-European integrated energy system supplying all of society and paving the way for a fully carbon-neutral circular economy by the year 2050, while maintaining and extending global industrial leadership in energy systems during the energy transition.

All emerging and developed economies around the world will decarbonise their energy systems. Europe will have to consider the strategic nature of low-carbon energy systems and support its industries and research to advance innovation accordingly, thus maintaining and enhancing competitiveness at all levels.

The electrification of Europe's energy systems will be the backbone of its societies and markets. This will require the incremental coupling of electricity and gas networks, via the production of carbon-neutral synthetic gases (methane), to ensure long-term security of supply (seasonal storage), for an electricity system powered by renewable energy sources. A low-carbon European economy will also include the coupling of electricity and heating and cooling systems, and of electricity and liquid fuels, supplemented with biofuels, for heavy-duty vehicles, maritime transport and aviation.

While using all available local energy sources and associated infrastructures for all types of needs, the massive electrification of the European economy (residential, tertiary, industry, agriculture and transport sectors) will embody full digitalisation and flexible electricity interconnections. All system flexibility solutions, including those for prosumers and consumers, will be adopted to optimise the grid capacity uses from different generation and consumption centres that are very distant and/or very near to one another.

The implementation of the energy transition will be market-based: the investments in energy system technologies will be catalysts for innovation and spill-over into other economic and technological sectors, thus contributing to the growth of the European economy. Implementing Vision 2050 will require major investments for the large-scale development and deployment of power conversion and storage devices, the upgrade and extension of the pan-European transmission (electricity and gas) and local distribution (electricity, gas, heating and cooling) energy networks and the use of digital solutions. Additionally, competitive retail markets will ensure consumer-based aggregation to be valued in local markets.

In comparison to 2018, the additional investments will be offset by increased social welfare and environmental benefits, including the avoided costs of adaptation to climate change and mitigation of effects. The *costs of not acting now* could be worth several times the cost of such investments against climate change; such costs are estimated for electricity transmission networks in the Ten-Year Network Development Plan (TYNDP) 2018 of ENTSO-E. Evidently, Europe must invest now, massively, in the energy transition.

The investments in local and pan-European infrastructures and flexibility solutions must be supported by adequate funding of innovative research validated in large-scale demonstrations to manage risks and to test the integration of Europe's digitalised energy systems.

This **ETIP SNET Vision 2050** is the basis for defining the specifications for further research and innovation needs in the transition from today towards Europe's energy systems of the future. Its purpose is to inspire readers, to let them discover the RD&I challenges associated with a 2050 low-carbon, fully-integrated, and circular pan-European energy system with the electricity system as its backbone.

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01
ENERGY SYSTEMS FOR EUROPEAN SOCIETY

The pan-European energy system comprises energy systems that are connected at cross-border and local levels.

Addressing climate change is a major driver for national energy policies around the world which converge on the urgent need to decarbonise energy systems in a context of moving towards circular economy models. In 2015, the United Nations (UN) adopted the 17 Sustainable Development Goals (SDGs) of the 2030 Agenda for Sustainable Development to ensure greater environmental sustainability. The SDGs most related to this ETIP SNET Vision 2050 emphasise the role of energy and more specifically of clean energy systems to meet citizen needs: **SDG 7** calls for **access to affordable, reliable, sustainable and modern energy for all**; **SDG 9** requests to **build resilient infrastructure, promote sustainable industrialisation and foster innovation**; and **SDG 11** asks to **make cities inclusive, safe, resilient and sustainable**.

Also in 2015, in the UN Framework Convention on Climate Change (UNFCCC), member countries adopted the Paris Agreement at the 21st Conference of Parties (CoP) to limit global temperature rise to "well below 2 degrees Celsius" and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius. This is in line with the most challenging energy future scenario advanced by the International Energy Agency (IEA) called "Beyond [meaning below] 2 Degrees Scenario" (B2DS).

Three objectives for 2050 energy systems

Energy systems are vital infrastructures that meet essential societal needs and without which our modern life would be impossible. They drive industrial processes, help exploit natural resources, make agriculture more efficient, enable most services, the distribution of goods and the movement of people, treat and pump water, keep us comfortable with heating and cooling. They are the basis for all industrial revolutions, including the Internet, which is also an example of the increasingly crucial role of electricity. They are a central foundation for prosperity, and by making life comfortable and productive for all, they support societal cohesion. By connecting all of Europe and providing mutual support during emergencies, they support European integration. There are multiple energy systems, including the electricity systems, the gas systems, the heating and cooling systems, the liquid fuel systems, as well as any other systems of energy carriers (any system or substance that contains energy for conversion as usable energy later or somewhere else).

European Union energy policy stipulates that energy systems should help implement three objectives that are crucial for the well-being of society:

1. **Protecting the environment**
2. **Creating affordable and market-based energy services**
3. **Ensuring security, reliability and resilience of energy supply**

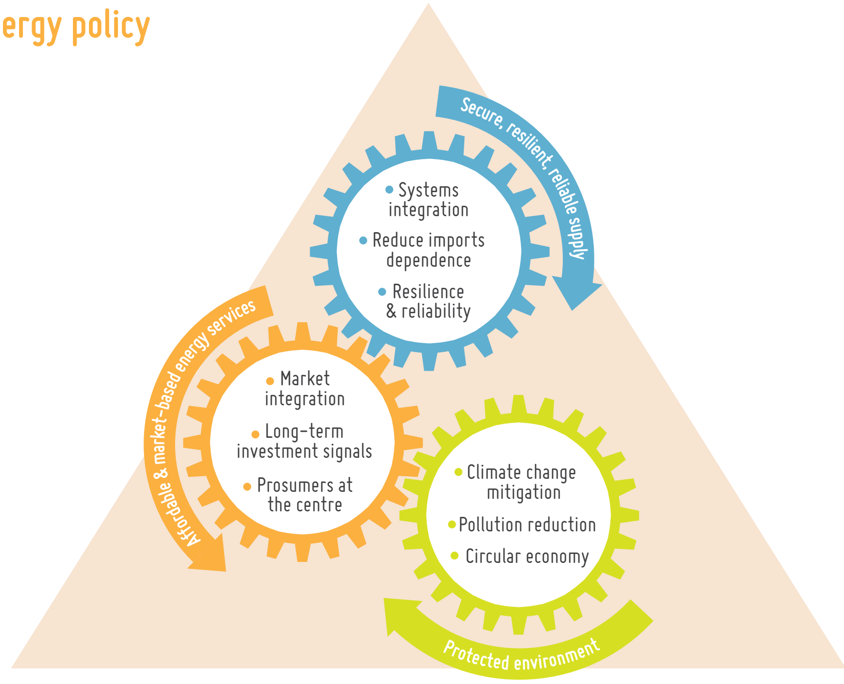
Protecting the environment

Mitigating environmental impacts of energy systems has several dimensions, including:

- Decrease greenhouse gases (GHG) emissions for climate change mitigation
- Control all sources of pollution originating from activities directly or indirectly linked to energy systems
- Minimise impacts on biodiversity and natural ecosystems
- Promote a circular economy (ideally all non-energy outputs are re-used) [see Figure 2]

Addressing these dimensions of environmental protection provides European citizens above all with a more stable climate, a clean environment, better air quality, and better human health and comfort.

Figure 1. The three goals for the EU energy policy



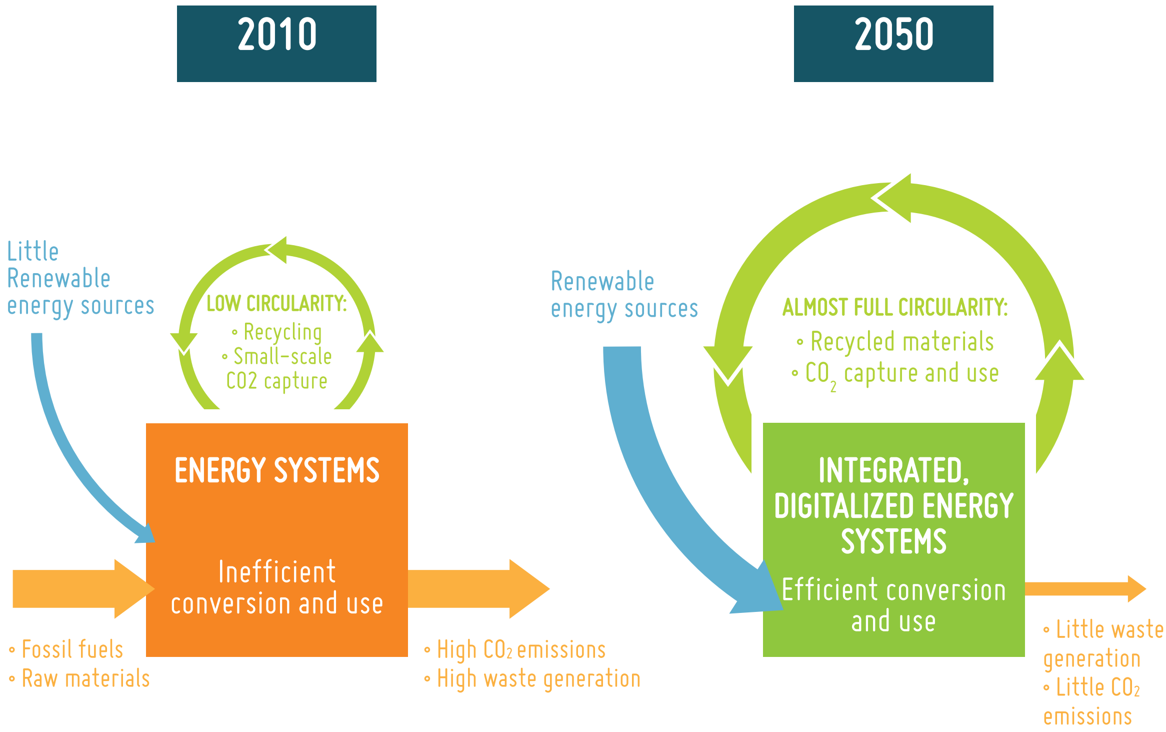
In 2050, the impact of European energy systems on the climate is reduced drastically. A combination of measures, including energy efficiency, renewable technology deployment for energy generation, new storage and power conversion technologies, and improved operational and market procedures, all help mitigate global and local environmental impacts, offsetting the effects of energy systems' increasing complexity.

