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optimising local energy communities

Local multi-vector energy systems within the European political and regulatory landscape: scope and key priorities for the study

WP2, T2.1 "Preliminary scoping of the study based on the Pan-European decarbonisation targets, regulatory acts and roadmaps".

Authors:
Andrei Morch and Hanne Sæle (SINTEF Energi AS)
Julia Merino, Andrés Cortés and Maider Santos-Mugica (TECNALIA)
Jesús Fraile, Álvaro Gutiérrez, David Jiménez and Juan Ignacio Pérez (UPM)
Marialaura Di Somma, Amedeo Buonanno, Martina Caliano, Valeria Palladino and Gabriella Rossi (ENEA)
Gabriele Comodi, Mosè Rossi and Andrea Monforti Ferrario (UNIVPM)
Victoria Rebillas-Loredo and Cristina Corchero-García (IREC)
Alison O'Connell and Alessio Coccia (EPRI)

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Project Coordinator	Marialaura Di Somma Department of Energy Technologies and Renewable Sources - Smart Grid and Energy Networks Lab, ENEA marialaura.disomma@enea.it
Technical Coordinator	Christina Papadimitriou FOSS Research Centre for Sustainable Energy, University of Cyprus papadimitriou.n.christina@ucy.ac.cy
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Executive summary

This deliverable includes the first results of work package 2 "Limitations and shortcomings for optimal use of local resources" of the eNeuron project and is the first in a series of three reports that is looking into regulatory aspects concerning the methodologies to be developed within the project. The following sub-activities will identify the present (technical) limitations, shortcomings and obstacles to innovation, which may prevent the intended transformation of the European energy landscape towards local multi-vector energy systems with a high level of decarbonisation.

The present document carries out an assessment of the project's scope based on the Pan-European decarbonisation targets and consequent regulatory acts, trends and roadmaps ensuring that the project outcomes comply with the overall Pan-European political targets.

The activity applies qualitative evaluation methods, based on data collected through literature screening of a selected documents from the key European stakeholders. The study restricts the focus to a pre-defined selection of issues, which have critical importance for eNeuron project and are called "topics of interest". These topics represent either some key assumptions made within the project, or/and some attributes, which can be directly and indirectly decisive for the development and later for the implementation of the project outcomes.

Table 0.1 presents a brief overview of the identified topics of interest and reports some concluding comments for each of them.

Table 0.1 Summary of concluding comments to the identified topics of interest.

Topic of interest	Conclusions
Limitations related to ownership and operation of the emerging technologies, including roles and responsibilities	There is still an ongoing public discussion about the involvement of system operators (SOs) in the ownership, operation and management of energy storage facilities. The EU Internal Electricity Market (IEM) Directive 2019/944 maintains a position from the previous editions, which do not allow to own, develop, manage or operate energy storage facilities for SOs. Therefore, the provision of flexibility from batteries will most likely be done as a service from independent operators in the near future. This also means that the system operators, which presently own electricity storage, will have to transfer the ownership to third companies unless they get a specific exception from their respective National Regulating Authorities (NRA). The present regulation of hydrogen facilities appears to be extremely rigid and is still lacking several principal decisions related to ownership and operation of electrolysers (regulated natural monopolies or commercial activities), regulation of Third-Party Access (TPA) to the hydrogen infrastructure and overall taxonomy, allowing to validate the origin of the produced hydrogen. The lack of a clear framework for hydrogen infrastructure is likely to limit the deployment of the technology.

	On the contrary, when it comes to newly introduced Citizen Energy Communities (CECs), an array of activities appears to be possible, which are not allowed to System Operators, including ownership and operation of storage facilities and EV charging points.
Energy vectors, which are preferred in Europe (2020-2050)	Through the IEM Directive 2019/944, common rules are established for the internal electricity market, which highlights moving towards decentralised generation, and consumers access to all markets – both to trade energy but also to contribute with flexibility services to the power system. Maturing and transposing these rules into national legislation is the main challenge for the next decade. Additionally, the RED II Directive (2018/2001) promotes the use of energy from renewable sources. Energy production based on RES is more variable than energy production in, for example, coal-fired plants and large hydropower plants, which increase the focus on the security of supply. Energy efficiency reamains to be a significant and cost-efficient part of the decarbonisation process. According to different scenarios, a larger share of RES will be introduced towards 2030, while hydrogen included in the scenarios towards 2050 in order to achieve the decarbonisation targets. In the future energy system, the share of renewable energy sources (RES), nuclear energy, as well as carbon-neutral gases and liquids, will increase with high contribution to grid stability and uninterrupted energy supply. Due to technology development, different types of energy storage will be available, such as pumped-storage hydropower plant, batteries, hydrogen storage, flywheels and supercapacitors, thermal energy storage, Superconducting Magnetic Energy Storage (SMES). The use of energy storage will affect both the natural gas, heat and transportation market due to its cross-sectoral nature.
Expected roll-out of the different technologies in the 2030 horizon	Integration of hydrogen as consistent part of the future European decarbonisation strategy brings a considerable demand for Power-to-H2 (P2H2), Power-to-CH4 (P2CH4) and Power-to-Liquid (PtL) by 2050. Considering that for the moment the hydrogen infrastructure almost none-existing, this will require massive investments in the next decades into electrolysers, storage, networks, Fuel Cell Electric Vehicles (FCEV) charging stations and other elements.

	Introduction of RES brings a need for more efforts in balancing of the power system, what may become a major driving force for deployment of grid-connected energy storage, while other technologies as pumped hydro and heat storage will become more important. Hybrid solutions, coupling different forms of energy storage with intermittent renewable energy sources will improve deployment of renewable energies. Several technologies on transmission level as AC/DC will inevitably have direct or indirect effects on the distribution networks.
Supporting Mechanisms for multi-vector energy systems	EU requires common rules for the internal market for electricity and network development plans for distribution systems in order to support the integration of installations generating electricity from RES, facilitate the development of energy storage facilities and the electrification of the transport sector. The need to promote the use of renewable energy in the electricity sector is recognized as one of the fundamental issues in order to reduce greenhouse gas emissions. A major driver of battery market growth has been the more widespread coupling of batteries with Variable Renewable Energy (VRE) generators. For launching hydrogen, several supporting mechanisms are planned. To achieve the goals of the internal market for electricity, it is important to establish support schemes that ensure that both small (incl. renewable energy communities) and large consumers can participate on equal terms. Further, to continue the growth in RES and deployment of new technologies such as energy storage, sufficient incentives need to be developed. The main challenges identified across the region for the renewables' integration process include market redesign, storage capacity, public acceptance, and grid interconnections.
Conversion processes (Power-to-X) in the context of integrated energy systems	The vision of the 2050 power system locates the electricity grid in the centre of the integrated energy system. 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 PtG, PtH, and Power-to-Liquid PtL technologies and to transport large amounts of energy all over Europe. This must rely on renewable hydrogen, which is the most compatible option with the EU's climate neutrality and zero pollution goal in the long term and the most coherent with an integrated energy system. This view is however challenged by the existing high costs for the production of renewable hydrogen.

	The study of feasibility for PtG and PtL in [19] concludes that PtX technologies are competitive only in few European countries, where low-cost renewable electricity can be generated. This study is supported by a pragmatic view from WindEurope, which suggests concentrating first on delivering decarbonisation in the easier-to-abate sectors by direct electrification of these. Instead of producing hydrogen from curtailed renewable electricity generated by wind and solar, the policy-makers should firstly incentivise energy-intensive hard-to-abate industries to locate close to coastal areas, where offshore wind is abundant, or to onshore areas with good wind resources and limited transmission.
Overview of policies supporting the empowerment of the final consumer	To achieve the planned energy transition, it is important to establish efficient energy markets that provide a playing field for all involved stakeholders. This also includes energy communities, which need the right to produce, consume, store and sell renewable energy. These communities also should be able to exchange, within the same community, the renewable energy produced by them and access all the appropriate electricity markets, directly or through aggregation, in a non-discriminatory way. To pave the way for this transition, the EU requires that the Member States shall ensure participation of consumers, including through demand response, through investments into, in particular, variable and flexible energy generation, energy storage, or the deployment of electromobility. Recent European legislation requires that the ENTSO-E and a new EU DSO entity must involve more active citizens and energy communities in the generation, consumption, storage, and sell-off of electricity without facing disproportionate burdens.
Storage characteristics and cost forecast	Storage technology in its various forms is foreseen as a key enabler of the energy transition and a binding element of different energy vectors. However, it has been concluded that today only few energy storage applications can justify market-based business cases, and this is why many energy storage technologies have not spread into the market yet. There is a strong expectation that the short-term electricity balancing market is where energy storage will be first applied, based on commercial business cases, and we believe the need for additional balancing power will be substantiated already within the next five years. From a longer-term perspective (15-20 years) energy storage will become an even more significant part of the electricity system, providing more services.

	Apart from electricity storage, heat storage will become increasingly important. Today more than 50 % of the final energy demand in the EU is used for generating heat and already now heat storage is utilised in water-based systems for domestic and district heating. In terms of thermal energy storage is by far the largest single energy storage application field in Europe.
EV forecast	Transport remains the sector with the lowest penetration of renewable energy in the EU energy system, and in 2015 the share of renewable energy in transport was below 7 %. The most recent figures show however a significant increase in number of sold vehicles in Europe during the recent years i.e., nearly one million BEV-PHEV vehicles were sold in Europe in 2020, representing more than 10% of car sales. The representatives from the EU, European Parliament and European Council has agreed that EV sales should account for 15 % of new car sales by 2025 and 35 % by 2030. Even if the level of adoption of EVs is small in the EU, it shows early signs of very deep transformation, close to exponential growth. Over 40 million of light-duty electric vehicles will be on EU roads by 2030. Electric mobility is an example of a cross-cutting technology requiring a thorough holistic approach: smart charging of electric vehicles and EVs acting as stationary batteries, feeding electricity back into the grid whenever it is profitable (V2G), could contribute to cost-effective integration of variable renewable sources in the power sector in 2030. Electric mobility is considered a key point for the decarbonisation of the transport sector, especially in urban areas, and it is a need for policies to promote EVs that must also support charging points deployment and include new codes to install these charging points in new (or refurbishment) buildings.
Expected consumer adoption of low carbon technologies	The screening creates an impression that despite a multitude of technologies, which can contribute to decarbonisation, the present situation of consumers' adoption of technologies is shaped by several interest organisations related to specific technologies. It appears that these organisation tend to emphasise their "own" technologies, sending the consumers information, which is not aligned or sometimes even contradicting. The situation is worsened by the complexity of the problem and variety of the available solutions and combination of these both on a single consumer level as well as on an energy community level. This highlights the necessity of holistic approach with dedicated and tailorable optimisation tools, which allow evaluating several decarbonisation technologies.

Existing local energy market mechanisms	According to the IEM Directive, all consumers should have access to all electricity markets, where they can both trade flexibility (from demand response, energy storage) and self-generated electricity (from distributed generation). With this specification, the directive opens up for all consumers to get the actual market price for both electricity and flexibility services. This is a first step towards an open market, where the consumers also pay the actual electricity price. However, there is a limited description of existing local energy market mechanisms, mainly because this is a new trend in the power system and not deployed in large scale. To handle these changes, and study the consequence for stakeholders involved, it is important to evaluate possible business models.
Integration of local energy markets into the Energy Market	From the screened documents, it appears that the establishment of well-functioning local markets is a compulsory attribute of the successful energy transition. Several functions are required: • Local trading of renewable electricity. • Trading of flexible resources necessary for ancillary services securing operation reliable system operation. • Cross-sector market arrangements for sector coupling. It is likely that the process will happen stepwise and require a certain maturing time.
V2G integration mechanisms	According to IEM Directive 2019/944, all consumers should be able to consume, store and sell self-generated electricity to the market and to provide flexibility to the system. EV is a potential storage for demand response application and will also help to accelerate the development of self-consumption schemes, enabling Vehicle-to-Grid (V2G) applications. EVs with V2G technology can contribute with flexibility services to the power system, and especially Grid to Vehicle (G2V) and V2G capabilities for load flattening, system balancing and voltage support. Some of the relevant technology for this is available today, and some are under development, while the challenge is to develop business models and incentives to realise the benefits from V2G/G2V.
Energy Communities - different actors and operations	Following the Pan-European legislation for CECs, an array of possibilities appears to be open e.g., it can undertake roles of final customers, producers, suppliers or distribution system operators, engaging in energy generation, distribution, supply, ownership and management of batteries, EV charging points etc. The IEM Directive also empowers the Member States to allow CECs to become distribution system operators either under the general regime or as "closed distribution system operators". Once a citizen energy community is granted the status of a DSO,

	it should be treated as, and be subject to the obligations as a DSO, with certain exemptions. At the very same time while undertaking these roles, CECs may have several exemptions form the responsibilities required from the full-scale operators. For the time being, it is up to Member States to define national regulatory regimes and there is an indication of considerable diversity among the forthcoming national models. However, simple inheritance of different roles as, for example, the role of DSO does not necessarily open all necessary functions for CECs, simply because these are none-existing at the DSO level.
Energy vectors integration and coupling technologies (Policies)	Relevant topics related to policies for integrating energy vectors and coupling technologies are, for example, market regulation so all consumers have access to all markets and can sell flexible services to the power system, which can defer the needs for grid updates and increase the security of supply. EVs, EV charging stations, and their potential for demand response are additional examples of resources that can offer services to the power system. For the energy transition towards 2050, it is needed to deploy power conversion units enabling the optimal coupling (integration) among all energy vectors. Coupling different energy networks occurs on all scales according to the most cost-effective way. In the medium-long term the sector coupling between power and other networks via hydrogen are expected, achieving the possibility to reach a vast range of applications (gas, buildings, mobility, power generation, storage)