This is achievable because long before 2050, innovative public policies enable **more choice and more conscious participation** by all stakeholders, including citizens, in the energy systems. This includes energy savings and energy efficiency measures, supported by the latest communication technologies. Based on coherent price signals and increased public awareness, users and prosumers contribute to the energy transition being efficient while mitigating environmental impacts and satisfying societal needs.

In 2050, carbon-neutral and especially renewable energy alternatives to fossil fuels are implemented for all energy needs. The use of crude oil for all domestic, industrial and mobility needs is marginal thanks to the substitution of crude-oil with biomass, biofuels and other renewable energy sources, such as CO_2-free electricity for cars, trains, and urban buses and delivery trucks. This results in low-carbon energy systems with carbon-neutral electricity systems and liquid fuels (this goes beyond the most ambitious scenario – high RES Scenario – in the EC Energy Roadmap 2050 (2012) for which fossil fuels account for under 10% of electricity generation and the share of renewables in transportation is 73% in 2050). A low-carbon pan-European energy system paves the way for a fully decarbonised and circular European economy beyond 2050 (this also goes beyond the high-RES scenario in which oil, natural gas, and solids account for 36% in the total gross inland consumption).

In 2050, the energy system is thus (almost) fully decarbonised, in line with the EC Energy Roadmap 2050 (2012) targeting greenhouse gas emissions reduction to 80-95% below 1990 levels by 2050**.** Low-carbon energy systems have been facilitated by the advent of sustainable supply chains (including the supply of raw materials like 'rare earths') with the support of coherent research strategies, regulatory frameworks, streamlined standardisation and interoperable processes. Electricity, mobility, heating and cooling needs, including storage from hours of a day to weeks and seasons, are provided by renewable energy sources (RES). In line with the assumptions of the most challenging scenarios developed, such as the IEA B2DS, ETIP SNET estimates that energy systems can be carbon-neutral by 2050 and carbon-negative beyond 2060.

Figure 2. From the past quasi-linear to the circular economy in 2050



In 2050, power conversion and flexible energy storage plays a key role in energy systems. All key energy system components are fully monitored and controlled in real-time in an integrated way. Large parts of any remaining greenhouse gas emissions are captured, stored and converted into energy sources, contributing to an almost fully circular energy system. Coal, as major carbon emission polluter, is completely phased out from European energy systems by 2050 (this is more ambitious than the high-RES scenario for which solid fuels have a 2.1% share in the gross inland consumption).

> Citizens should be able to participate actively in the energy transition.

Seen from today, although there are many kinds of renewable energy sources (RES), wind and solar electricity generation have experienced the strongest cost decreases and are available in large quantity in Europe. While solar and wind have the greatest potential at EU level, all renewables e.g. hydro power, geothermal energy, ocean energy or biomass/gas will be developed taking in consideration their potential, cost and their added value to the regional systems and to grid stability. The 2050 energy system will use overall less energy than today, due to energy efficiency for instance in industry and in buildings. But still, the daily and seasonal differences between energy demand and especially wind and solar availability will require a very flexible system:

- Coordinated by coherent market price signals that lead, for example, to lower demand in response to high prices during low wind and sunshine, and with the different energy choices a customer faces prices cost-reflectively.

- With strong and smart, local and continental electric and carbon-neutral, synthetic gas networks, dimensioned such that the diversity of renewable resources, weather and demand across Europe is used optimally.

- With as much biomass and synthetic gas as can be integrated efficiently, together with hydro and ocean energy and nuclear (possibly fusion beyond 2050) being used when the value of their use is high for embedding biomass or gas-fired flexible thermal generation and gas for certain industrial processes or for aviation, shipping and long-distance trucking.

- With injections in daily or seasonal energy storage such as pumped hydro, batteries, hot water reservoir thermal storage, or Power-to-Gas (PtG) conversion, whenever the value of energy in storage is higher than the value from additional energy use at the time of generation – such as in summer at times of very high electricity generation from PV.

- With provisions from daily or seasonal energy storage when the value of the use of the stored energy is higher than of the energy remaining in storage, for example during a windless, cloudy and cold winter week.

In 2050, the mitigation of environmental impacts from energy systems is supported by:

- Technologies and market-based incentives allowing for fossil-free EU energy systems.

- Energy generation, storage, power conversion, and consumption equipment, grids and Information and Communications Technology (ICT) equipment, monitoring and control (automation) devices, all designed and manufactured to be almost fully recyclable.

- Europe as a global leader for **carbon-neutral energy systems**, based on an integrated energy systems' policy harmonised across European countries.

From now on and beyond 2050, Europe is at the **forefront of climate change research** and takes the **international lead** on environmental action plans and the establishment of global environmental standards.

Creating efficient energy markets

For the energy transition to be driven by people and their choices, and to reward innovation and drive energy conversions and storage, the energy transition requires efficient energy markets that provide a level playing field for all stakeholders involved, non-discriminatory open access, and preclude cross-subsidies.

Long before 2050, energy markets provide coherent price signals for required investments. This ensures appropriate amounts, location and grid-hosting capacity for renewable energy generation as well as for the integration of different energy systems (electricity, gas, heat/cooling and liquid fuels). This means that energy systems are connected thanks to power conversion and storage devices, including their monitoring and control devices and software systems.

Long before 2050, citizens are empowered, active consumers and prosumers, using user-friendly local, regional and continental energy exchanges as well as peer-to-peer trading, for a wide choice of services and with energy prices at an economic optimum.

In 2050, flexible energy storage, power conversion and demand flexibility play a key role as products and services in energy markets: these services and products allow the storage, conversion and shifting of excess power from renewable generation in hydro reservoirs, gas storage, batteries or thermal storage. The needed flexibility is offered largely by active grid users being generators, (active) consumers or prosumers, or aggregators, all combined with controllable storage.

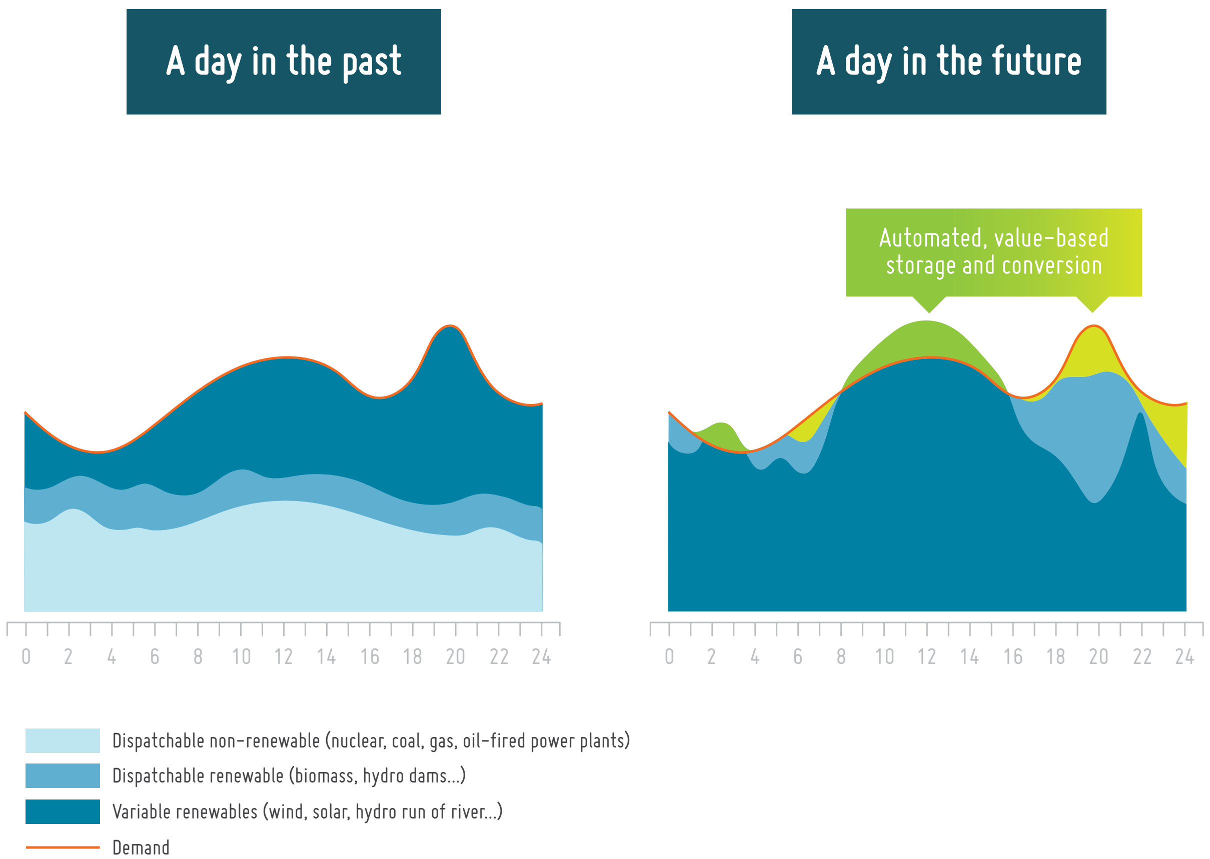
Flexible storage is also used by electricity grid operators for managing very short-term balancing needs including for nominal frequency, for handling grid congestion and respecting other system constraints, like for standardised upper and lower voltage limits. In addition, investments into storage capacity, their associated conversion processes and their optimal operational use allows to find the optimisation of grid development. Figure 3 shows an example the excess electricity from wind from 02:00-04:00am in the morning and from 09:00-15:00 is stored and then reused during those times (06:00-08:00 and 16:00-20:00) where demand is higher than generation from renewable sources.