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Abbreviations and acronyms

Acronym	Meaning
µCHP	Micro Combined Heat and Power
AFID	Alternative Fuels Infrastructure Directive
BEV	Battery Electric Vehicles
BNEF	Bloomberg New Energy Finance
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Utilisation and Storage
CDTI	Centro para el Desarrollo Tecnológico Industrial (Center for the Industrial Technology Development
CEC	Citizens Energy Community
CEER	Council of European Energy Regulators
CfDS	Contracts-for-Difference
CHP	Combined Heat and Power
CNG	Compressed natural gas
CTES	Long-term thermal energy storage
DSO	Distribution System Operator
EASE	European Association for Storage of Energy
EC	European Commission
EC LTS	European Commission Long-term Strategy
EEG	Erneuerbare Energien Gesetz (The Renewable Energy Act)
EMD	Electricity Market Directive
ENTSO-E	European Network of Transmission System Operators for Electricity
ETIP-SNET	European Technology & Innovation Platform - Smart Networks for Energy Transition
ETS	EU Emission Trading Scheme
EU	European Union
EU28/EU27	European Union of 28 Member States (27 after 2020-02-01)
EV	Electric Vehicle
FC	Fuel Cell
FCEV	Fuel Cell Electric Vehicles

FIP	Feed-in Premium
FiT	Feed-in Tariff
FOM	Fixed Operation and Maintenenace
G2V	Grid to Vehicle
G2V	Grid to Vehicle
GDP	Gross Domestic Product
GHG	Greenhouse Gas (-es)
GIC	Gross Inland Consumption
GIC	Gross Inland Consumption
GIPL	Gas interconnection between Lithuania and Poland
GO	Guarantee of Origin
H2	Hydrogen
HRS	Hydrogen Refuelling Stations
HVAC	Heating Ventilation Air Conditioning
ICE	Internal Combustion Engines
ICT	Information and Communications Technology
IEA	International Energy Agency
IEM	Internal Electricity Market (Directive)
INECP	Integrated National Energy and Climate Plan
IoT	Internet of Things
IRENA	International Renewable Energy Agency
ITES	Individual thermal energy storage
LDV	Light Duty Vehicles
LNG	Liquefied natural gas
LTO	Landing and Take-Off Cycles
LTS	Long-term Strategy
NCA	Nickel Cobalt Aluminium
NEV	New Energy Vehicles
NRA	National Regulating Authority
O&M	Operation and Maintenance

P2CH4	Power-to-CH4
P2H2	Power-to-H2
PES	Primary energy supply
PHEV	Plug-in Hybrid Electric Vehicle
PHS	Pumped hydro storage
PNIEC	Plan Nacional Integrado de Energía y Clima 2021-2030 (Spanish INECP) Piano Nazionale Integrato per l'Energia e il Clima (Italian INECP)
PPA	Power Purchase Agreement
PPP	Public-private Partnerships
PtG	Power-to-Gas
PtH	Power-to-Heat
PtL	Power-to-Liquid
PtX	Power-to-X
PV	Photovoltaic
RD&I	Research, Development and Innovation
REC	Renewable Energy Community
RED	Renewable Energy Directive
RES	Renewable Energy Sources
SDE++	Sustainable energy transition support scheme
SDS	Sustainable Development Scenario
SET Plan	Strategic Energy Technology Plan
SME	Small and medium-sized enterprise
SMES	Superconducting Magnetic Energy Storage
SMR	Steam Methane Reforming
SO	System Operator
TEN-E	Trans-European Networks for Energy
TPA	Third Party Access
TSO	Transmission System Operator
TYNDP	Ten-Year Network Development Plan
V2G	Vehicle to Grid

VRE	Variable Renewable Energy
ZEV	Zero-Emission Vehicle

1 Introduction

This deliverable is the first one in the series of three reports that are planned to be developed in the activity "Limitations and shortcomings for optimal use of local resources" in the H2020 project eNeuron. The main objective of this activity is to scope the study based on the Pan-European decarbonisation targets and consequent regulatory acts, trends and roadmaps, e.g., European Technology & Innovation Platform - Smart Networks for Energy Transition (ETIP-SNET) "Vision 2050". The study further identifies and benchmarks the indicative status for the deployment of integrated local multi-vector energy systems (including batteries and electric vehicles - EVs) and corresponding supporting mechanisms, tools and technologies in the Member States. The next step will identify the present (technical) limitations, shortcomings, and obstacles to innovation, which may prevent the intended transformation of the European energy landscape towards local multi-vector energy systems with a high level of decarbonisation.

The results will be presented in three different technical reports:

- D2.1 Local multi-vector energy systems within the European political and regulatory landscape: scope and key priorities for the study (the present document)
- D2.2 Technical solutions for multi-carrier integrated systems under the LEC concept: A review
- D2.3 Limitations and shortcomings for optimal use of local resources

Potential implications of the identified gaps, limitations and shortcomings will be qualitatively evaluated, and the results will be used as an input to the specification of the pilots.

1.1 eNeuron in a nutshell

The main goal of the eNeuron (greEN Energy hUbs for local integRated energy cOmmunities optimizatioN) project is to develop innovative tools for the optimal design and operation of local energy communities (LECs), integrating distributed energy resources and multiple energy carriers at different scales.

This goal will be achieved by having in mind all the potential benefits achievable for the different actors involved and by promoting the Energy Hub concept as a conceptual model for controlling and managing multi-carrier and integrated energy systems in order to optimize their architecture and operation. To ensure both the short-term and the long-term sustainability of this new energy paradigm and thus support an effective implementation and deployment, economic and environmental aspects will be taken into account in the optimisation tools through a multi-objective approach.

eNeuron’s proposed tools enable tangible sustainability and energy security benefits for all the stakeholders in the LEC. Local prosumers (households, commercial and industrial actors) stand to benefit through the reduction of energy costs while leveraging local, low carbon energy. Developers and solution providers will find new opportunities for technologies as part of an integrated, replicable operational business model. Distribution system operators (DSOs) benefit from avoiding grid congestion and deferring network investments. Policymakers benefit from increasingly sustainable and secure energy supply systems.

eNeuron is a high TRL project in line with the Work Programme by developing innovative approaches and methodologies to optimally plan and operate integrated LECs through the optimal selection and use of multiple energy carriers and by considering both short- and long-run priorities. Through optimally coordinating all energy carriers and vectors, cost-effective and low-carbon solutions will be provided to foster the deployment and implementation of this new energy paradigm at the European level.

1.2 Structure of the document

This deliverable starts with a summary chapter and a list of abbreviations, followed by an introduction where both the purpose of the work and the eNeuron project is described. In Section 2, the methodology of the screening study is described, also giving an overview of both the topics of interest defined and the document selected for the study. The results of the screening study are described in Section 3, with one sub-chapter per selected topic of interest. The conclusions of the study are presented in Section 4, and an overview of the reports included in this study is given in Section 5. Annex I contains a glossary of relevant terms, and Annex II summarises the screened documents.

2 Methodology

To facilitate this analysis, it was necessary to first decide which aspects of the project would be important and informative for optimal use of local resources. These are referred here as *topics of interest* and are described in detail in subsection 2.2. The second step was to decide upon the documents that would be screened, and against which defined topics of interest these would be evaluated.

2.1 Terms and definitions

The continuous changes in the regulatory landscape create several new technical terms and definitions. Some of these have been already modified several times, or in some cases, vary from one official document to another. In order to reduce any potential ambiguity, this document has a specific Glossary section (see Annex I, page 92), which refers to terms and definitions stipulated in the most recent official European documents.

2.2 Topics of interest defined for the study

In order to create a more systematic approach, a set of topics of interest has been identified. These topics represent either some key assumptions made within the project, or/and some attributes, which can be directly or indirectly decisive for the development of and later implementation of the project's outcomes.

Table 2.1: Topics of interest defined for the study

Nr.	Title	Explanation
1	Limitations related to ownership and operation of the emerging technologies, including roles and responsibilities	Existing or forthcoming limitations, which may influence the involvement of different actors into the new business models. The limitations can be technology-, market-, actor-specific, etc.
2	Energy vectors, which are preferred in Europe (2020-2050)	The most recent roadmaps re-define the energy vectors, which are preferred for decarbonisation in Europe, sectoral specifics, e.g., batteries for personal transport, but hydrogen for cargo transport.
3	Expected roll-out of the different technologies in the 2030 horizon (covers several technologies, including combination/hybrid technologies)	Forthcoming technologies with an expected bigger impact on energy production. It can be new or a combination of different technologies. The topic focuses on technologies, not energy vectors.
4	Supporting Mechanisms for multi-vector energy systems	Sustaining schemes and tools for multi-vector energy systems (the existing practice).

5	Conversion processes (Power-to-X) in the context of integrated energy systems	Recent roadmaps to define conversion processes as storage for the multi-carrier energy system, the current status and link to the future priorities.
6	Overview of policies supporting the empowerment of the final consumer	Regulatory aspects and roadmaps related to consumers' empowerment towards collective self-consumption and energy communities.
7	Storage characteristics and cost forecast	Energy storage will be a key factor to empower electrification. Main characteristics and cost evolution will determine the future deployment of different storage technologies (it can be any storage technology, e.g., thermal storage, electricity, etc.)
8	Electrical Vehicles (EVs) forecast	EV penetration will affect the total energy consumption and the amount of storage capacity available to support the electric grid. The forecast covers several factors penetration of EVs, load, number and location of charging points, etc.
9	Expected consumer adoption of low carbon technologies	Consumer adoption of solar photovoltaic (PV), storage, heat pumps, electric vehicles, as well as willingness to participate in demand response, energy efficiency programs, etc., will heavily influence the available resources and needs with relation to the energy system.
10	Existing local energy market mechanisms	Awareness of existing local market mechanisms is a critical input for business models in WP3 " Identification of the “Local Integrated Energy Community” subject and definition of the Use Cases" (needs for new markets/trials/tested models).
11	Integration of local energy markets into the Energy Market	Limitation and shortcomings of the integration of Local Energy markets with the "main" Energy Market. Any policy related to the different carrier's integration market.
12	V2G integration mechanisms	Opportunities associated with the provision of aggregation and other control-related services to manage the energy supply to/from vehicle batteries and to use this to deliver services to customers (e.g., DSOs, energy companies) when required. This includes technologic, legal (support schemes) or a combination of these.
13	Energy Communities - Different actors and operations	The different actors involved and their role in Energy Communities. Operations of Integrated Energy Systems as a Web of Cells (see WoC definition in the Glossary).

2.3 Selection of documents for the screening

The selection of the documents is determined by the previously defined purpose of the study. The list of the screened document is presented in Subsection 5.1, and a short summary of each document is included in Annex II.

The documents considered in this study have been issued by several types of stakeholders, including:

- Governmental Organisations – the Europeans Commission (EC), issuing Directives and Regulations.
- National Governments and National Regulating Authorities (NRAs)
- Interest organisations and Industrial Associations as for example, WindEurope, Solar Power Europe
- Worldwide international organisations as International Energy Agency (IEA) and similar

2.4 Covering the national practices

Following the objectives from the project's description of work, the screening primarily focuses on the Pan-European level in order to scope the whole study. However, some sections refer to certain country-specific documents whenever these provide valuable information for the study, especially when it comes to implementation of emerging technologies. It has been noticed that some of the roadmaps, especially linked to specific technologies, appear to be very ambitious. Considering how these techologies have been reflected in the national dimensions, provides a certain validation, even though this is indicative.

2.5 Limitations of the study

Evolving regulatory landscape: Several key regulatory documents from the recent regulatory package "Clean Energy for all Europeans", including Directive (EU) 2019/944 on common rules for the internal market for electricity and the corresponding Regulation (EU) 2019/943, have been amended several times, resulting in several recasts. Some of the formulations have had a significant transformation, and some new terms have been introduced. The study refers to the most recent recast existing at the time of writing this report. Describing important issues, in addition to regular references, the study also mentions specific sections or chapters in the referred documents, so the information can be checked for further details if needed.

Focus of the study: Considering the focus and the scope of the activity "Limitations and shortcomings for optimal use of local resources'', the present study will primarily focus on the distribution level, including DSOs, Active customers, CECs, distributed generators, aggregators and other relevant actors and roles. However, in addition to this, the study also considers important issues at the transmission level, if they may have any significant impacts on the primary scope of the study. It is also necessary to mention that CECs will be further addressed in another activity/WP in the project: *Identification of the "Local Integrated Energy Community", subject and definition of the Use Cases*.