Energy can be stored seasonally in the form of gas (like methane and hydrogen), liquids or other energy carriers; or in non-battery massive storage (such as large hydro reservoirs, compressed air or hot water), to essentially shift otherwise excess renewable energy production to those periods where more end-use energy is needed, for instance in many parts of Europe during winter.

Figure 4 shows an example of the monthly total demand for all uses over a calendar year, superimposed by the injection, withdrawal and energy content of seasonal storage. Today's (natural) gas grid infrastructures and connected gas storages can be used for this purpose and can be a cost-effective enabler of a circular energy system with significant amounts of biogas and Power to Gas (using CO_2 and renewable electricity).

An additional aspect for the future integrated energy system is the low-cost and efficient balance of thermal energy supply and demand in heating systems of buildings (assuming optimised insulation), for industrial processes and for all combined power-(electricity) to-gas (PtG) and Power-to-Heat (PtH) conversion processes.

Figure 3. Outcomes of the daily electricity market



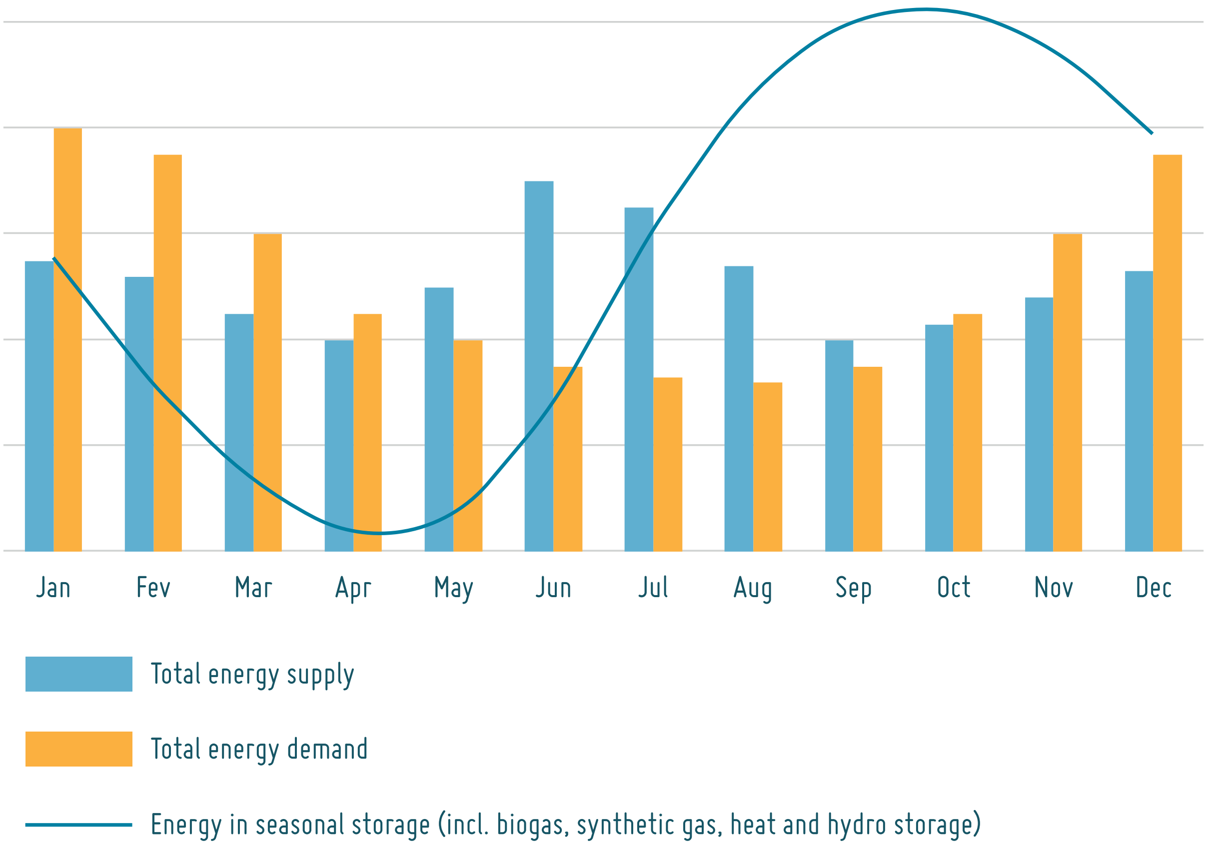
This figure is provided for illustration purposes only: ratios between the different types of energy source not necessarily corresponding to the EU case; the demand profile should also be different in the future because of demand response measures that should be broadly implemented and possibly the massive roll-out of electric vehicles (EVs).

In 2050, competitive and efficient retail markets provide citizens – which can be active consumers and prosumers – with a favourable environment to choose their energy suppliers and to control their self- and grid-supplied energy consumptions with the necessary framework (data protection and privacy, interoperable smart solutions). Retailers propose service-oriented, customised, easy-to-access offers, focusing on top quality service at any time and location, with market-price-based rescheduling if a citizen's energy needs change in the short-term.

A citizen's willingness to provide flexibility is achieved by adequate price signals and innovative services guaranteeing high-level comfort with high electricity supply and quality both in terms of satisfying norms (such as voltage and frequency within upper and lower limits) and over time to avoid blackouts and provide fast restoration.

In 2050, consumers of any size can access directly or indirectly **energy markets** to sell (as prosumers) and buy energy, power capacity and flexibility services to satisfy their needs via low-cost, cyber-secure communication and Internet services. These ICT-based services can be integrated with other information services, not directly related to energy (weather conditions and forecast, air quality, mobility); they also provide dynamic information (price, quality, state of the system, incentives for energy systems-friendly actions) for any energy related needs, be it for selling or buying energy.

Figure 4. Outcomes of integrated energy markets across multiple energy carriers



This figure is provided for illustration of the principles of seasonal storage only, not based on real data or modelling.

In 2050, energy network operators work within a legal framework to ensure overall security, reliability, resilience and quality of supply to satisfy citizen and business needs at affordable costs. To realise the energy transition, network operators design and operate robust and smart electricity, gas, and heat and cooling grids, to become more active players, for example by purchasing flexibility from prosumers in order to adapt consumption and generation behaviours depending on local needs.

The Goal of Efficient Markets

- **Informed choices:** citizens can make informed choices about any energy-related need.
- **Tailored information services and infrastructures**: citizens can use continuous, secure and robust high-speed communication technologies for energy-related applications and all information purposes.
- **Procurement of any energy-related needs**: prosumers can sell and purchase anytime their energy.
- **An integrated infrastructure for all energy carriers with the electricity system as the backbone**: it includes adapted storage (storage capacity size, loading and unloading power related ramp rates, and conversion losses) and power conversion capacities, able to supply all consumers' and prosumers' needs at any space – from local to pan-European – and any time scales – from seconds to months.
- **Balancing of unplanned, sudden deviations between planned and real-time residual load**: imbalances between electricity generation and demand are handled automatically using market-based mechanisms which consider forecasted weather conditions and system operational states and available energy from storages.
- **Smoothly interacting, resilient and reliable grid-based energy management systems**: such service-based systems are operational at all network levels to handle energy-related needs for all types of grid users, from small prosumers (consumption) to large-scale wind and PV power plants (generation), at all time-scales, from fractions of seconds to months. This includes the provision of redundant or back-up-energy if there are deviations from the planned as well as the resilient and reliable handling of any operational grid issues.

Ensuring security of energy supply

From 2018 towards 2050, energy availability remains an important issue for European citizens who experience fluctuating prices for basic energy-related needs, such as heating, cooling and mobility. Improving the security of energy supply through energy savings, energy efficiency and renewable energy sources, lowers European dependence on imported fuels. Security of supply is also linked to the delivery of energy through different types of energy networks which enable the overall energy system to be more secure, reliable and resilient.

In 2050, Europe has strongly reduced its energy import dependence by using carbon-neutral energy sources, mainly located within Europe, and storage capacities. This is achieved by a system design that does not heavily depend on imported primary fuels such as gases and liquid fuels from outside of Europe. Ultimately, a fully circular, carbon-free economy operates on European energy systems relying on energy sources available in Europe. The development of technologies, relative costs and reliably functioning global markets will determine how much low-carbon electricity, biogas or PtG might be imported from outside Europe or exported elsewhere.

In 2050, locally available energy resources are used to their full economic potential, partly deferring needs for upgrades of the electricity transmission and distribution networks and helping maximise the resilience of supply channels for heating and cooling needs.

In 2050, energy systems' planning and operation processes ensure high overall system reliability. At any time and location and under contingencies, these processes enable a level of quality of energy supply adequate to the needs of the different users and at acceptable average prices over the year – price spikes during scarcities are balanced by low prices over the many periods of high renewable resource availability. For electricity grids, this requires robust and flexible electricity interconnections, of sizeable capacity to optimise the time-variable power flows between distant generation and consumption centres, or between regions of temporary surpluses and deficits of renewable energy generation. By 2050, power transmission highways have been developed to foster the internal electricity market, to increase shared reserves and therefore security of supply, and to further strengthen system stability (frequency and voltage); they link all EU regions and some neighbouring countries. Local grids and markets are managed under the subsidiarity principle. System balancing for electricity grids as well as mid-term security of supply (e.g. adequacy studies) are ensured by transmission system operators (TSOs).

> A low-carbon pan-European energy system paves the way for a fully decarbonised and circular European economy beyond 2050.

In 2050, a holistic approach to system security of supply is applied across all energy systems with a focus on resilient operation, efficient control and optimal redundancy, to support systems' operational reliability in cases of usual disturbances or deviations from planned energy consumption and planned energy infeed into the various energy networks. A resilient energy system is designed and operated to be able to adapt automatically and dynamically to ride through any individual disturbance or multiple contingencies and to operate in a partly isolated, degraded mode to safeguard essential energy services. This applies in case of extreme climate conditions, such as heavy snowfalls, flooding, droughts, forest fires, storms as well as for intentional human-incited events like acts of terrorism or cyberattacks.

In 2050, the reliability and resilience of energy systems are part of an integrated strategy for all modes of energy systems use. Risk monitoring, assessment and prevention regarding energy systems' security are integrated for all types of users.

Next page: Figure 5. ETIP SNET Vision 2050 of integrated smart energy systems

Part 1 Summary

Europe's security of energy supply is ensured mainly by minimising fossil-fuel imports thanks to energy efficiency policies, the production of low-carbon fuels within Europe as well as the increase of wind, solar, hydro, and biomass as the main sources of renewable electricity production.

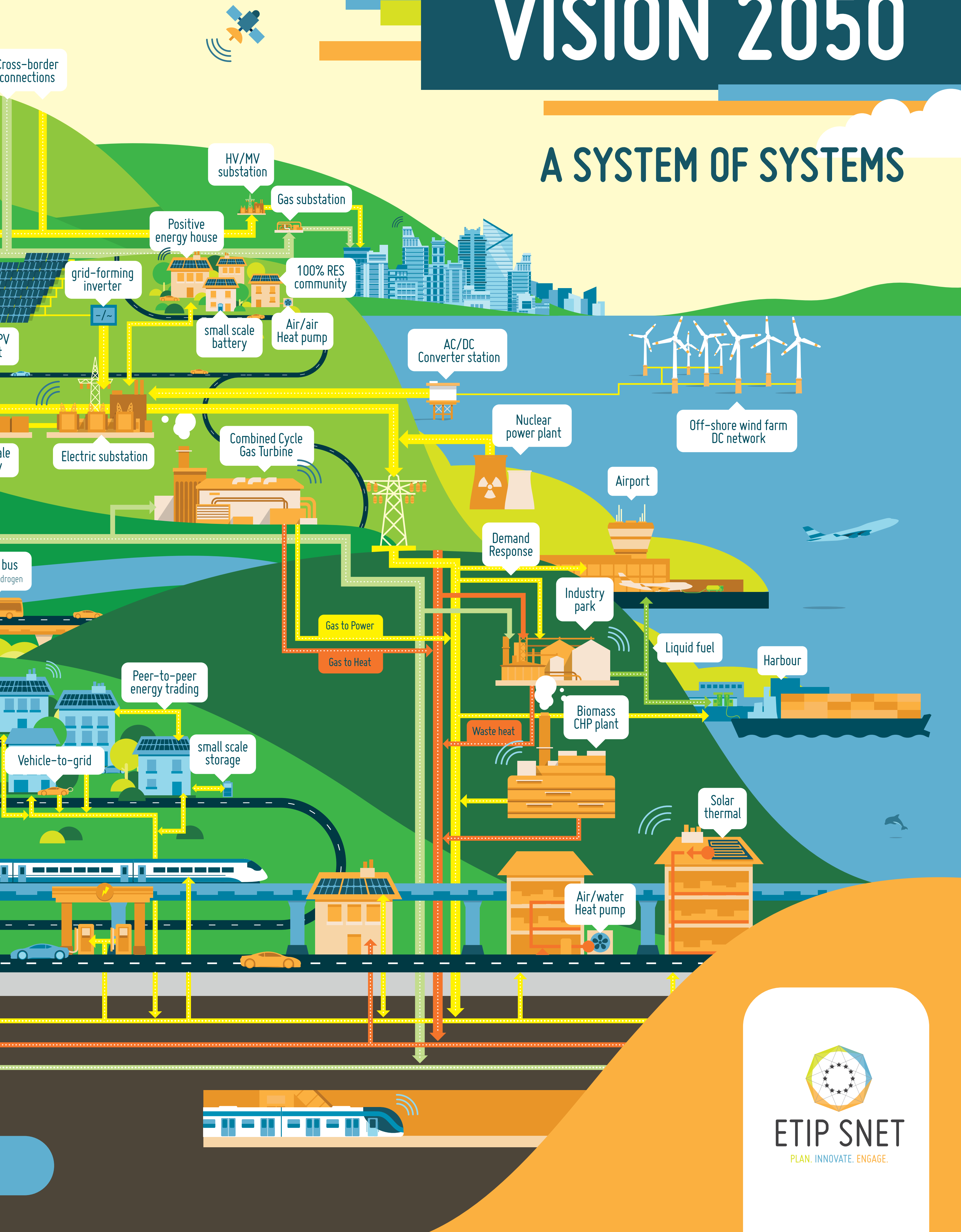
Reliability and resilience for the pan-European, regional and local systems are ensured by:

- **Integrated energy systems,** with the electricity systems as the backbone, designed and operated to prevent or minimise the effects of contingencies, with local/regional black-start capabilities activated within a few minutes.
- **Risk (weather and other hazards)** assessment and mitigation measures, considered in system planning and operation.
- **Seamless** (strongly automated) **operation through fully interoperable and networked sub-systems** allowing the coupling of all energy carriers in an optimal, integrated way.
- **Peer-to-peer transactions integrated with centrally- and locally-controlled electricity networks,** supported by automated local grids together with network operator actions.


Wind farm
Farm
Biogas production
Carbon capture & use
Biogas cleaning
Methanation
Electrolyzer
Pumped Hydro Storage
Underground gas storage
CH_4
H_2
Compressor station
Power to gas
Zero energy building
Micro CHP
H_2O
ICT network for digitalization of energy system
Fast charging station
Hybrid
Peer-to-peer energy trading
Electric tram
Hydrogen station
Liquid fuel station
Geothermal Heat pump
NETWORKS
Electricity
Heating & Cooling
Gas
Data

VISION 2050

A SYSTEM OF SYSTEMS



ETIP SNET

PLAN. INNOVATE. ENGAGE.

02

TOWARDS INTEGRATED ENERGY SYSTEMS IN 2050

Today's achievements

Over the past decades, the energy systems in Europe (in particular European electricity systems) have fostered the emergence of world-leading industries. This outstanding achievement was obtained through collective efforts encompassing public and private entities, major companies, thousands of small and medium enterprises (SMEs), academia and research centres. Today, European low-carbon energy excellence includes all kinds of renewable energy generators and energy network components, monitoring, control and automation devices and ICT.

Most of today's energy network infrastructures (electricity, gas, heating and cooling, liquid fuels) will still be in operation in 2050. However, they will be used in different ways. Capacity expansion and transition policies, and tariffs for infrastructure uses will need to be redesigned and adapted to the enhanced features of the fully integrated energy systems and markets.

> Energy system technologies and markets are catalysts for innovation and spill-over into the industrial and technological sectors, thus contributing to the growth of the European economy.

The unbundling of the European electricity and gas sectors during the 1990s has led to today's more efficient grid-coupled wholesale markets, but more efforts to integrate service markets are required: they need to be accompanied by the continued roll-out of remote metering, intelligent monitoring and control as well as smart operations and innovative services empowering citizens to support the evolution of today's energy systems towards low-carbon European energy systems. Transmission and Distribution System Operators (TSO/DSO) cooperation and joint electricity and gas network planning are examples of needed improvements.

Energy system technologies and markets are catalysts for innovation and spill-over into other industrial and technological sectors, thus contributing to the growth of the European economy.

Challenges and opportunities to move to low-carbon energy systems

Moving towards an integrated, low- or even carbon-neutral pan-European energy system brings many challenges and opportunities. Significant progress is necessary so that today's energy systems change towards satisfying the needs of society and the economy by:

- Becoming as environmentally sustainable and as circular as possible
- Supplying energy for all citizens, businesses and industries in Europe in a fully digitalised economy
- Generating wealth, economic growth (jobs), and global competitiveness
- Promoting Europe's innovation economy with more R&D investment
- Contributing to global prosperity, security and self-reliance

While ensuring security of supply and mitigating energy poverty from today towards 2050, Europe must maintain its long-lasting leadership in technology and environmental protection, despite increasing competition in the world economy.

Sustainable, integrated energy systems in the short- and mid-term will require much more initial investments than continuing to use fossil fuel in non-integrated, compartmented energy sub-systems and markets. These higher investment costs will be offset by reduced operational and external costs. To do so, four key challenges must be addressed:

1. Increase the level of **technology investment**, including break-through integration technologies via intensified research and innovation.