EU28/EU27: Due to BREXIT procedure, the official number of the Member of States reduced from 28 to 27 from 2020-02-01. However, the major part of the screened documents use figures and calculations related to EU28. Therfore, the present study uses both EU27 and EU28 terms.

Consequences of COVID19: Due to the circumstances related to COVID19, timeline for some of the mentioned roadmaps and plans may be revised.

3 The screening study

Articles are related to the specific topics of interest and present the content in the following order:

- Pan-European view based on documents from Governmental Organisations as for example the EC, issuing Directives and Regulations.
- Documents from National Governments and NRAs.
- Interest organisations and Industrial Associations as for example, WindEurope, Solar Power Europe.
- Worldwide international organisations as International Energy Agency (IEA) and similar.
- Discussion and conclusions.

However, the order is approximate, and in some articles, the sequence is changed in order to make the content more logical and consistent.

3.1 Limitations related to ownership and operation of the emerging technologies, including roles and responsibilities

This section looks at existing or forthcoming limitations, which may influence the involvement of different actors in the new business models. The limitations can be technology-, market-, actor-specific, etc. Several key regulatory issues related to ownership and operation were identified in the screened documents.

3.1.1 Ownership and operation of Energy Storage

The IEM (Internal Electricity Market) Directive 2019/944 (art.1 in [13]) underlines the importance of the energy storage by defining the regulatory conditions for it on equal terms with generation, transmission and distribution. Two specific sections (art.36 and art.54) in the most recent version of the IEM Directive present the official position of the EC regarding ownership of energy storage facilities by Distribution System Operators (DSOs) and Transmission System Operators (TSOs), respectively. The document maintains a position from the previous editions of the Directive, which do not allow to own, develop, manage or operate energy storage facilities for System Operators (SOs). The Directive refers to several reasons for this position, including avoidance of cross-subsidising between the energy storage and regulated functions, distortion of competition and securing free access to the storage services to all market participants.

However, by way of derogation from it, the Member States may allow SOs to own, develop, manage or operate energy storage facilities, where they are fully integrated network components, and the regulatory authority has granted its approval, or where all of the following conditions are fulfilled [13] (almost similar conditions for TSOs and DSOs):

- other parties, following an open, transparent and non-discriminatory tendering procedure that is subject to review and approval by the regulatory authority, have not been awarded a right to own, develop, manage or operate such facilities, or could not deliver those services at a reasonable cost and in a timely manner
- such facilities (or non-frequency ancillary services for TSOs) are necessary for the system operators to fulfil their obligations under this Directive for the efficient, reliable and secure

operation of the system and they are not used to buy or sell electricity in the electricity markets; and
- the regulatory authority has assessed the necessity of such a derogation, has carried out an ex-ante review of the applicability of a tendering procedure, including the conditions of the tendering procedure, and has granted its approval.

Active customers (see the Glossary) are allowed to own energy storage facilities (art.15 in [13]) and have several rights stipulated in the document, related to grid connection, not subject to additional fees and charges.

The "European Energy Storage Roadmap" [15] (section 5.1.5) recognises that the electrical storages have several challenges that need to be addressed:
- The first challenge is related to value materialisation due to the following reasons:
  - No compensation scheme for storage among stakeholders
  - No clear ownership and operating models
  - No models for fully capturing different value streams
- The second is related to the cost issues in order to position the electric storage technologies in front of the alternative solutions as for example:
  - Flexible generation systems
  - Grid (Transmission/Distribution) upgrades
  - Demand side management

A legal framework for energy storage in the EU and adequate financial support are required to solve the current challenges that affect the different storage technologies described in this work.

The involvement of network operators (transmission and distribution) in the ownership and operation of energy storage devices is discussed in "The Study on Energy Storage" [27] regarding its potential negative impact for the creation of a fair and level playing field for investments in energy storage. The document briefly explains the arguments both in favour and opposition of network operators owning and operating energy storage assets, summarises the current status of this topic in EU Member States and points to the creation of clear national rules as best practice to address this topic.

3.1.2 Ownership of hydrogen infrastructure

There are several obstacles to the deployment of hydrogen infrastructure related to the ownership and operation. WindEurope (see [4]) pointed out that there are several missing elements in the present regulation related to hydrogen infrastructure:

- **The hydrogen taxonomy**

  The taxonomy is needed to classify the different routes to produce hydrogen, particularly when produced via electrolysis with renewable electricity. There is no commonly agreed definition and classification for hydrogen at EU-level, including the associated CO_2 and environmental impacts.
- **Traceability of hydrogen and guarantees of origin**

  It is necessary to establish the traceability of the renewable electricity used for hydrogen production in a system with a mix of power generating technologies. The taxonomy of hydrogen will also determine the type and amount of Guarantees of Origin (GOs) given to hydrogen producers when using renewable energy.

- **The roles and responsibilities**
  It is necessary to define roles and responsibilities of market and regulated players in the production of hydrogen, crucially who can own, operate and offer sector coupling and cross-vector integration services to the market

Therefore, there is a clear necessity to define regulations in the energy sector with regards to ownership, production, and storage of hydrogen facilities. Especially it appears to be unclear whether electrolyser facilities are natural monopolies, which should be regulated, as for example, DSOs or not. So far, to alternative approaches have been defined for the production of hydrogen:

- **Natural monopoly**: One approach defines these activities as "conversion" service is not an energy production facility, and therefore believe that these installations should be perceived as a natural monopoly.
- **Commercial activity**: A second approach is that it is necessary to get the first investments to enable Power-to-Gas (PtG) business cases for investors: public funding for financial R&D support should be envisaged, while industrial consortia can play a key role. Once mature and commercially available, PtG technologies are in principle commercial activities which cannot be carried out by regulated entities.

The difference between regulated natural monopoly and commercial activity is essential when it comes to investment decisions since it defines future revenues.

WindEurope in [4] makes a clear point that SOs should not be involved in competitive activities like PtG, as they will have a potential conflict of interest when planning, granting access and operating / dispatching infrastructures, i.e., the effective separation of networks from activities of production and supply is a fundamental pillar for achieving the objective of a well-functioning energy market.

In addition to the ownership and operation of electrolysers, there are several interlinked issues, including Third Party Access (TPA) to pipelines and gas storage facilities from competing producers and suppliers of hydrogen. The introduction of TPA and its type (negotiated vs regulated) is essential for both recovering the initial investments into the pipeline networks as well as development of competing for hydrogen-producing infrastructure, i.e., electrolysers.

The "Hydrogen Map Europe" [14] acknowledges that in the case of hydrogen for transport applications, the so-called "chicken-and-egg" problem entails that the lack of end-users as Fuel Cell Electric Vehicles (FCEV) determines a lack of demand for the required infrastructure as Hydrogen Refuelling Stations (HRS), inhibiting the possible growth of the sector.

When it comes to the national states, Spain had a clear strategy towards hydrogen, which is elaborated in the Spanish Government's "Hydrogen Roadmap" [21]. The document concludes that in Spain, green hydrogen production is considered to be an industrial activity, and as such, it can be only developed on pieces of land that are classified as "Industrial". Industrial activities are subject to rigorous environmental impact assessments. There is no certification scheme labelling the origin of hydrogen. There are no standards for heavy-duty hydrogen vehicles. In Spain, the design, building, commissioning, and operation of hydrogen fuelling stations is regulated in a Royal Decree, mixed with other road transport fuels such as natural gas, biofuels or electricity. Current Spanish regulations allow a maximum of 5 % hydrogen blending in the natural gas network.

3.1.3 Citizen Energy Communities

At present, no common Pan-European rules define all aspects of ownership and operation [7] and there are several country-specific variations of national laws, which in some cases (for example, UK) have advisory nature. Topics related to energy communities are further described in subsection 3.13.

According to [16], the main limitations are related to legal, financial, and political issues. Current legislation lacks definition and guidelines on what the energy communities are and what are their needs (e.g., access to finance, connection to the grid, administrative burden, etc.).

In addition to this, it is also interesting to mention that the so-called CECs may engage in energy storage services or charging services for electric vehicles or provide other energy services to its members or shareholders (see Section (11) in [13]).

3.1.4 Ownership and operation of EV charging points

Electrification of transport is an important part required for decarbonisation of the European economies. Construction of charging infrastructure is a necessary step in this direction. Following Art. 33 in [13] several European countries elaborate very ambitious plans for electrification of transport, making the development of the new EV charging stations to become one of the main reasons for the expansion of distribution networks in the coming years.

The IEM Directive [13] defines that DSOs shall not own, develop, manage or operate recharging points for electric vehicles, except where DSOs own private recharging points solely for their own use. However, Member States may allow DSOs to own, develop, manage or operate recharging points for electric vehicles, provided that all of the following conditions are fulfilled:

- other parties, following an open, transparent and non-discriminatory tendering procedure that is subject to review and approval by the regulatory authority, have not been awarded a right to own, develop, manage or operate recharging points for electric vehicles, or could not deliver those services at a reasonable cost and in a timely manner.
- the regulatory authority has carried out an ex-ante review of the conditions of the tendering procedure under point (a) and has granted its approval.
- the DSO operates the recharging points on the basis of third-party access and does not discriminate between system users or classes of system users, and in particular in favour of its related undertakings.

The same document directly mentions that CECs are allowed to own and operate EV charging points.

3.1.5 Summary

There is still an ongoing public discussion about the involvement of SOs in the ownership, operation and management of energy storage facilities. The IEM Directive maintains a position from the previous editions, which do not allow to own, develop, manage or operate energy storage facilities for SOs. Therefore, the provision of flexibility from batteries will most likely be done as a service from independent operators in the near future. This also means that the system operators, which presently own electricity storage, will have to transfer the ownership to third companies unless they get a specific exception from their respective NRA. It seems it could be possible to own and operate batteries for some new actors as active customers and possibly CECs.

The present regulation of hydrogen facilities appears to be extremely rigid and is still lacking several principal decisions related to ownership and operation of electrolysers (regulated natural monopolies or commercial activities), regulation of TPA to the hydrogen infrastructure and overall taxonomy, allowing to validate the origin of the produced hydrogen. The lack of a clear framework for hydrogen infrastructure is likely to limit the deployment of the technology.

On the contrary, when it comes to newly introduced CECs, an array of activities appears to be possible, which are not allowed to SOs, including ownership and operation of storage facilities and EV charging points.

3.2 Energy vectors, which are preferred in Europe (2020-2050)

Several of the screened documents contained information about energy vectors (see definition in the Glossary) preferred in Europe for the time horizon 2020-2050. The most recent roadmaps redefine the energy vectors preferred for decarbonisation in Europe according to different sectors, such as electrification for personal transport, while hydrogen is a preferred technology for cargo transport.

3.2.1 The Pan-European dimension

The IEM Directive highlights moving towards decentralised generation (RES) and decarbonised markets as the main reason for changing rules for electricity trading [13]. In addition, the Directive also provides a guideline for the Member States, regulatory authorities, and TSOs to develop a common and interconnected network, as well as an internal energy market, to deploy RES, free competition and security of supply [13]. The Directive defines tasks for the NRAs and mention specifically facilitating access to the network for new generation capacity and energy storage facilities.

Further, the Renewable Energy Directive (RED II) 2018/2001 on the promotion of the use of energy from RES [18] opens for the introduction of support schemes and modalities for integration of electricity from renewable sources but does not indicate any strong priorities among these resources. "Renewable energy" is used as a common term, including wind, solar (thermal and photovoltaic) and geothermal energy, ambient energy (see Glossary), tide, wave and other ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas, and biogas.

Security of supply is important for different infrastructures for different energy vectors, and according to the 2020 report on the "State of the Energy Union pursuant to Regulation (EU) 2018/1999 on Governance of the Energy Union and Climate Action" [17], the Risk Preparedness Regulation implemented in the electricity sector ensures cooperation between the Member States in relation to energy security. This Regulation ensures that Member States have sufficient tools for cooperation to prevent, prepare for and mitigate electricity crisis. For the security of gas supply, preventive action and emergency plans have been developed, containing measures for mitigating the impact of gas supply disruption and risks identified at the national and regional level.

Important initiatives for integrating electricity and gas markets have been performed, and more work is needed, according to [17]. The document refers repeatedly to the recent EU's Communication [41], which defines several European flagships (coordinated investments and reforms):

- "Power-up flagship" frontloading future-proof clean technologies and in particular renewables and hydrogen
- "Renovate flagship" to improve the energy and resource efficiency of buildings
- "Recharge and refuel flagship" to accelerate the use of sustainable, accessible and smart transport, charging and refuelling stations and the extension of public transport

For electricity, the "Clean energy for all Europeans" package [32] is mentioned as important, and in the area of gas, the internal market has made good progress, where the traded volumes are increasing.

3.2.2 Reference Scenario towards 2050

The EU Reference Scenario is one of the EC’s key analysis tools in energy, transport and climate action [5], focusing on trend projections and providing a benchmark based on today's policy. The Reference Scenario reflects current trends and developments in the EU energy system and GHG emissions. The horizon of the projection is 2050, and results are available in five-year time steps for each Member State and the European Union of 27 states (after 2020-02-01).