2. Enhance **global competitiveness** in all types of pan-European low-carbon energy markets.

3. Foster **local energy markets** and their design implementation.

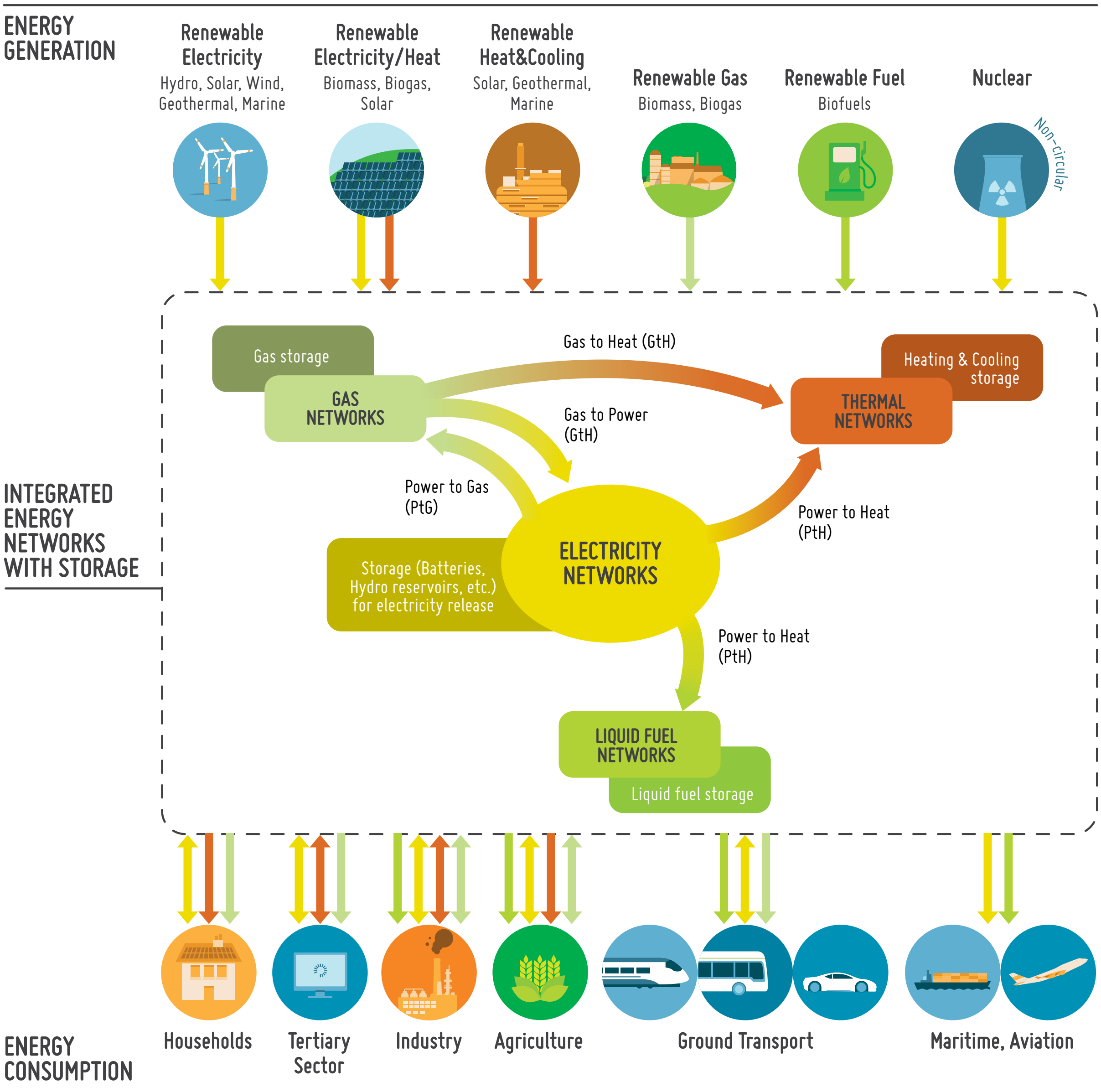
4. Foster the **circular economy** to mitigate environmental impacts and maximise energy efficiency by minimising energy losses and anticipating possible raw material shortages such as 'rare earths'.

From 2018 towards 2050, Europe must seize the opportunity of the expanding low-carbon energy system markets and preserve Europe's leading position on the global arena. All emerging and developed economies will decarbonise their energy systems. European-based industries will face fierce industrial competition from other world economies. European authorities must consider the strategic nature of low-carbon energy systems and support European industries accordingly, enhancing competitiveness at all levels.

With today's knowledge and integration capabilities, European energy system industries can define and shape a sustainable future. Remaining competitive is also about the timely delivery of products and services. Advancing competition is linked to a common playing field with government support, which requires policy action to redress distortions and facilitate a favourable environment for innovation to flourish.

> All emerging and developed economies will decarbonise their energy systems. European authorities must consider the strategic nature of low-carbon energy systems and support European industries accordingly, enhancing competitiveness at all levels.

Figure 6. The future integrated energy systems with conversion and storage devices



A storage and power conversion transition towards integrated energy systems

Achieving the IEA (2017) "Beyond 2 Degrees Scenario" (B2DS) in 2050 will require moving toward a low-carbon economy with major innovations and deployments in energy efficiency, renewable energies, fuel switching, and Carbon Capture and Use (CCU). This will require fundamental changes to energy systems with all available technologies in order to reach the goal of a carbon-neutral power sector by 2050. Major changes are necessary for mobility and for heating and cooling; many of them imply intensified electrification with the integration of renewables.

Low-carbon energy systems will require a high level of integration to supply all sectors of the economy. This high level of integration will be achieved through the deployment of power conversion units enabling the coupling among all energy carriers and the installation of storage units for each energy carrier, thus enabling higher security of supply.

Ultimately, the energy transition will be facilitated by integrating storage and power conversion with the various energy carrier grids using the electricity system as its "backbone": electricity enables for a switch of energy carriers through Power-to-Gas (PtG), Power-to-Heat (PtH), and Power-to-Liquid (PtL) technologies and to transport large amounts of energy all over Europe, between distant and strategically interconnected hubs in the energy systems. In contrast to heat or gases such as hydrogen or (carbon-neutral) methane, electricity is not directly storable: this leads to high complexity and challenges for permanent balancing and congestion management within the electricity network as well as with the integration and power conversion of other energy carriers.

European energy systems will rely on electricity stored in significant quantities by conversion of PtG, PtH and PtL. [See Figure 6] Other examples of energy storage include centralised and distributed stationary batteries as well as a plethora of batteries on board electric vehicles (EVs) that can deliver services to the network. Moving towards a low-carbon economy will require fully integrated energy systems able to supply at all times low-carbon energy for all sectors (households, tertiary sector, industry, agriculture and transport) from the different energy sources (hydropower, solar, wind, geothermal energy, marine energy, biomass, biogas, biofuels, and nuclear – as the only remaining non-circular electricity generation source), as well as integrating surplus heating and cooling from industrial and commercial processes.

> The energy transition integrates energy storage and power conversion within the various energy carrier grids using the electricity system as its "backbone".

Besides hydropower providing seasonal and short-term storage capabilities in some mountainous regions of Europe, the storage capacity of gas systems will be a crucial element for the adequacy of 2050 low-carbon energy systems. Several tens of terrawatt hours (TWh) of electricity can be stored in the gas grid via PtG during periods of excess wind and solar production and used later, especially during times where end-use demand exceeds renewable generation. PtL will also be pivotal to decarbonise the transport sector since liquid fuels will remain necessary, especially for heavy duty vehicles and airplanes.

Besides these longer-term balancing needs, conversion between energy carriers will occur to meet short-term (minute, hourly and daily) energy system needs. Energy will need to be stored within the gas networks, in heating and cooling units, and in storage devices connected to them, thus supporting the optimal electricity network capacity use; each involved energy network will transmit and distribute its share of the needed energy thereby using the various conversion possibilities and available storage units.

Part 2: Summary

Key characteristics to achieve the energy transition in 2050:

- **Make significant progress towards satisfying the needs of society and the economy** in terms of environment, circularity, security of energy supply, affordable costs, resilience, reliability, and quality.
- **Maintain a long-lasting leadership in technology and environment protection** in light of increasing competition in the world economy.
- **Increase market-based investments** within different areas: **technology** (intensification of research and innovation) and circular economy.
- **Deploy power conversion units enabling the optimal coupling (integration) among all energy carriers**: connect each energy carrier and storage devices to enable a higher security of supply.

> The storage capacity of gas systems together with power-to-gas technologies will be a crucial element for the adequacy of the 2050 low-carbon energy systems.

03

THE BUILDING BLOCKS OF VISION 2050

In 2050, integrated energy systems (IES) consist of four inter-connected and inter-related layers that drive economic growth and global competitiveness for Europe:

- **The market layer** allows for exchanges between market players (generators, retailers, aggregators, consumers, grid operators, conversion and storage managers, and any other player).
- **The communication layer** supports the vertical and horizontal integration of energy systems and the relaying of information with the market.
- **The physical system layer** consists of automated energy infrastructures (generation, power conversion, storage and networks) designed to meet citizen needs.
- **The digital infrastructure layer** supports network operations to manage the integrated energy systems with higher levels of automation.

> In 2050, European transmission and distribution networks operations have dynamic cooperation of their respective operators.

The Efficient Organisation of Energy Systems

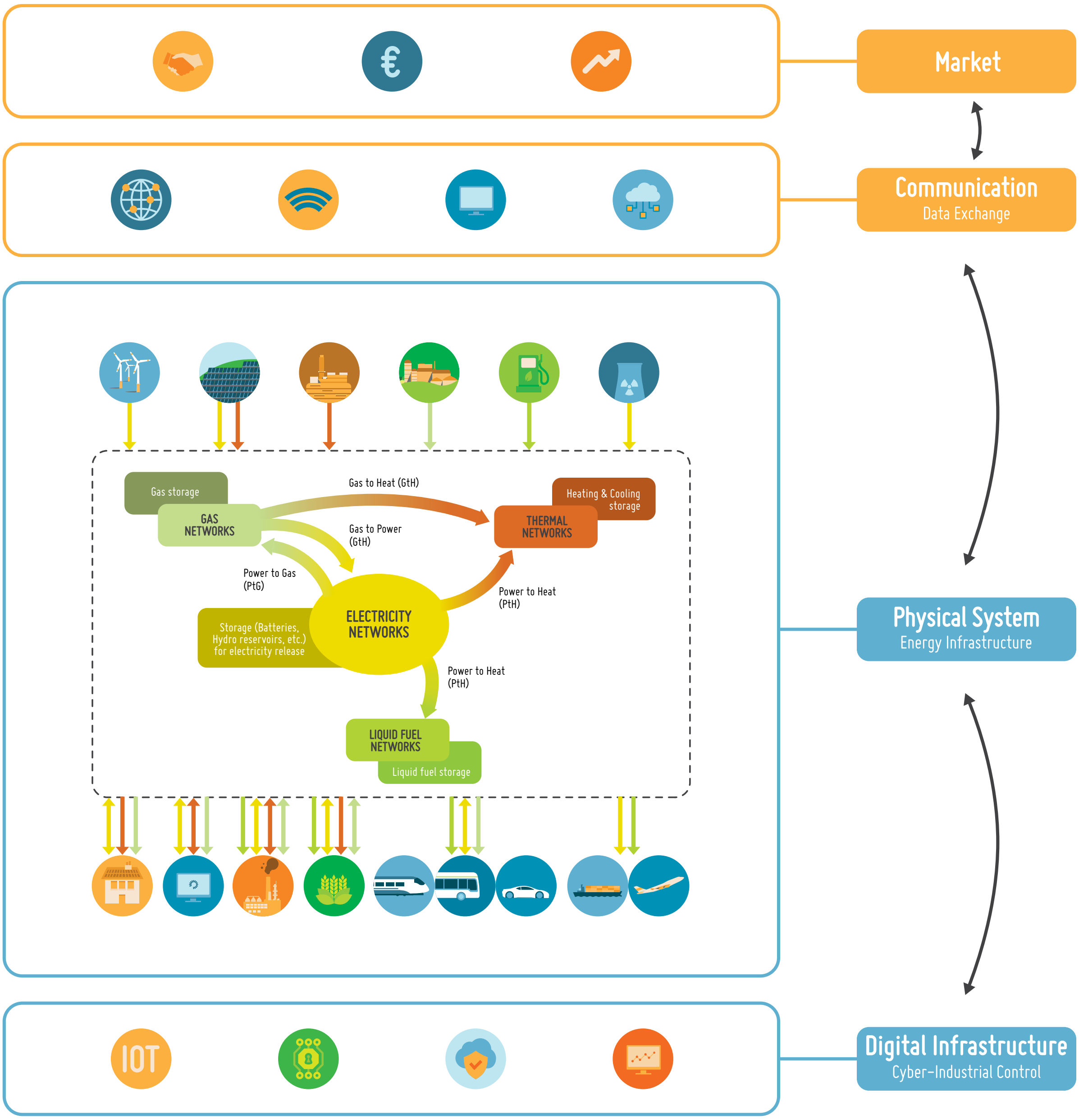
Cooperation between system operators

In 2050, European transmission and distribution networks operations leverage the dynamic cooperation of their respective operators. This implies a more efficient management of energy networks, their use, the associated conversion processes, and ultimately connecting market users in an integrated, optimal way to exploit all sources of coordinated flexibility.

In 2050, electricity system operation is based on the highly automated optimisation of the grid, power generation and of all types of energy consumption. This is combined with the best location, size and operational conditions for storage and power conversion to minimise energy losses and to avoid other undesirable contingencies leading to power outages. Coupling different energy networks occurs on all scales according to the most cost-effective way (from integrated electricity, gas and heat infrastructures for buildings and mobility in cities with storage facilities, towards large-scale pan-European gas transmission and storage with conversion from and to electricity) as well as through new infrastructures for mobility (charging stations and refueling stations). Conventional gas infrastructures operated with synthetic methane (CH_4) and new infrastructure associated with hydrogen (H_2) will play a role. Today's unpredictable progress in conversion and storage technology and developments will determine the future with relative amounts and roles of CH_4 versus H_2.

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

Figure 7. The 4 layers of integrated energy systems



High levels of automation for energy systems

In 2050, integrated energy networks for electricity, gas, and heating and cooling can handle the available capacities through new services based on higher degrees of automated management and control of flexible energy network resources. Dynamic and distributed automation can handle any energy and data communication system constraint – this changes the roles of network operators (above all for distribution systems) and of market players (above all in retail markets). During normal operations, network operator actions remain an essential part of the strongly automated network control.

In 2050, network operators intervene mainly when capacities and other rated constraints such as system frequency, voltages, gas pressures, temperature levels, and water reservoir levels approach their limits due to minimum costs and maximum welfare operations. Market players make bids for products and services at all spatial and time scales: to buy and sell power capacity, power flexibility and energy in all kinds of markets covering different time intervals (real-time balancing, intraday, day-ahead, other time horizons) either on the coupled wholesale pan-European market level or at local levels, for instance energy communities and prosumers.

A 'cell' refers to an integral element of a dynamically sizable energy system – from a single home to a region. A cell has the inherent ability to balance itself through the integrated and ICT-monitored and controlled use of all components. A microgrid is a typical distribution network structure that satisfies this requirement. Interconnecting multiple of these cells offers significant benefits, amongst which balancing of energy supply and demand between different cells without causing congestions in the networks which connect them. This concept can be scaled to a self-adjusting whole energy system, and as such, is an important step towards the energy system in the year 2050. How to coordinate the different cells over the entire continent from a grid, system and markets perspective remains an important RD&I topic today to be solved well before 2050.

In 2050, some parts of the electricity grids are fully automated, with 'islanding' and reconnection capabilities to various grids, especially when local balancing can provide support to the upstream parts of the electricity systems. Local energy communities based on microgrids are fully developed, where the stakeholders benefit, through informed and active participation, from the enabled services, resources, and forms of sharing energy.

Application of the subsidiarity principle

In 2050, the subsidiarity principle is applied to European energy systems. Monitoring and control of generation, conversion, storage and consumption in all energy sectors is done in an integrated, highly automated, fully-trusted way, within regions which are dynamically sized and cell-based. **The subsidiarity principle** means that energy systems are operated in such a way that actions are optimised locally (at the most immediate level). Actions that cannot be handled locally are handled at the next level.

> In 2050, continuous energy efficiency improvements offset the energy demand generated by the growth of data centres and the development of mobile networks.

Markets as key enablers of the energy transition

Higher volumes exchanged on energy markets

In 2050, the transaction volumes on European energy, capacity and flexibility markets are much larger than today. Electricity and gas transmission, distribution and conversion – combined with more local heat storage – are the main means to satisfy the growing supply from renewable energy sources.

In 2050, short-term (seconds-minutes-hours) electricity imbalances are handled by highly efficient, electricity market-based operations for fast ramping and using controllable storage and power conversion. Longer-term seasonal imbalances of the electricity system are mitigated by carbon-neutral gas storage and enabled by highly efficient conversion of power-to-gas and gas-to-power and heat ideally combined with local heating and cooling needs to maximise overall conversion efficiency.

> In 2050, single pan-European electricity and gas markets are fully implemented to address dynamic market-time intervals, price zones and grid-constraints.

Wholesale markets enabling cross-border exchanges of renewable energy across Europe

In 2050, carbon-neutral electricity and gas transmission networks are the main way to connect Europe's renewable energy generation at all sizes with large-scale consumption centres (industries and cities) that are often located far from RES generation sites.

In 2050, the single pan-European wholesale electricity and gas markets are fully implemented to address dynamic market-time intervals, dynamic price zones and grid-constraints. Price zones are adjusted in accordance with system operations and congestion management, ensuring maximum efficiency of the wholesale markets in a context of fluctuating electricity generation, flexible electricity consumption and the fully integrated use of the large hydro and circular gas-based storages and grid-infrastructures.

In 2050, today's marginal, variable energy cost electricity markets have evolved with new markets and services able to incentivise market-driven investments into a 100%-renewable energy mix with very low marginal energy generation costs. They are complemented or replaced by a combination of capacity and flexibility products and services markets which allow economically efficient, renewable power generators to cover their investment costs in a market-based, zero-subsidy environment.

Local markets enabling citizen involvement

In 2050, local retail markets ensure high-quality, efficient operations with high security of supply. Energy distribution supplying citizens located in geographical areas with locally available renewable energy sources, such as solar photovoltaics, are handled in tandem with local storage and conversion devices from and to local gas networks.

In 2050, consumers and prosumers are enabled to plan, predict and adjust their consumption needs almost in real-time using peer-to-peer energy services. Where the physical system is strongly constrained, these services are coordinated by central control and dispatch for macro-balancing, back-up, safety, and emergencies.

In 2050, data on customer's past, actual and predicted behavior (for example with people commuting or for energy in relation to weather conditions) **enables** model-based forecasting and the real-time optimisation of the **energy systems' operations at all levels**.

- **Decentralised control techniques** and **peer-to-peer electricity trade** permeates local energy communities and their interconnection to the electricity system.
- **Shared platforms** facilitate data exchange and decision-making in all parts of the integrated energy systems, thus enabling advanced planning, operation, protection, control and automation of the energy systems.
- **Digitalisation supports optimised and interconnected services**, providing real-time information to operators and aggregators as well as to users connected to any energy network thereby enhancing system balancing and resilience at all time scales from seconds to weeks and in the case of any unforeseen, sudden contingencies.

Digitalisation enables new services for integrated energy systems

In 2050, digitalisation provides better, user-friendly services to all kinds of customers for planning, maintenance and operational issues, fostering information, analytics and connectivity.

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

- Several million households actively participate in real-time, automated **demand response** (electricity, heating and cooling) with connected appliances and equipment, in addition to the existing and emerging solutions for industry and commerce.
- **Aggregation** of smart charging technologies for electric vehicles, stationary batteries, heat pumps and power-to-gas provides controllable electricity loads.

Digitalisation in 2018 has 3 main components:

1. **Information is generated and collected by connected devices (Internet of things, IoT)**. A large amount of data is provided by smart meters and sensors in the network for real-time monitoring and control.
2. **Analytics for** data mining, machine learning, and digital twins, amongst other software tools, are used to generate information to support network operators and market stakeholders to improve the efficiency of energy markets.
3. **Connectivity allows for the exchange of massive data between humans, devices and machines,** including machine-to-machine (M2M) through digital communication networks.

Data privacy and ownership

In 2050, rights for privacy are guaranteed to all stakeholders including for data ownership, especially information from smart meters about consumer (and prosumer) energy and service use.

This is supported by citizen's rights to allow (or not to allow) access to their data by third parties in all cases beyond the needs of system operators for carrying out their institutional duties. In any case, all processes and their management are interoperable and certified to account for all possible cases where system security measures may impact privacy.

> In 2050, in low-carbon district networks, heat is produced from heat pumps, biomass, biogas or Synthetic Natural Gas (SNG)-powered boilers.

Cybersecurity

In 2050, energy systems are not vulnerable to cyber-attacks even under strong growth of IoT and rapid changes in digital technologies and decentralisation. Energy carrier systems, particularly electricity systems, are operated in real-time which implies specific security precautions. In 2050, a system-wide resilience is built with 'cyber hygiene and security by design' (according to the 2017 IEA *Digitalisation and Energy*) for energy systems state monitoring and control, ICT networks, including for critical system operations and market-based processes, from pan-European transmission all the way down to local levels.