Energy efficiency plays a crucial role in delivering cost-effective decarbonisation, and energy consumption has fallen by 10 % in primary energy and 7 % in final energy terms since 2005 [29]. In Reference Scenario [5], the energy consumption is expected to reduce due to improved energy efficiency, also resulting in declining energy intensity to Gross Domestic Product (GDP) (even if the energy intensity per GDP varies per country). The Gross inland consumption (GIC) and GDP continue to decouple [5]. The main drivers of the decreasing trend of total primary energy requirements are the developments in final energy demand.

The scenarios for power generation are dependent on assumptions on policies, technological costs and fuel price developments [5]. The reference Scenario related to *electricity generation* by fuel and by plant type is presented in Figure 1.

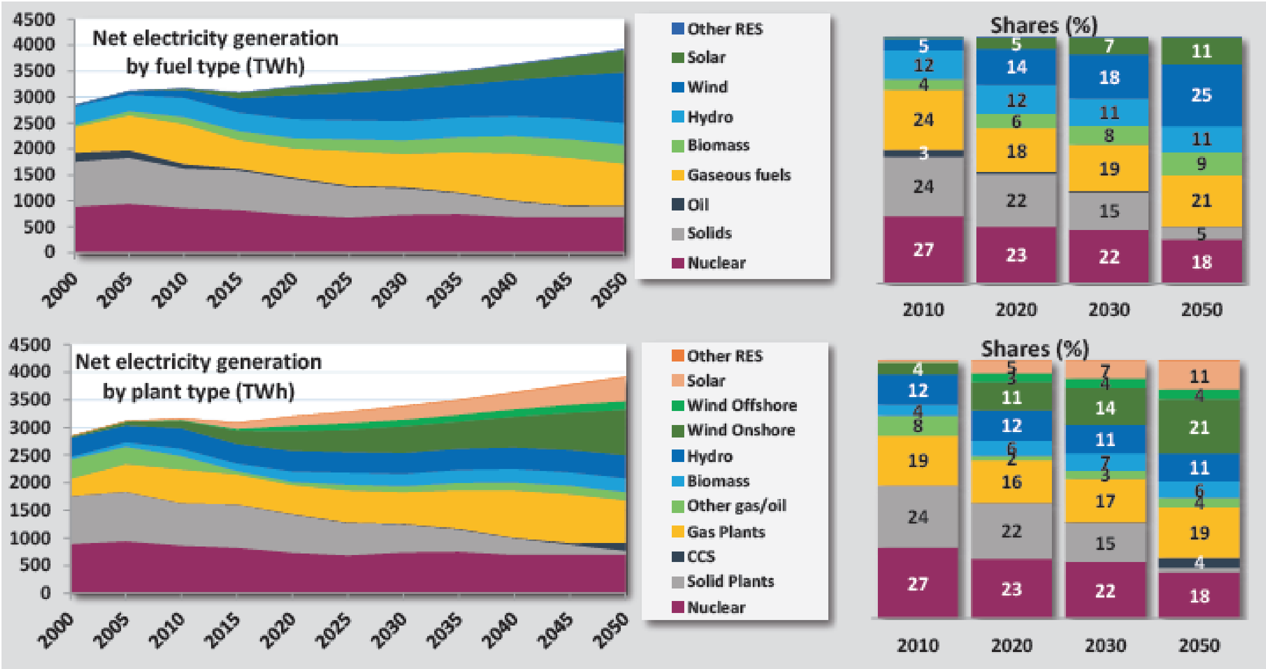

Figure 1 Electricity generation by fuel and by plant type. Source: [5]

According to [5], *steam and heat demand* in EU28 rises slightly towards 2025 and then remains approximately stable towards 2050. The main sources of demand are industry and households. It is projected that district heating will maintain its share in demand for heat. In the short and medium-term, there is a gradual shift from solids and gas district heating boilers to biomass/waste boilers, and in the long-term, electric boilers, heat pumps, geothermal and thermal solar penetrate the district heating market and gain in market share. During the whole period, it is projected that electricity generation from Combined Heat and Power (CHP) plants increases and steam output increases up to 2020 and remains almost constant towards 2050.

For *total primary energy supply* (PES), the trend is downward throughout the projection period due to energy efficiency reflected on primary energy demand (Gross Inland Consumption) [5], but the reduction pace slows down mainly after 2030.

The following changes for different types of energy vectors are estimated [5]:

- *Natural gas and nuclear*: almost stable share in total primary energy requirements throughout the whole period.
- *Oil*: represents the largest share in total primary energy requirements. This continues as the largest consumer is transport where substitution possibilities are limited.
- *Gas*: maintains its share in total primary energy requirements due to convenience and low emissions relative to other fossil fuels. Some emergences in transport and wide use in power generation.
- *Solids*: decrease in share due to the decline of solid use in all sectors of demand and energy supply sectors.
- *Biomass and waste*: increase in volume and share mainly due to increases in power generation and industrial uses.

- *Other renewables*: increase steadily throughout the projection period towards a share as high as that of gas, driven mainly by the impressive developments in the power generation sector.

3.2.3 Vision 2025-2030

Several reports in the screening process are looking at energy vectors and sector coupling towards 2025-2030 (near future). The ENTSO-E's "Research, Development and Innovation (RD&I) Roadmap 2020-2030" [2] underlines the importance of sector coupling by defining a dedicated RDI Area/Cluster “One System of Integrated Systems", mentioning electricity, gas, heating and cooling, and transport in relation to optimising cross-sector integration (so-called Flagship 1) [2]. Electrification of transport, heating and cooling are the key elements in the development of an ecosystem for deep electrification (so-called Flagship 2) [2].

In the future energy system, the share of renewable energy sources, nuclear energy, as well as carbon-neutral gases and liquids, will increase with high contribution to grid stability and uninterrupted energy supply [28]. New energy carriers are being considered in energy, industrial and transport applications, such as hydrogen and other carbon-neutral liquids and gases. Additionally, the future energy system also has to rely on much better balancing capacities, including better interconnections, storage capabilities, demand response, low carbon flexible generation units and effective energy conversion options as Power-to-X (PtX).

The report "Renewable Energy Prospects for the EU" [11] provides an approach to the deployment of renewables by 2030 under two scenarios. The first one called “Reference” following the current policies, and a second one, called REmap (from the forecasting model applied). In the Reference case, it is estimated that EU28 will reach a 24 % renewable energy share by 2030 (below the current proposed 27 % target), while the REmap case identified significant cost-effective renewable energy potential that could be realised by 2030 to reach the proposed 27 % target and go beyond.

Renewable energy deployment by source and application by sector and by Member State are estimated for 2030, as presented in Figure 2. Power generation forms almost half of the gross final renewable energy consumption in the 2030 REmap scenario.

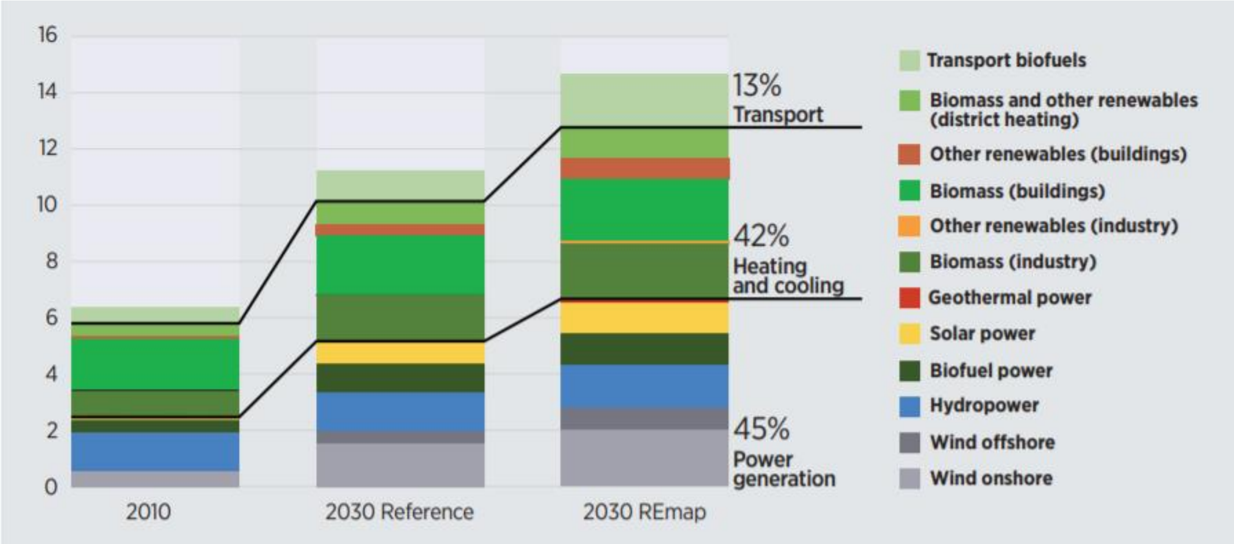

Figure 2 Breakdown of gross final energy consumption in the EU28 by source and application in 2010 and 2030 [11]

Power generation by technology in the EU28 in 2010 and 2030 is presented in Figure 3.

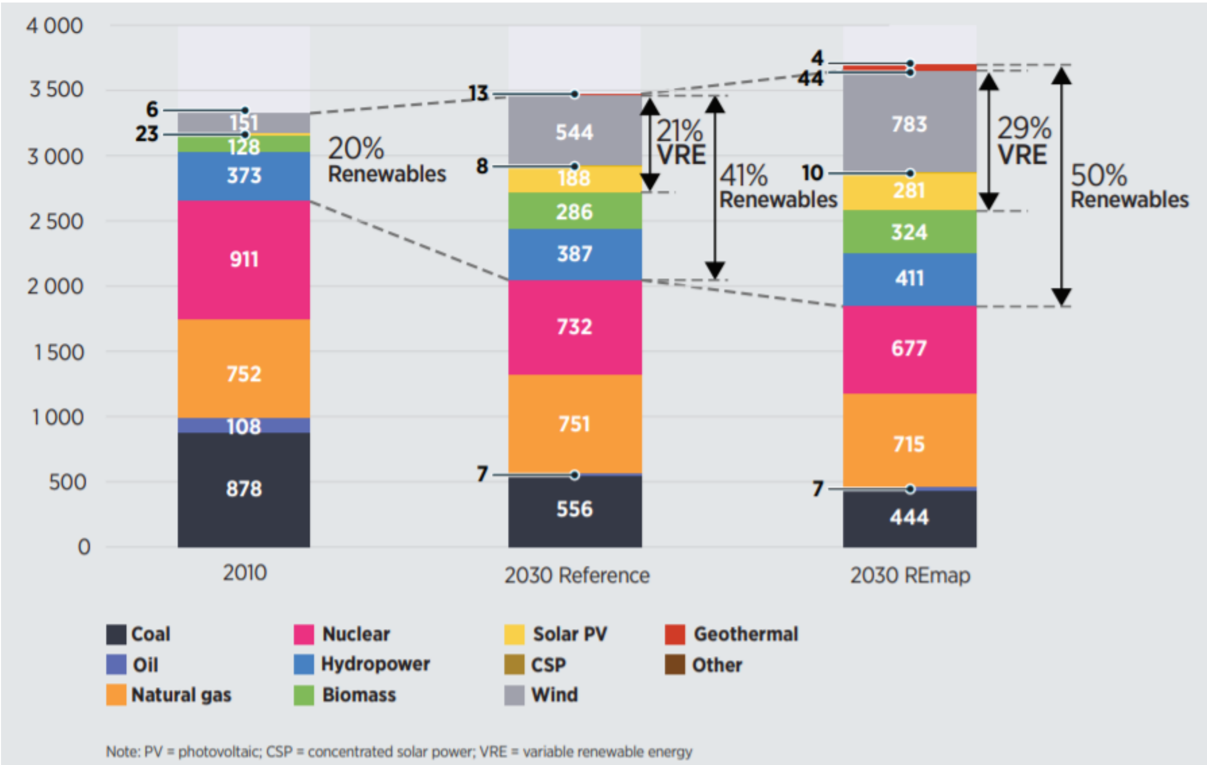

Figure 3 Power generation by technology in the EU28 in 2010 and 2030 under the Reference Vase versus REmap (TWh) [11]

The use of energy storage will also affect the natural gas, heat and transportation markets due to its cross-sector nature [15]. Storage systems can be integrated at different levels of the electrical systems to support the security and reliability of the system. Examples of energy storage services are:

- Voltage and frequency control,

- Capacity support,
- Peak shaving,
- Renewable generation flexibility,
- Time of use, energy cost management, and
- Limitation of disturbances.

Examples of services offered by different types of energy storage are [15]:

- Hydrogen can be used as fuels for light and heavy transport applications.
- Flywheels and supercapacitors can be used in transportation to increase efficiency.
- Thermal Energy storage can allow the integration of electricity and heating-cooling sectors.
- Superconducting Magnetic Energy Storage (SMES) can be combined with other storage systems, such as electrochemical batteries or liquid hydrogen (LH2). Such a hybrid system will combine storage with the production and distribution of hydrogen.

Additionally, hydrogen is a potential energy vector to account for up to 4-6 % and 8-24 % of the total energy demand in 2030 and 2050, respectively [14]. In particular, the role of hydrogen as an energy vector is dedicated to:

- Energy vector for industrial energy.
- Fuel Cell µCHP systems for buildings.
- Fuel for mobility.
- Power generation, energy storage.

3.2.4 Vision 2050

According to the ETIP SNET Vision for 2050 [1], the electrification of Europe's energy systems will be the backbone of its societies and markets. This will require an incremental coupling of electricity and gas networks via the production of carbon-neutral synthetic gases (methane) to ensure the long-term security of supply (seasonal storage) for an electricity system powered by renewable energy sources. Additionally, as major carbon emission polluter, coal is completely phased out from European energy systems by 2050.

While solar and wind have the greatest potential at the EU level, all renewables such as hydropower, geothermal energy, ocean energy or biomass/gas will be developed considering their potential, cost, and their added value to the regional systems and grid stability [1].

Biomass and synthetic gas, 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 [1].

Daily or seasonal differences between energy demand will require a flexible system with injections in daily or seasonal energy storage such as pumped hydro, batteries, hot water reservoir thermal storage, or PtG conversion technologies [1]. More in general, locally available energy resources are used to their full economic potential, partly deferring needs for upgrades of the electricity transmission and distribution networks and maximising the resilience of supply channels for heating and cooling needs [1].

The future integrated energy systems will mainly rely on [1]:

- Renewable electricity (hydro, solar, wind, geothermal, marine).
- Renewable electricity/heat (biomass, biogas, solar).
- Renewable heat and cooling (solar, geothermal, marine).
- Renewable gas (biomass, biogas).
- Renewable fuels as biofuels.
- Nuclear.

In "Power Facts Europe 2019" [29], the main focus is on the future power system and the distributed generation that can be connected (for example, electricity produced by solar PV and wind). In this report, investment in power system infrastructure is mentioned as key to promote PtG and other PtX technologies.

WindEurope [4] calls for a regulatory framework for sector coupling in which energy generation, conversion, storage, transmission and distribution are unbundled and market players, not regulated entities like TSOs and DSOs, drive the development and operation of assets. Further, WindEurope [4] calls for prioritising direct electrification, and this also includes incentives for the use of heat pumps including direct heating and electrification of transport by building charging infrastructure.

The most promising energy vectors in the future energy scenario by the end of 2050 are presented in [19]. Hydrogen and methane are mainly involved in the power sector, and technologies like fuel cells and industrial chemical processes, which use the above-mentioned energy vectors, have been analysed. In addition, synthetic fuels applied to the mobility sector, which are produced by industrial chemical processes as well, have been discussed.

In the "Hydrogen strategy for a climate-neutral Europe" [20], it is mentioned that clean hydrogen generation will help to decarbonise energy-intensive sectors (transportation, heavy industry – i.e., steel and chemical) and that this will mainly be produced by wind and PV energy.

3.2.5 The national dimension

Uncertainties revolve around building the ideal energy mix and implementing decarbonisation plans while ensuring energy security and economic growth, especially in countries like Poland, where fossil fuels play an important (overreliance) role, or Belgium and Bulgaria, which strongly rely on nuclear. Hydrogen emerges as a stronger candidate for decarbonisation of energy uses, with Germany and the UK leading efforts, but uncertainty still remains high regarding its potential role [24].

RES maintain their high impact and low uncertainty position. In line with decarbonisation commitments, European governments are putting forward ambitious plans and incentives for private investments in wind, solar, as well as hydro and biofuels generation fuelled by technology improvements leading to greater affordability and sustainability.

Table 3.1 Energy vectors relevant for different countries

Country	Relevant energy vectors
Austria (AT)	Additional funding has been allocated as an amendment to the Green Electricity Act passed in October 2019 to secure the expansion of wind, small hydro, biomass and biogas power generation. Hydro is seen with increased impact [24].
Belgium (BE)	Phasing out nuclear power. In 2018, nuclear energy accounted for 39% of Belgium's total net electricity production and will have to be replaced [24].
Bosnia and Herzegovina (BA)	The uncertainty stems from the current progress in the planned replacement of three ageing coal units with a single 450 MW unit at the 715 MW Tuzla Power plant. Coal is 60 % of the current energy mix [24].
Bulgaria (BG)	Diversifying of natural gas supplies and modernisation of its infrastructure [24].
Czechia (CZ)	Nuclear energy is regarded as a low emission technology that, together with renewables, can replace fossil fuels in the future. Diversification of natural gas supplies [24]
Estonia (EE)	Synchronisation with the continental European power grid is due to be completed in 2025 [24]
Finland (FI)	Completion of the sixth nuclear power plant. The majority of Finland's renewable energy is based on biomass [24]
France (FR)	In November 2019, a new law focused on energy and climate change raised the target of reducing fossil fuel consumption from 30 % to 40 % of its 2012 levels by 2030. The law also supports hydrogen and solar panel deployments to achieve a 33 % share of renewables in the energy mix by 2033. [24]
Germany (DE)	No specific vectors are mentioned [24]
Hungary (HU)	Diversification of gas supplies. Nuclear appears as the main Action Priority: plans for the construction of a new nuclear power plant. Consideration of geothermal and biomass potential [24].
Island (IS)	Measures range from an increase in reforestation to a ban on new registration of fossil fuel cars by 2030. Geothermal and hydro, electrification of transport [24].
Ireland (IE)	Renewable Energies appear as another Action Priority. Ireland has made much progress in expanding renewables deployment. Offshore wind projects are only starting to be developed, and CCS and hydrogen still need development [24]. In [26], electrification is the preferred energy vector in Ireland for the new targets. This is mainly caused by the fast-falling battery prices that made this option the most cost-effective in the transport sector. The same is in the residential sector, as the replacement of oil boiler electric heating sources (e.g., heat pumps) is required.

	Compressed natural gas (CNG) and hydrogen for medium and heavy-duty trucks and injection of bio-methane into the gas grid for the heating sector will be explored for the pathway to 2050 [26].
Italy (IT)	Ongoing negotiations for the supply of Liquefied natural gas (LNG). The price reduction of PV panels and wind turbines has boosted investments in these technologies over the year. Together, solar and wind power covered 14,5 % of national electricity demand [24]. The promotion of the use of alternative fuels, particular electricity, natural gas (as LNG, compressed natural gas (CNG)) and hydrogen in the Legislative Decree No 257 of 16 December 2016 [12], underlines the important role of biofuels and the increasing use of non-biological renewable fuels, such as hydrogen in the transport sector, in order to achieve the 2030 target (14 % RES in transport) [12]. The gas system will be fundamental for the national energy system, with the potential to become the centre of the 'hybrid' electric-gas energy system for the development of renewable gas and the transport sector [12].
Latvia (LV)	Hydro persists as an Action Priority. As the main source of electricity generation in Latvia, hydro is very well placed in the regional power market and continues to benefit the country [24].
Lithuania (LT)	Lithuania's strategic projects in the energy sector are highly dependent on EU support. These projects are i) synchronisation of the Baltic States electricity network with Continental Europe and ii) gas interconnection between Lithuania and Poland (GIPL). LNG remains an Action Priority [24].
Malta (MT)	Use of solar power for water heating and electricity generation (PV) in the residential sector. LNG/Natural Gas is also among Malta's Action Priorities [24].
Poland (PL)	Diversification of natural gas imports, especially towards LNG, phasing out coal. The country has set an objective for renewables – mostly wind and solar PV – to make up 20 % of the energy mix by 2030. The country is currently focusing on a diversification strategy by securing additional natural gas and introducing energy efficiency measures. It is also considering nuclear power options [24].
Portugal (PT)	Renewable energy remains stable as an Action Priority as new generation capacity is being awarded, particularly in solar generation. In 2018, Portugal produced 46 % of its electricity from renewables, including biomass, hydropower, wind and solar energies [24].
Romania (RO)	Focus on securing supplies of natural gas by imports or own production. Nuclear, by completion of two units of the nuclear power plant. Coal is an important part of energy production is challenging on environmental grounds [24].
Slovakia (SI)	Nuclear, the government is discussing the possibility of building a second nuclear power plant with the aim of improving energy security, sustainability and affordability [24].

Spain (ES)	Renewables, consideration of hydrogen [24]. Hydrogen, heating/cooling [6]. Use of green hydrogen in industry and transport [21].
Sweden (SE)	The electricity sector has been decarbonised mainly through the deployment of hydro and nuclear power. Wind power capacity has been expanding rapidly, its further expansion is planned, and offshore wind is also being considered. Sweden is exploring the possible use of large-scale hydrogen in the steel industry. Sweden uses bioenergy for district heating, taking advantage of the country's naturally available resources. The government is also promoting the use of biofuels in aviation [24].
Great Britain (UK)	The development of low cost, low carbon hydrogen for use in industry, buildings and transport, along with decarbonising the gas network, will be critical to meet the UK's 2050 net-zero emissions target. According to the government, the present rise in renewable output results from the increased capacity with new offshore wind farms [24].

3.2.6 Summary

Through the IEM Directive, common rules are established for the internal electricity market, which highlights moving towards decentralised generation, and consumers access to all markets – both to trade energy but also to contribute with flexibility services to the power system. Maturing and transposing these rules into national legislation is the main challenge for the next decade.

Additionally, the RED II-Directive promotes the use of energy from renewable sources. Energy production based on RES is more variable than energy production in, for example, coal-fired plants and large hydropower plants, which increase the focus on the security of supply.

Energy efficiency reamains to be a significant and cost-efficient part of the decarbonisation process. According to different scenarios, a larger share of RES will be introduced towards 2030, while hydrogen included in the scenarios towards 2050 in order to achieve the decarbonisation targets.

In the future energy system, the share of RES, nuclear energy, as well as carbon-neutral gases and liquids, will increase with high contribution to grid stability and uninterrupted energy supply. Due to technology development, different types of energy storage will be available, such as pumped-storage hydropower plant, batteries, hydrogen storage, flywheels and supercapacitors, thermal energy storage, SMES. The use of energy storage will affect both the natural gas, heat and transportation market due to its cross-sectoral nature.

3.3 Expected roll-out of the different technologies in the 2030 horizon

This part of the study concentrates primarily on forthcoming technologies with an expected bigger impact on energy production; it can be new, or a combination of different technologies related to the *energy distribution* part. The electricity transmission part is also mentioned when it directly influences the distribution part.

According to RED II Directive [18], the lack of transparent rules and coordination between the different authorisation bodies is reported as a critical issue that hampers energy deployment from renewable sources.

3.3.1 Deployment of hydrogen infrastructure

As it was mentioned in the preceding section, hydrogen is a consistent part of the future decarbonisation strategy. The importance of hydrogen production and deployment of Power-to-X is underlined in [19], referring to Power-to-H2 (PTH2) as the most promising, since the electrolysis of water can be performed through RES or other conventional systems, which are rearranged according to the used energy vector. The same document estimates:

- The potential demand for P2H2 in 2050: more than 500 TWh in Industry and Transportation.
- Potential demand for power-to-CH4 (P2CH4) in 2050: 900 TWh in Industry, 70 TWh in Transport and 950 TWh in other uses, excluding power generation.
- Potential demand for power-to-liquid in 2050: 60 TWh (industry), 2 430 TWh (transport) and 100 TWh (other applications).

In order to meet these ambitious targets, it is required to establish the necessary infrastructure, which is almost non-existing at the moment.

The EC's "Hydrogen Strategy" [20] defines several critical action points related to the deployment of hydrogen infrastructure:

- To produce renewable hydrogen, a huge investment in building electrolysers is needed in Europe for the next ten years (up to 6 GW of renewable hydrogen electrolysers by 2024) to reach the strategic objective of 40 GW electrolyser capacity by 2030.
- The electrolysers are planned to be built next to existing demand centres so they will be a distributed generation model (hydrogen valleys).
- To expand the coverage, infrastructure for the transport should be deployed (medium and backbone transmission)
- For a complete integration of hydrogen as an energetic solution in Europe, a Pan-European grid needs to be built, and infrastructures for transporting (via pipelines) and storage hydrogen accomplished, connecting supply and demand.
- For long-range transportation, the Trans-European Networks for Energy (TEN-E) should be revised. The Pan-European gas infrastructure could be reshaped to be used for large-scale cross-border transport of hydrogen.
- The transitional phase may accept the blending of hydrogen in the natural gas network at a limited percentage aiming at decentralised renewable hydrogen production in local networks, but this leads to practical difficulties and safety-related risks.

The "Hydrogen Roadmap Europe" [14] expects that the roll-out of electrochemical hydrogen generation (electrolysers) and utilization (fuel cells) technologies is expected to increase dramatically.

- In particular, electrolysis capacity is meant to increase by 15 to 40 GW deployed in 2030; scale-up to multi-MW systems is also foreseen.
- The deployment of more than 2.5 million fuel cell CHP units (considering each CHP unit of kW-scale results in the order of 1-10 GW) by 2040.

The document [14] argues the necessity for the development of charging infrastructure for FCEVs. By 2050, hydrogen could power a European fleet of approximately 45 million passenger cars, 6.5 million LCVs, 250,000 buses and 1.7 million trucks. With about 3,700 large refuelling stations in 2030, FCEVs could provide “full mobility” across Europe.