Infrastructure for integrated energy systems

Upgraded electricity networks

In 2050, electricity networks operate with very high penetration of power electronics and the associated monitoring and control equipment. They are dynamic and fully secured and coordinated at all voltage levels, with the participation of European consumers and prosumers, thanks to coordinated processes between network operators and market players. Variable frequency or zero-frequency (DC) electricity grids, interconnected with the main fixed frequency AC grid and combined with use of Flexible AC Transmission Systems (FACTS) for better control of the system flows and more efficient network operation are developed thanks to increased deployment of power electronics at decreasing costs.

In 2050, large quantities of electricity produced from renewable energy sources flows across Europe using HVAC grids, HVDC grids (including offshore grids) and hybrid AC/DC grids. Continental or even global-scale, inter-continental interconnections allow European transmission system operators to take advantage of weather-based conditions, by applying dynamic rating for transmission-line flow limits based on temperature and by RES diversity, seasonal and daily load and generation pattern diversity, and mutual support during scarcities, such as windless winter weeks.

In 2050, the electricity system can handle reduced inertia by adapted monitoring and control equipment and new protection solutions with associated cyber-secure, fast data communication. Methods for planning and operations are adapted to these new contexts by relying on much more power electronics-based control, electronic switches, grid-inherent controls, distributed and decentralised control techniques. They handle all network states in a reliable way so that the overall system remains resilient against unforeseen, sudden events.

In 2050, a full system monitoring and control approach ensures system support as well as optimisation of grid costs (for example in times of critical grid capacity use and voltage constraints) and consumer costs (or prosumer welfare), and provides win-win situations in terms of economic convenience, system resilience, robustness and sustainable contributions.

In 2050, thermal power generation, mainly running with renewable energy sources (concentrated solar power, biomass, biogas, synthetic gas such as methane and hydrogen, and geothermal) provides flexibility (including at partial loads) while guaranteeing electricity and heat supply during (winter) times with limited or less renewable energy supply.

Large-scale roll-out of conversion and storage technologies

In 2050, PtG and PtH conversion allow for the efficient coupling of electricity, gas and heat networks, together with Gas-to-Power-and-Heat (GtP&H) and Gas-to-Heat (GtH) conversion technologies. Most of these required technologies are already available today: some of them (electrolyser, methanation, CCU, fuel cells, turbines and internal combustion engines operating with different fuels) have gone through further developments and investments to reach the necessary maturity, efficiency and profitability.

In 2050, technological choices and penetration rates of each of these technologies depend on their relative competitiveness and performance.

In 2050, coupling heat and electricity production impacts the gas grid, where electricity storage can be performed in different ways (thermal, chemical or electrical energy). Coupling electricity and gas networks with electrolyser and methanation units enables long-term (seasonal) storage, and flexibility options for the electricity grids (PtG and GtP&H) and supply for the transport and industry sectors. This can provide adequacy of energy supply at moderate overall cost even at times when renewable generation is low and demand very high, such as in windless winter weeks.

In 2050, PtL technologies rely on similar processes as PtG – primarily methanation. Coupling electricity and liquid fuels is key to supply the transport sector (heavy duty vehicles, large freights and airplanes) with low-carbon fuels (including different biofuels) and for industry using carbon-neutral inputs (petrochemical industry for instance).

> In 2050, coupling electricity and gas networks with electrolyser and methanation units enables long-term (seasonal) storage, and flexibility options for the electricity grids, plus adequate supply for transport and industry.

Efficient energy use

Heating and cooling of buildings

In 2050, the heating and cooling of buildings is powered by renewable energy sources. Electricity is the main energy source for new buildings and to a large extent for refurbished buildings.

Due to active, local energy generation (building-integrated generation) combined with energy efficiency solutions (e.g. insulation and efficient appliances), while ensuring indoor air quality, new buildings in most cases are nearly zero-energy and possibly positive-energy buildings. In such buildings, information and flexibility controls of heating and cooling devices coupled to storage possibilities support the real-time operations of the electricity as well as heating and cooling systems during short-time (minutes or even less) intervals.

In addition to efficient electricity-based (via heat pumps) heating and cooling devices in single houses and small residential buildings, low-carbon district heating and cooling grids cover the generation and distribution of thermal energy in urban districts.

In 2050, in low-carbon district networks, heat is produced from heat pumps, biomass, biogas or Synthetic Natural Gas (SNG)-powered boilers. Smart district heating and cooling grids improve the management of energy demand. Such networks can be optimised in real-time with digital heat meters and control of heat sub-stations (heat exchangers).

In 2050, **waste heat recovery solutions** are deployed for most buildings in the commercial and tertiary sectors. Moreover, waste heat recovery solutions are used in other networks such as waste water networks to produce heat for buildings.

> In 2050, waste heat recovery solutions are implemented in all industrial sites as a mean to improve energy efficiency.

Energy efficiency and heat supply in industry

In 2050, various renewable energy sources, such as bioenergy, solar energy, geothermal energy and power-to-heat conversion are used to produce heat for industrial purposes, considering that the availability of these resources is neither spatially nor temporally uniform within Europe. Load-shifting and load-shedding through short duration heat storage are increasing flexibility and allow for the greater uptake of renewable power by industry, facilitating the handling of variability, for example with combined heat and power (CHP).

In 2050, **waste heat recovery solutions** are implemented in all industrial sites as a mean to improve energy efficiency: when possible waste heat recovery solutions are used to foster energy exchanges for instance in industrial parks.

Carbon-neutral liquid fuels and electricity for the transport sector

In 2050, in addition to improving efficiency of all relevant energy conversion processes, **the availability of liquid fuels is part of an overall carbon-neutral fuel strategy** for all energy producing and consuming sectors, including for mobility and heating. By doing so, their cost impact on the energy systems and on the transport/mobility sector, and their impacts on the environment, the quality, reliability, resilience and security of supply minimise total costs or maximise total societal welfare.

In 2050, the vehicle-based mobility system has shifted strongly towards electricity but continue to rely on liquid carbon-neutral fuels (PtL and biofuels) **and gases** (synthetic methane and hydrogen), driven by environmental, operational, technological and economic considerations. A coordinated approach to fuel development with minimum carbon emissions is taken for the transport applications that are highly dependent on liquid hydro-carbon fuels: aviation, maritime and heavy-duty long-distance road transport.

Minimising energy use for the digital layer

In 2050, ICT spread over the whole energy system becomes a significant source of energy demand (electricity and heating/cooling): data centres (computer servers to store, process and distribute data) need energy to power the servers and run the cooling system. Data transmission networks (fixed and mobile) need energy to transfer data between connected devices. Connected devices need energy to generate data.

In 2050, continuous energy efficiency improvements offset the energy demand generated by the growth of data centres and the development of mobile networks (with the advent of the next generations of high speed communication) which consume more energy than fixed-line networks at the same data-traffic rate. Scaling-up effects are realised through larger data centres and optimised capacity utilisation. Non-avoidable waste heat from data centres is re-used, when possible, in district heating networks to reach the goal of a circular economy.

PART 3 SUMMARY:

The Building Blocks of Vision 2050

- **Enhancement of the integration of the different energy networks** at any scale and considering the most cost-effective way and using new infrastructures for mobility.
- **Higher degree of automated management and contro**l of all energy network users.
- **Efficient wholesale markets** in a context of nearly 100%-renewable energy mix and fluctuating, non-dispatchable generation.
- **Development of local markets** providing high quality and economical supply for local prosumers.
- **Digitalisation plays a major role in the integrated energy systems** since supporting the provision of new services, while ensuring data privacy and ownership for all stakeholders and enhancing cybersecurity.
- **Development of infrastructures: power networks are upgraded** to ensure the high penetration of renewables with the associated power electronics, monitoring and control equipment and to enhance the use of the available pan-European grid capacities; **storage and conversion technologies are deployed widely** with all the possible couplings between electricity, gas and heating and cooling networks and infrastructures to tap into local resources.
- **Energy is use more efficiently within several sectors:**
  - Buildings: improvement of the management of the energy demand, including waste heat recovery and integration for economies of scale.
  - Industry: diversification of heat and electricity supply from renewables, including waste heat recovery.
  - Mobility: utilisation of electricity, liquid carbon-neutral fuels and gases.
  - ICT: minimisation of the energy consumption, re-use non-avoidable waste heat in district heating networks.

04

THE FRAMEWORK FOR VISION 2050

A European industry able to serve the energy transition

The pan-European energy industry needs to strengthen its leadership in the world economy, particularly for integrated generation, transmission, distribution, energy conversion, storage and end-use processes. The European industry must improve its cutting-edge capabilities and competitiveness through continuous and focused investments funded by strategic industrial partnerships and Public-Private Partnerships (PPPs) and support from public funds (e.g. for cutting-edge research and education, organised in geographic clusters and networks).

> In 2050, across the energy sector, all workers have ICT skills to use and operate digital technologies.

In 2050, the regulatory environment enables the emergence of **global operators** (for example for pan-European electricity, including electric mobility) and facilitates fair, balanced and reciprocal international cooperation.

In 2050, Europe also leads globally the harmonisation of interoperability, standardisation and certification processes for the integration of the overall energy system. Simulation tools for all interoperability issues are applied with open-source and open data layers.

Europe drives global standardisation covering all elements of the industry through the entire life-cycle from design through operation, maintenance and to disposal, both for energy and ICT-related sub systems.

Managing economic disruption and job creation

System complexity and automation requires highly-skilled staff, with various professional backgrounds. The best researchers, engineers and managers are attracted by the European energy systems community. Europe proves that continuous investments into scientific research and innovation related all aspects of energy systems integration and new technologies leads to highly-educated and skilled expertise in all areas of the integrated energy systems and could yield important spill-overs into other sectors.