3.3.2 Energy Storage

The European Energy Storage Technology Development Roadmap [15] envisages that short-term balancing will become a major problem for the European power system, and the short-term electricity balancing market is where energy storage will be first applied based on commercial business cases. The need for additional balancing power will be substantiated already within the next five years. From a long-term perspective – and this could well be 15-20 years, the energy storage will become an even more significant part of the electricity system. By this time, from ES Technology Development Roadmap 2030 perspective, not only ancillary services but also energy arbitrage based on stored energy will be finding bridgeheads on the shore of the energy market. This will be a consequence of the increasing penetration of renewable supply sources alongside the corresponding withdrawal of fossil, dispatchable generation capacity. The same document underlines the importance of heat storage, which in terms of energy is by far the largest single energy storage application field in Europe. The document states that heat storage technologies will soon become even more important for balancing the electricity grids and for better and more economy-efficient heat management by the consumers.

"Study on Energy Storage" [27] estimates the optimal roll-out of diverse technology solutions capable of providing flexibility to the power system. According to the results shown in the document and the assumptions made by the authors of the study, a moderate/relevant increase in the installed capacity of pumped-hydro energy storage and Li-ion batteries is required to optimally deal with the system’s flexibility needs in 2030. A substantial investment in combined and open-cycle gas turbines is required as well for such a purpose. According to the sensitivity analysis performed in the study, the investment in Li-ion batteries can be partly replaced by a higher penetration of flexible demands.

Related to battery storage, according to [29] in recent years the cost of electrochemical battery storage has fallen significantly as interest amongst consumers, network operators and policy-makers has risen. The battery storage costs have fallen, and the uptake of storage has increased - also “behind-the-meter battery storage”.

The ENTSO-E's "Power Facts Europe" study [29] concludes that grid-connected storage (in-front of consumers’ meters) and behind-the-meter consumer storage devices are important flexibility resources, as storage technologies support the flexible operation of the power system, helping to balance out the peaks and troughs in supply and demand across different timescales. This report focuses on storage types such as pumped hydro and battery storage.

3.3.3 Hybrid solutions

Deployment of renewable energy sources as for example PV can be significantly improved by coupling of these with energy storage [8].

The EU Market Outlook [3] for the Solar Power connects PVs to production of renewable hydrogen, so it can help to decarbonise so-called hard-to abate sectors and will be a key role to reach carbon neutrality. The same document also expects that on-site PV Generation with storage, demand response and smart applications can contribute to stable renewable energy supply and to provide flexibility in the electric system. The combination of PV and green roofs increase the building efficiency and provide valuable services to the electricity system.

Spain can be mentioned as an example of considering hybrid solutions in member states. In their national "Integrated Plan for Energy and Climate" (2021-2030) [6] allowing to avoid the renewable energy spills by investing that energy in producing hydrogen. It also mentions the hybridization of renewables + storage to avoid unnecessary investments in the grid or thermal storage linked to thermo-solar power plants.

Increase of self-consumption is also mentioned as an additional benefit from combining different technologies (battery storage + PV generation) [8]. Depending upon different locations it can be Solar Thermal with PV generation (examples from Portugal). Integration of PV generation with energy storage and demand-side response to increase the self-consumption degree.

3.3.4 New T&D technologies in the Electricity Sector

ENTSO-E's RD&I Roadmap [2] outlines a list of technologies, where large-scale offshore-wind integration is strongly emphasised in the document and defined as a separate topic or so-called flagship. Hybrid AC/DC grids are defined as a key enabler for development of a power grid with high penetration of renewables in another flagship. Development of optimisation tools and strategies for operating the integrated energy system and planning tools are scheduled for 2025.

In the same document under cluster “Power Grid (PG), the Backbone of the Energy System” a broad spectrum of technologies is mentioned, which are mostly relevant for the transmission system, some of which are intended to directly support the increasing share of renewables as new tools for the optimal exploitation of flexibility sources along with the sizing and positioning of storage systems.

3.3.5 Digitalisation in the electric power system as enabling technologies

Implementation of Smart Metering solutions can be considered as a first step and mandatory pre-requisite for implementation of Smart Grid solutions, empowering end-users to follow dynamic prices and improving observability of distribution networks. The IEM Directive [13] specifically refers to Smart Metering, stating that the Member States should ensure its deployment. In World Energy Issues Monitor [24] Smart Metering is mentioned specifically as a priority area for Belgium.

Digitalisation is mentioned [24] as a priority area for several countries, including Portugal, Estonia, Latvia, Slovenia, the latter with specific reference to blockchain technologies.

3.3.6 Summary

Integration of hydrogen as consistent part of the future European decarbonisation strategy brings a considerable demand for P2H2, P2CH4 and PtL by 2050. Considering that for the moment the hydrogen infrastructure is almost none-existing, this will require massive investments in the next decades into electrolysers, storage, networks, FCEV charging stations and other elements.

Introduction of RES brings a need for more efforts in balancing of the power system, what may become a major driving force for deployment of grid-connected energy storage, while other technologies as pumped hydro and heat storage will become more important.

Hybrid solutions, coupling different forms of energy storage with intermittent renewable energy sources will improve deployment of renewable energies. Several technologies on Transmission level as AC/DC will inevitably have direct or indirect effects on the distribution networks.

3.4 Supporting Mechanisms for multi-vector energy systems

This section gives an overview of sustaining schemes and tools for multi-vector energy systems (the existing practice), including supporting mechanisms relevant for multi-vector energy systems.

3.4.1 The Pan-European perspective

According to IEM Directive [13], the DSO should be enabled, and provided with incentives from the Member States, to use services from distributed energy resources such as demand response and energy storage. For example, following art. 33 several European countries elaborate very ambitious plans for electrification of transport, making development of the new EV charging stations to become one of the main reasons for the expansion of distribution networks in the coming years. The Directive points out in provision (41) that demand response is pivotal for enabling smart EV charging. In addition, provision (42) refers to EVs as a potential storage for demand response application. Combination of these factors means, in practice, that the expansion plans for distribution networks should meet the growing demand for electric transport but should also consider its demand response potential as a consistent part of their planning approach and the future operaton.

In addition, end-users should be able to sustain themselves on the energy point of view, thus being able to enter actively into the electricity markets and provide flexibility services to the system.

Further, the Member States should also introduce network development plans for distribution systems in order to support the integration of installations generating electricity from RES, facilitate the development of energy storage facilities and the electrification of the transport sector [13]. Member States may also require the DSO, when dispatching power generation, to give priority to renewable sources.

DSOs are required to ensure the effective participation of all qualified market participants, including market participants offering energy from renewable sources, market participants engaged in demand response, operators of energy storage facilities in procurement of the products and services necessary for the system operation. This shall be ensured by the regulatory framework in the Member States [13].

Although supporting mechanisms specifically tailored to multi-vector energy systems are not addressed in the RED II [18], sustaining schemes dealing with energy systems integrating renewable energy in the electricity sector are reported. They are briefly reported taking into consideration that this last category is conceptually overlapping, in part, with the first one.

The need to promote the use of renewable energy in the electricity sector is recognized as one of the fundamental issues in order to reduce greenhouse gas emissions [18]. It is highlighted that the supporting schemes for electricity from renewable sources shall provide incentives for its integration in the electricity market in a market-based way, while taking into account possible system integration costs and grid stability. In particular, the directive suggests that, with regard to direct price support schemes, support should be granted in the form of a market premium, which could be sliding or fixed. Joint supporting schemes for two or more Member States are also foreseen, on a voluntary basis, to join or partly coordinate national support schemes.

The need to take into consideration the different capabilities of small and large producers to respond to signal markets is also stressed in the Directive [18]. The Member States may exempt small-scale installations and demonstration projects from tendering procedures. Further, the importance of ensuring the participation of renewable energy communities in available support schemes on equal terms with large participants is also pointed out in [18].

The ENTSO-E RD&I Roadmap [2] defines “Markets for cross-sector integration are developed and coupled” as a part of so-called Flagship 1: Optimise cross-sector integration, where cross-sector integration – “sector coupling”, assuming the coordination of the different energy networks (electricity, gas, heat and cooling, transport, fuels, etc.) with the supply, storage (electricity and thermal) and end use (transport, industry, households, and services). European TSOs are preparing to deal with these challenges as well as to harvest the foreseen benefits. Further, in [2], it is specified that ancillary service markets should enable the provision of distributed flexibility service to the grid, control centres operation and interoperability.

A major driver of battery market growth has been the more widespread coupling of batteries with Variable Renewable Energy (VRE) generators [22]. At Orkney islands (UK) it has been demonstrated production of green hydrogen using surplus (curtailalble) electricity, generated from wind, wave and tidal energy. The renewable energy converted to hydrogen can be long-term stored used for heating, power, transport and other purposes. This demonstration is based on a combination of private and community investment.

Decentralised, behind-the-meter battery storage – including both stand-alone storage and VRE-plus-storage – showed strong growth in several markets. Germany was the leading European market for residential storage in 2019, with 369 MWh [22].

The report "Study on energy storage" [27] does not provide information about existing supporting mechanisms at European level for multi-vector energy systems, but only for electricity storage systems. Based on this report, there is no direct support mechanisms to energy storage in most

Member States. However, a few countries have implemented direct investment support schemes for home batteries and pumped-hydro storage[1].

In the "Hydrogen Roadmap Europe" [14] several supporting mechanisms for launching hydrogen are presented. These are:

- Green Hydrogen Certification mechanism CertifHy [42] as a Guarantee of Origin (GOs).
- EU Emission Trading Scheme (ETS).
- Contracts-for-Difference (CfDs).
- Feed-in Tariffs (FiTs).
- Investment supports for ultra-low-carbon hydrogen (like e.g., those for biogas).

3.4.2 The national dimension

The focus in [24] is on improving efficiency in buildings, with strong state, EU and donor support to upgrade buildings' infrastructure including lighting, insulation and heat. Incentives being promoted across Europe include tax credits and competitive tenders though the effectiveness of these measures is still a subject of debate.

European governments are putting forward ambitious plans and incentives for private investments in wind, solar, as well as hydro and biofuels generation [24]. The main challenges identified across Europe for the renewables' integration process include market redesign, storage capacity, public acceptance, and grid interconnections.

In [6], coupling of different sectors is foreseen to manage the electrical demand, reducing spills of renewable energy and get a cheaper cost for the use of the energy. Annex I of [21] lists in details some Spanish and European supporting mechanisms, that are financial instruments intended to support initiatives and projects with a high R&D content. In brief these are:

- Projects CIEN11 is a financing mechanism of the Center for Industrial Technology Development (CDTI) in form of a partially reimbursable aid, led to large industrial research projects and development.
- Science and Innovation Missions12 is part of a CDTI program that seeks to support, through grants, and major strategic initiatives research contributing to the development of five priority missions in Spain.
- The MOVES II Program is an aid program, in the form of subsidy, which contributes to the decarbonisation of the transport sector.
- The General Secretariat of Industry and Small and Medium Enterprises of the Ministry of Industry, Commerce and Tourism, including financial aid programs and investment projects for the best of competitiveness industrial or contributing to the reindustrialization.

None of the four above-mentioned Spanish supporting mechanisms listed in the document is specific for multi-vector energy systems. Nonetheless, it is worth to mention the Plan MOVES II by which the Spanish Government provides subsidies for the purchase of vehicles using "alternative

[1] The diverse policies on energy storage implemented in each EU Member State are summarised in annex 4 of [27]. The policies in annex 4 are classified in 8 categories, one of which refers to public support mechanisms.

fuels" (hydrogen, electricity, natural gas, etc.), and the installation of charging stations for electric vehicles.

The European supporting mechanisms listed in [21] are not specific for multi-vector energy systems either, but it is relevant to mention the European Green Deal Call, under the framework of the H2020 programme. One of the topics of the European Green Deal Call is aimed to develop and demonstrate a 100-MW electrolyser for the production of green hydrogen from renewable energy.

§1.2 in the Integrated National Energy and Climate Plan (INECP) for Italy [12] describes the Legislative Decree No 257 of 16 December 2016 that promotes the National strategic framework for the development of the alternative fuels market in the transport sector and the creation of associated infrastructure, and the Ministerial Decree of 2 March 2018 and previous, to promote the usage of biomethane in order to increase the decarbonization.

Further, in §2.5 [12] defines as priority the development of storage systems, including thermal, electrochemical and PtG to guarantee high levels of penetration for non-programmable renewables and to store the excess production, incentives in the period 2018-2022 for fostering biofuel employment to reduce the fossil fuel usage (§3.1.2) and the promotion of the hybrid installations in buildings context to supply heat (§3.1.2).

Renewables 2020 [10] mentions several support schemes incentivising deployment of renewables. The first example is related to PV; Italy introduced auction schemes in 2019 and Poland continued to raise auction volumes while in 2020. Spain announced plans to resume tenders and Germany proposed to increase and extend annual auction volumes. However, the impact of support-scheme changes on large commercial systems in large markets is a forecast uncertainty. In an effort to stimulate growth while balancing support costs, several countries are modifying their policy designs by changing size eligibility and mechanism to determine remuneration levels. Germany, the largest commercial market, proposes changing support for large commercial rooftop systems from Feed-in Premiums (FIPs) to competitive auctions, while in France, which has decided to move support for self-consumption in the segment back to administratively set tariffs, auctions were under subscribed.