In 2050, new methods of learning and teaching at bachelor, masters and PhD levels, including interdisciplinary and experimental approaches, research-based training or through digital media, but also continuous education for professionals, are explored and tested together with users from the many industrial stakeholders. Higher education courses provide the latest available knowledge, thereby training future engineers, researchers, innovators and professionals and support the evolving needs of industry and research.

The energy systems community engages actively with European students from the earliest age and is committed to life-long learning and continuous education thus promoting interest in the sector and stimulating innovation. Educational policies across the EU and Member States motivate students to pursue further studies in science and technology to ensure a steady supply of talent for a highly-skilled work force.

Education and training for operators, aggregators, market participants, prosumers of any size and energy systems engineers with high-end ICT knowledge are incorporated, supported by training and simulation tools.

In 2050, Europe remains highly competitive in a global economy by supporting European-based companies designing and manufacturing components of the future energy systems with highly-skilled work force. Digitalisation and the associated high-level of automation implies new jobs with different qualifications to perform the operation and the maintenance of the digitalised energy systems. New markets create business opportunities for new players**. In 2050, across the energy sector, all workers have ICT skills to use and operate digital technologies**.

Prioritising research and innovation

Shared research, demonstration and validation infrastructures

On the road to 2050, Europe's energy systems industry must be underpinned by world-class capabilities and facilities in research, demonstration and validation. Europe must have the world's leading research infrastructures covering the entire energy system through advanced laboratory facilities to plan, design and operate efficient and secure, market-based energy systems with all energy carriers.

In 2050, innovative research must be validated in large-scale demonstrations to manage risks and to test the integration of new electricity production, consumption and other developments of new and established technologies, as well as for energy conversion technologies with the adequate level of digitalisation. The validation of full-scale technology integration must be demonstrated and tested by interacting European laboratories. Comprehensive and consolidated testing, demonstration and validation infrastructures must be available across Europe harmonised, and interoperable to support the transition to market-based, automated, and integrated energy systems. They must include modelling, fast and real-time simulation of integrated multi-energy carrier and ICT-systems. These capabilities must integrate the interoperability standards validation and certification processes.

> To reach the goals set out in this Vision 2050, full participation of ETIP SNET representatives in all operational energy systems areas, especially RD&I activities, must be achieved.

Governance, funding and financing conditions

The risk spectrum associated with massive investments in long-term technological RD&I can lead to market uptake failures and/or the non-optimal use of resources. On the road to 2050, companies, universities and research organizations must continue to need funding which cannot be obtained only from financial markets. Therefore, public sector incentive support is essential, both at European and national/regional levels, as well as the private sector's investment in research, development and innovation. To achieve the Vision 2050, publicly-funded RD&I activities must focus on high-risk innovations.

In 2050, European energy systems research is defined, organised and funded in a coherent and coordinated way with minimum administrative burden. In parallel to these efforts, transparency and accountability in publicly funded programs are well-balanced with timeliness and efficiency with the appropriate protection of intellectual capital.

EU mechanisms to foster venture capital and sustainable finance are designed in the early energy system transition years to support entrepreneurship with start-up funding rounds. The European energy systems community needs are underpinned by an efficient and effective policy and regulatory framework that addresses funding and financing issues as a prerequisite for Vision 2050 to be realised.

PART 4 SUMMARY

The Framework for Vision 2050

- **Maintain and enlarge the European leadership in the world economy** through its expansion in integration of energy conversion processes with storage, distribution and transmission of all energy carriers, RD&I activities and standardisation processes;
- **Adapt education and training** to consider the high system complexity and automation requirements by developing new programs and simulation tools for students and professionals;
- **Foster new businesses creating jobs,** thus supporting growth thanks to the digitalisation of the energy system and the development of new energy markets;
- **Accelerate deployment of the results from RD&I projects** by implementing specific methodologies all along the value chain (test, demonstration, validation) and adapt the funding mechanism of the RD&I activities.

ETIP SNET CALL FOR ACTION

To reach the goals set out in this Vision 2050, there is an urgent need to act today in a fully coordinated way, thereby considering the RD&I priorities and needs of the ETIP SNET stakeholders and beyond.

This **ETIP SNET Vision 2050** is the basis for defining the specifications for further RD&I needs in the transition from today towards Europe's energy systems of the future. Its purpose is to inspire readers, to let them discover the RD&I challenges associated with a low-carbon, fully-integrated, and circular pan-European energy system in 2050 and the electricity system as its backbone. The vision leverages the contributions from more than 200 ETIP SNET experts and stakeholders, coming from all fields of current and future energy systems.

The next step following the Vision 2050 will be the **ETIP SNET Mission 2035,** describing what efforts will be necessary in the 15 years to come between 2020-2035, to ensure the effectiveness of research and innovation funding for integrated energy systems innovation needs, related economic growth and society welfare. The ETIP SNET Mission 2035 will clarify what complex societal challenges need to be solved by what types of RD&I projects applying high openness, intensive cross-disciplinary and cross-sectoral collaboration, using dynamic co-investment along the entire innovation chain of Europe's energy systems.

The **ETIP SNET 10-year RD&I roadmaps** will support Vision 2050 and Mission 2035 towards achieving fully-integrated, grid-based energy systems with electricity infrastructures as the backbone of Europe's energy markets. Using the Vision 2050 and the upcoming Mission 2035, regular updates and significant extensions of any non-resolved, specific RD&I activities will enable Europe to cover gaps by means of concrete projects suitably-funded from all possible public and private sources.

The **ETIP SNET Implementation Plans** set Europe's RD&I priorities for a smarter energy transition as specified in the ETIP SNET 10-year RD&I roadmaps. Such plans have a time horizon of approximately two-three years. They present the short-term key RD&I priorities to enable the progressively-intensified transition towards reliable, secure, resilient, market-based, sustainable, renewable and circular European energy systems, at affordable costs.

In the context of its core activities, ETIP SNET proposes to establish a stronger link with policy-makers in order to maximise the chances for the successful implementation of results coming from the RD&I that encompasses integrated energy systems and associates regulatory and institutional enablers. ETIP SNET aims to be Europe's leading organisation to:

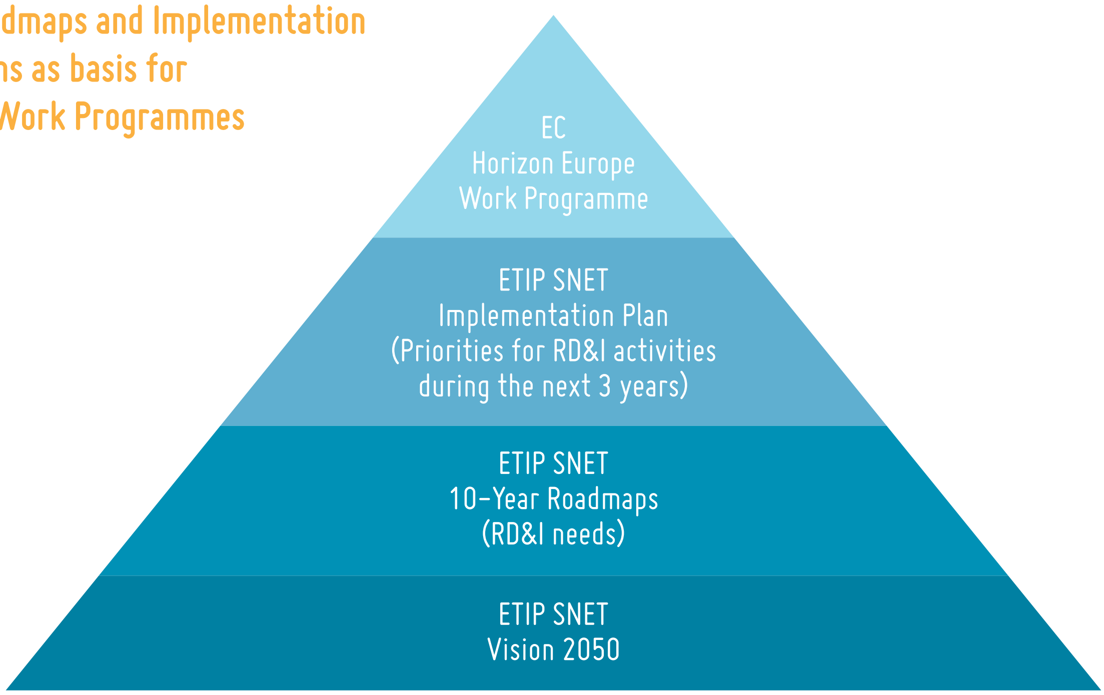
- Achieve fully-coordinated participation of all ETIP SNET stakeholders in all energy systems areas, avoiding silo visions, missions, roadmaps and implementation plans;
- Provide guidelines and recommendations to each of the ETIP SNET stakeholders including national governments to guide their way towards achieving the integrated Vision 2050;
- Develop as next step the ETIP SNET Mission 2035, being the guideline for the ETIP SNET 10-year RD&I Roadmaps which intend to realise the mission in concrete, measurable ways to account for both the evolution of technology of all energy carriers and their conversions, technology step changes but also societal changes.

ETIP SNET calls for the creation of the appropriate coordinated mechanisms to connect to the many technology and innovations platforms of related climate and circular economy organisations and relevant technology sectors (for example: rare earths, aviation) to better share the Vision 2050 and its subsequent mission, roadmaps, implementation plans and actions.

ETIP SNET calls for the collaboration of authoritative, senior figures from all energy systems stakeholders, Member States, Associated Countries and the EC to build consensus on strategic actions as defined by this Vision 2050, the upcoming ETIP SNET Mission 2035, 10-year ETIP SNET Roadmaps and short-term ETIP SNET Implementations plans;

ETIP SNET calls for adequate funding for future European Framework Programmes leading to a fully converged Europe-wide consensus among all energy systems stakeholders in coherence with funding from national and regional governments in Europe.

Figure 8. ETIP SNET Vision, Roadmaps and Implementation Plans as basis for EC Work Programmes



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