Related to the support scheme for onshore wind [10], competitive auctions in France and Germany to support new 2030 targets for both onshore wind (71 GW) and offshore wind (20 GW), are the main driver for growth. The Netherlands - the new Sustainable energy transition support scheme (SDE++) is expected to stimulate growth.

Germany is under pressure to align its economic objectives with its climate targets, and this has led to the stimulation of an increasingly competitive energy market. Since 2016, Feed-in Tariffs (FiTs) for renewable generation have been gradually replaced by competitive tenders [24].

In Italy, the need for timely adaptation of the energy market is necessary to support technological evolution and enable renewables growth together with flexibility and security of supply [24]. The newly launched Capacity Market and the advancement of PPAs for renewable plants are among the most significant developments.

Sweden is currently offering tax incentives to encourage the use of biofuels and for low emission cars in the transport sector, which accounts for roughly half of energy-related CO_2 emissions in the country [24]. There is internal political discussion under way to assess the benefit of incentives such as white certificates for energy efficiency. Electricity storage has been exempted from taxation and special incentives have been introduced for solar cells.

In the Great Britain, the 2013 Electricity Market Reform introduced several mechanisms to incentivise investment in secure, low-carbon electricity and improve energy affordability, but neither technological nor regulatory transitions are fully completed [24].

3.4.3 Summary

EU requires common rules for the internal market for electricity and network development plans for distribution systems in order to support the integration of installations generating electricity from RES, facilitate the development of energy storage facilities and the electrification of the transport sector.

The need to promote the use of renewable energy in the electricity sector is recognized as one of the fundamental issues in order to reduce greenhouse gas emissions. A major driver of battery market growth has been the more widespread coupling of batteries with VRE generators. For launching hydrogen, several supporting mechanisms are planned.

To achieve the goals of the internal market for electricity, it is important to establish support schemes that ensure that both small (incl. renewable energy communities) and large consumers can participate on equal terms. Further, to continue the growth in RES and deployment of new technologies such as energy storage, sufficient incentives need to be developed. The main challenges identified across the region for the renewables' integration process include market redesign, storage capacity, public acceptance, and grid interconnections.

3.5 Conversion processes (Power-to-X) in the context of integrated energy systems

This topic points towards the recent roadmaps to define conversion processes as storage for the multi-carrier energy systems, the current status and link to the future priorities.

3.5.1 The Pan-European roadmaps and visions

The ETIP-SNET Vision 2050 [1] draws a picture of the future energy system, placing the electricity grid in the centre as its "backbone": electricity enables for a switch of energy carriers through (PtG), (PtH), and (PtL) technologies and to transport large amounts of energy all over Europe, between distant and strategically interconnected hubs in the energy systems. The overall European energy systems will strongly rely on electricity stored in significant quantities by conversion of PtG, PtH and PtL, where longer-term seasonal imbalances of the electricity system are enabled by these highly efficient conversions and ideally combined with local heating and cooling needs to maximise overall conversion efficiency.

The EU's paper "A Hydrogen strategy for a climate-neutral Europe"[20] is a paramount document, explaining the necessity for hydrogen first and then the present obstacles, limitations, and the necessary actions. The document points out that the priority for the EU is to develop renewable hydrogen, produced using mainly wind and solar energy. Renewable hydrogen is the most compatible option with the EU's climate neutrality and zero pollution goal in the long term and the most coherent with an integrated energy system. The document further defines the three main phases:

- **The first phase 2020-2024:** The strategic objective is to install at least 6 GW of renewable hydrogen electrolysers in the EU and the production of up to 1 million tonnes of renewable hydrogen, to decarbonise existing hydrogen production, e.g., in the chemical sector and facilitating take up of hydrogen consumption in new end-use applications such as other industrial processes and possibly in heavy-duty transport.
- **The second phase 2025-2030:** Hydrogen needs to become an intrinsic part of an integrated energy system with a strategic objective to install at least 40 GW of renewable hydrogen electrolysers by 2030 and the production of up to 10 million tonnes of renewable hydrogen in the EU.
- **The third phase 2030-2050:** Renewable hydrogen technologies should reach maturity and be deployed at large scale to reach all hard-to decarbonise sectors where other alternatives might not be feasible or have higher costs.

The document mentions that sustainable biogas may also have a role in replacing natural gas in hydrogen production facilities with carbon capture and storage to create harmful emissions, at the condition that biomethane leakage is avoided and only in line with the biodiversity objectives and the principles stated in the EU2030 Biodiversity Strategy [43].

The EU's document "The role and potential of Power-to-X in 2050" [19] evaluates under which conditions PtG and PtL (referred to as PtX technologies in this document) can compete with alternative low-carbon production processes by the year 2050. The study uses the European Commission EUCO30 scenario [30] to determine the generation mix in 2050 (renewables will represent around 65 % of the EU's net electricity generation) and the METIS Power system model (which is an energy modelling software that can model all EU power system and markets) to forecast the electricity and gas prices in the same period (2050). With this information, the authors estimate the profitability of power-to-X in 2050 in different European countries. The study concludes that power-to-X technologies are competitive only in countries with more than 3,000 hours of electricity prices below 10 EUR/MWh, namely Spain, Portugal and Cyprus (the issue of costs is also mentioned in Subsection 3.1). However, this result highly depends on the evolution of the technology CAPEX, along with the cost and availability of alternative solutions. In particular, if biomethane and advanced liquid biofuel potentials are already dedicated to other uses, or if their availability is limited (due to land-use constraints, other policies objectives, etc.), the utilisation of power-to-X may become necessary and competitive.

Compared to the above-mentioned vision, The Renewable Energy Prospect for EU [11] has a shorter time horizon until 2030 and suggests biomass to any kind of transport-suitable energy. Furthermore, the possibility of further electrification of the sector for heating needs should be considered (heat pumps are used as an example). More efforts on innovation and research and development are necessary to bring electrification technologies to commercial readiness.

3.5.2 Views towards Power-to-X from the renewable industry

Several European associations and interest organisations are related to and represent specific technologies. Accordingly, the official position and activities of these organisations aim at promoting the corresponding technologies. The following section is therefore categorised according to these technologies:

Hydrogen: The Hydrogen Roadmap of the "Fuel Cells and Hydrogen 2 Joint Undertaking" [14] considers hydrogen as a Power-to-X technology for sector coupling and integrated energy systems throughout the whole document. The deployment of hydrogen is meant to increase in all sectors up to 4-6 % and 8-24 % of the total energy demand in 2030 and 2050, respectively. In particular, the role of hydrogen as an energy vector is dedicated to:

- Energy vector for industrial energy
- Fuel Cell µCHP systems for buildings
- Fuel for mobility
- Power generation, energy storage

Storage: The European Energy Storage Technology Development Roadmap [15] mentions hydrogen as an important storage technology: it can be stored in liquid (cryogenic temperature) or in gaseous state (up to 700 bars or in solid-state materials). It can be generated using renewable energy in electrolysers and can be transported using dedicated pipes or admixed into the existing natural gas network.

In the EU's "Study on Energy Storage" [27] both PtG through electrolysis and Gas-to-Power through methanation are considered as technology solutions capable of providing flexibility to the power systems and as investment options. The current technology readiness level of electrolysers and methanation plants is not discussed in the document. The document evaluates the importance of PtX technologies, such as electrolysers, in the provision of flexibility in the future and their expected roll out by 2050 in a few scenarios that are presented.

Solar: From the solar energy perspective [3], PtG technologies will be required to allow the integration of high level of renewable energy share and to provide fully sustainable seasonal storage to the energy system (main focus on electricity-intensive sectors, transport and industry). In order to get green hydrogen, very cheap electricity is required. Solar is now the cheapest source of electric generation, and therefore, it is an ideal solution.

Wind: In its position paper [4] WindEurope makes a critical evaluation of the present limitations and shortcomings related to Power-to-X technologies (see Section 3.1) and based on this, expresses serious concerns and outlines the necessary steps and priorities. The document suggests concentrating first on delivering decarbonisation in the easier-to-abate sectors including power generation, light-duty transport, rail, pulp and paper, aluminium, buildings, and agriculture. For these sectors, policy-makers should pursue direct electrification using renewable electricity, wherever it is available and whenever it is possible. Indirect electrification with renewables should be used only where necessary, like in the hard-to-abate sectors of the economy. The document also suggests that instead of producing hydrogen from curtailed renewable electricity generated by wind and solar, the policy-makers should firstly incentivise energy-intensive hard-to-abate industries to locate close to coastal areas, where offshore wind is abundant, or to onshore areas with good wind resources and limited transmission.

The document suggests that the EC should propose a roadmap on how to incentivise scaling-up and reducing the cost of production of renewable hydrogen, derivative fuels and gases based on renewable energy to enable substituting fossil fuels in hard-to-abate sectors.

3.5.3 National roadmaps

In the screened national documents Power-to-X is mentioned in the Spanish "Integrated National Energy and Climate Plan (PNIEC)" [6], which considers avoiding curtailment of renewable energy by investing that energy in producing hydrogen, for example, but it does not gather a specific strategy for this.

The Spanish "Hydrogen Roadmap" [21] summarizes the existing methods that use renewable electricity for the production of green hydrogen, as well as other methods for producing hydrogen from natural gas and biogas. The role of hydrogen in the integration of the various energy applications (electricity, gas, energy storage, biomass) is highlighted in the document as well. The document lists a series of measures that the Spanish Government intends to take in the period 2021-2030 so as to foster the use of green hydrogen in the industry, transport and as a means for the integration of the various energy sectors. The document does not clarify which measures have the highest/lowest priority.

The Italian "Integrated National Energy and Climate Plan" (INECP) [12] describes the intention to promote the development of other technologies that enable energy to be stored and/or integrated with other forms, pointing out that the PtG could play a key role. The document defines as a priority the development of storage systems, including thermal, electrochemical and power-to-gas to guarantee high levels of penetration for non-programmable renewables and to store the excess production of them.

It is also mentioned in [10] that there is an existing practice in UK, Spain, Denmark and Australia, and among some SOs in the United States to incentivising demand-side response, storage technologies and PtX to unlock flexibility and respond to shifts in demand would reduce the need to dispatch-down VRE generation. It also indicates the goals for 2040 including the usage of PtX forms of energy delivery such as hydrogen, biomethane and liquid e-fuels.

3.5.4 Summary

The vision of the 2050 power system locates the electricity grid in the centre of the integrated energy system. 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 PtG, PtH, and Power-to-Liquid PtL technologies and to transport large amounts of energy all over Europe. This must rely on renewable hydrogen, which is the most compatible option with the EU’s climate neutrality and zero pollution goal in the long term and the most coherent with an integrated energy system. This view is however challenged by the existing high costs for the production of renewable hydrogen. The study of feasibility for PtG and PtL in [19] concludes that PtX technologies are competitive only in few European countries, where low-cost renewable electricity can be generated. This study is supported by a pragmatic view from WindEurope, which suggests concentrating first on delivering decarbonisation in the easier-to-abate sectors by direct electrification of these. Instead of producing hydrogen from curtailed renewable electricity generated by wind and solar, the policy-makers should firstly incentivise energy-intensive hard-to-abate industries to locate close to coastal areas, where offshore wind is abundant, or to onshore areas with good wind resources and limited transmission.

3.6 Overview of policies supporting the empowerment of the final consumer

This part is focusing on regulatory aspects and roadmaps related to consumers' empowerment towards collective self-consumption and energy communities. The selected topics are relevant for supporting the empowerment of the final consumers, and the transition towards this. The focus is both on single consumers and consumers in different types of energy communities.

3.6.1 Energy transition and market regulation

According to ETIP SNET Vision 2050 [1], the energy transition requires efficient energy markets that provide a playing field for all involved stakeholders. The energy transition should be driven by people and their choices, to reward innovation and drive energy conservation and storage. 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 [1].

In 2050, competitive and efficient retail markets provide consumers and active customers with a favourable environment to select suppliers, control their production/consumption and provide power capacity and flexibility to the grid [1]. Empowering will also be supported by a set of ICT services.

The combination of microgrid installations with smart technologies may be particularly influential in their ongoing development in local energy communities [29]. According to the scenario for 2050, 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 [1].

ENTSO-E RD&I Roadmap states that during the overall process of system modernisation, it is important to foster the engagement of stakeholders and end-users (prosumers) to raise awareness of the evolution of the energy system and the benefits associated with improved grid solutions and infrastructures [2].

The IEM Directive mentions real-time or near real-time information about energy consumption as an important part of empowering consumers and engaging them in active participation in energy markets, and the deployment of smart meters is fundamental to achieve this goal [13].

The RED II Directive [18] provides opportunities to develop more targeted measures for empowering consumers as active participants in the energy market and being able to self-consume and store renewable energy. The Directive pays particular attention to the self-consumption of renewable energy [18]. Indeed, Article 21 states that consumers can become consumers of renewable energy and also be able to produce, store and sell the electricity produced in surplus, both individually and through aggregators[2] while guaranteeing consumer's rights.

Consumers should benefit from direct participation in the energy markets and actively adjust their consumption according to market signals and should be able to participate in all forms of demand response schemes benefiting from Smart Metering [13]. Additionally, all customer groups should have access to the electricity markets to trade their flexibility or self-generated electricity.

The IEM Directive [13] introduces and formalises roles of active customer and Citizen Energy Communities, and it also states explicitly that the latter may engage in generation, including from renewable sources, distribution, supply, consumption, aggregation, energy storage, energy efficiency services or charging services for electric vehicles or provide other energy services to its members or shareholders.

The IEM Directive [13] mentions explicitly that the Member States shall ensure participation of consumers, including through demand response, through investments into, in particular, variable and flexible energy generation, energy storage, or the deployment of electromobility. The same document includes a separate chapter (III) dedicated to consumer empowerment, which includes a separate section about active customers. This section defines the main operational aspects for the active customers, and it gives freedom to Member State to define their own provisions in the national law. It secures the right of active customers to own energy storage facility and grid connection (see Section (5)). Further, Chapter (II) strengthens the deployment of smart meters among end-users, ensuring data security, with the aim of having an active part into the electric market. Article 16 in Chapter (III) related to consumer empowerment is dedicated to (CECs), defining the main organisational principles. It allows the Member States to have certain variation in the regulatory framework, including cross-border participation, to own, establish, purchase or lease distribution networks and to autonomously manage the distribution network, and shall ensure that CECs are entitled to make such agreement [13]. It further secures access to electricity markets and non-discriminatory treatment from other actors.

Regarding consumption of self-generated electricity, CECs are treated like active customers. It also defines principles for separate application network charges for the own and outside network.

Energy poverty is a major challenge in the EU, where nearly 34 million Europeans are unable to afford to heat their homes adequately (in 2018) [17]. Even if most member status have presented an overview of energy poverty in their national energy and climate plans, most of them have not yet adopted a systematic approach to address energy poverty.

In "A Policy Brief from the Policy Learning Platform on Low-carbon economy" [8], it is specified that policies supporting self-consumption will allow to achieve the national climate targets and help to promote a behaviour change in citizens, empowering them (making them part of the climate solution).

[2] Aggregators will enable multiple small loads and generating assets to provide flexibility services to the grid in return for compensation [29]. Development of portfolios consisting of demand resources from different customers opens up the energy market to greater participation from a range of consumers.

- EU has launched different strategies to put final consumers in the core of the energy system, promoting an active role in its operation (EU Energy Union Strategy, Clean Energy for all Europeans' package, indcluding two Directives: RED II [18] and IEM [8].
- Several policy options are available to promote self-consumption, such as Legislative frameworks investments subsidies (which must be eliminated as the market develops), Feed-in-Tariff (FIT) and premiums tariffs [8].

The European Union has also set out an enabling framework for self-consumption and is supporting its roll-out, Europe-wide, such as European Structural Investment Funds, European Regional Development Funds, Regional Development and Cohesion Policy, EU Research and Innovation Programs, Sustainable Energy Technologies (SET) Plan [8].

3.6.2 Energy Communities

Recent European legislation requires that the ENTSO for Electricity (ENTSO-E) and a new EU DSO entity must involve more active citizens and energy communities in the generation, consumption, storage, and sell-off of electricity without facing disproportionate burdens [28].

The RED II Directive [18] introduces the "Renewable Energy Community (REC)". These communities must have the right to produce, consume, store and sell renewable energy [18]. They will also be able to exchange, within the same community, the renewable energy produced by them and access all the appropriate electricity markets, directly or through aggregation, in a non-discriminatory way.

RED II requires the establishment of simplified procedures for grid connections whereby installations or aggregated production units of renewables self-consumers and demonstration projects, with an electrical capacity of 10.8 kW or less. Optionally it can be extended up to 50 kW, provided that grid stability, grid reliability and grid safety are maintained. RED II in general introduces several modalities related to renewables self-consumers, individually or through aggregators, non-discriminatory and proportionate charges and fees, sharing of renewable energy with other consumers located in the same building, ownership of the renewables self-consumers installation (can be a third party) and availability of enabling framework promoting and facilitating the development of renewables self-consumption (Art.21 in [18]).

Models of local energy ownership and the role of local energy communities in energy transition in Europe are discussed in [16]. The organisational structures of community energy initiatives vary, including different legal forms related to partnerships, cooperatives, community trusts and foundations, limited liability companies, non-profit customer-owned enterprises, housing associations and municipal ownership. One example of ownership is participative governance which refers to the empowerment of citizens to act in the ownership of local energy communities and influence energy and climate policies which promotes energy democracy.

Examples of regulations that allow consumers to participate in the local energy communities are given for the Member States, that are selected to cover a broad range of local energy models; from those that are well-established and regarded as leaders of community energy, to those that currently have no national strategy for community energy [16]. A brief overview of the current state of community energy, as well as the background and rationale behind it, is given for each country.

- **Germany and Denmark:** Examples of deployment of different drivers and legal models that have made these countries to be at the forefront of local energy generation within the EU.
- **Ireland:** Example of the prevalence of local energy in a Member State with limited regulatory support for community energy projects.
- **Greece:** An example of a Member State attempting to progress towards a more supportive national structure for local energy generation, to revolutionise its energy sector in favour of community energy to ensure a successful energy transition.

3.6.3 Energy Technologies

Solar Power: In the EU "Market Outlook for Solar Power 2019-2023" [3] self-consumption FIPs for medium to large scale commercial system (40 kW - 750 kW) was the main drivers for the solar boost in 2019. Different policies are promoting PV self-consumption such as *Mieterstrommodel* (on-site community solar regulation) in Germany. Introduced in 2017 to enable collective self-consumption of PV installations on apartment buildings. Attracted limited interest in 2019, because participants are subject to full levy payments related to *Erneuerbare Energien Gesetz* (EEG) or The Renewable Energy Act.

Hydrogen: According to EC COM (2020) 301 "A hydrogen strategy for a climate-neutral Europe" [20] the Member States have included plans for clean hydrogen in their National Energy and Climate Plans, 26 Member States have signed up to the “Hydrogen Initiative”, and 14 Member States have included hydrogen in the context of their alternative fuels infrastructure national policy frameworks.

Albeit increase of hydrogen to the final consumer is foreseen to grow through the gas network (up to 20 % vol of the natural gas and the possibility to install micro combined heat and power (µCHP) systems), the regulatory aspects of blending hydrogen in natural gas are still not widely consolidated [14]. However, the EU industrial strategy has promoted the European Clean Hydrogen Alliance, where renewable and low-carbon hydrogen have been identified as a strategic element of EU National Energy and Climate Plans [20].

Sustainable and Smart Mobility Strategy (part of the European Green Deal) will address the use of hydrogen in the transport sector, and to incentive the use in the demand side, potential quotas of renewable hydrogen could be imposed to end-sectors [20]. EU may include other supporting rules via EU-wide instruments.

The Renewable Energy Directive and the Emission Trading System (ETS), besides the Next Generation EU, the 2030 Climate Target Plan, and the Industrial Policy provide the supportive framework to incentivise instruments and financial resources to accelerate the hydrogen adoption [20].

3.6.4 The national dimension

There are many changes in policy to pave the ground for more active consumers, which contribute with demand response, energy storage, distributed generation on consumer level and self-consumption of the electricity they produce. Examples of this are Spain, Portugal, Germany and Belgium that have adopted PV regulations to promote self-consumption, and Ireland and Germany that have put in place measures to encourage community ownership of renewable energy [22]. "Green power programmes" where consumers can purchase renewable energy are now offered in Australia, Canada, Denmark, Finland, France, Germany, the Netherlands, Slovenia, Sweden and the USA, among others. In some countries (UK, Scotland, Denmark), it is already common for developers to establish some form of a benefit package for local communities, as for example fund for local community projects, education bursaries or discounts on electricity bills. A limited number of EU Member States have implemented direct support schemes for home batteries and prosumers in several countries are incentivized to invest in batteries [27].

The INECP for Spain [6] promotes the use of the self-consumption, not only for the residential sector but also for the industry or the irrigation systems (through Royal Decree 244/2019) and mentions that self-consumption systems can be a tool to mitigate energy poverty, since it can reduce the electricity bill and the energy dependence of families and vulnerable groups. Additionally, the plan gathers the right for the final customers to choose price-based tariffs to effectively participate in demand management and foreseen the evaluation of possible bilateral contracts and energy exchanges towards a P2P system [6]. Self-consumed energy from renewables is exempted from network tariffs in Spain [27].

Being a Spanish document [7] mentions the Royal Decree 15/2018, which admits self- and shared consumption, with many restrictions. However, a previous Royal Decree 413/2014 regulates the procedure of connection to the electrical grid. Therefore, it is mandatory to create some legislation related to the Aggregator role, and to define the minimum and maximum energy to be aggregated in terms of power and energy. However, this is still not solved. Nonetheless, [7] also introduces Royal Decree 20/2018, which presents the concept of closed energy distribution networks and provides the framework for energy communities.

Ireland is, according to their Climate Action Plan 2019 [26], planning to establish a pilot micro-generation grant scheme for solar PV, targeting self-consumption, providing a grant to cover around 30% of the installation costs for homes, to enable people to sell excess electricity they have produced back to the grid. In relation to this, a smart meter will be installed in every house by 2024 facilitating demand side management and micro-generation [26]. In 2018, Irish government launched a pilot scheme that offered grants for homeowners to promote PV self-consumption [8]

The situation for Italy is represented in the "Integrated National Energy and Climate Plan" [12]. In §1.2, the document cites the draft European Delegation Law for 2019 and its aim to promote the active role of consumers, in both direct and aggregate form, in electricity and services markets. Further, in §2.1.2, the document remarks that Italy is highly invested in the development of self-consumption systems (in particular in buildings) and energy communities. Moreover, an under-way study will contribute to better define the most appropriate policies, and therefore specific and achievable targets.

Further, several initiatives to promote the active role of the consumer are described in §2.4.3 [12]. It states that some technological improvements such as new smart meters or Internet of Things (IoT) can spread out the self-consumption paradigm and point out that the current central dispatch model might not be fully appropriate.

The close connection between the active role of consumers, the transparency and competitiveness on the retail market describing some legal initiatives for domestic consumers (Competition Law No 124/2017) is described in §2.4.3, and the regulatory and economic measures to support the self-consumption in individual and collective forms are described in §3.1.2 [12]. Moreover, the RECs will be promoted because they help to support the economies of the smaller regions, and they will also allow to produce and consume renewable energy locally, including in situations where self-consumption is technically difficult [12].

Measures to support the self-consumption paradigm linking to the more detailed paragraph in §3.1.2 are described in §3.4.3 [12]. The document points out the necessity to introduce new regulatory measures in order to permit and oversee the development of citizen-led initiatives.

Further, several regions in Italy have implemented support schemes for the installation of behind the meter energy storage systems [27]. The Italian Government implemented a tax credit for residential storage devices in 2013.

In Germany, there is a network tariff reduction for energy-intensive consumers. A monthly capacity component is offered for consumers having a seasonal peak electricity consumption. A reduced tariff is applied to consumers with their peak load not coinciding with the system's peak load [27]. Germany initiated Feed-in-Tariff (FIT) scheme and current premium tariffs to promote self-consumption and load-shifting (reducing the amount of energy injected into the electricity grid) [8].

The Brussels-Capital Region has issued a decree to set up a support system through green certificates that allows a return on investment in renewable energy self-consumption systems in just seven years [8]. Home batteries are subsidized by the Government of Flanders (Belgium). The Belgian National Energy and Climate Plan puts emphasis on flexibility, including demand management, and mentions that the installation of home or neighbourhood batteries will be clarified in the regulations [27].

Other examples of policies directly or indirectly supporting the empowerment of the final consumer are [27]:

- *Cyprus*: The National Energy and Climate Plan of Cyprus foresees the roll-out of 400,000 smart meters by January 2027.
- *Czech Republic*: A specific support scheme exists for small-scale home batteries.
- *Denmark*: One of the objectives of the Danish National Energy and Climate Plan is to support structures that favour demand response, and demand response can today participate in the Danish electricity market. A pilot program is begin run by the Danish TSO so as to allow electric vehicles to participate in the system's balancing services.
- *Finland*: In October 2018, a specific working group set up by the Finnish Ministry of Economic Affairs and Employment proposed an operational programme aimed to promote the electricity

demand response. A big Virtual Battery is operated in Finland, and this virtual battery aggregates water heaters owned by customers for grid balancing purposes.

- *Hungarian*: The Hungarian National Energy and Climate Plan foresees the development of a complex price regulation so as to promote the market procurement of balancing services by demand response, as well as of house-hold smart power plants combining renewable generation, smart metering and storage.
- *Lithuania*: The National Energy and Climate Plan foresees the provision of financial support to renewable energies, energy storage, prosumers and renewable energy communities.
- *Luxembourg*: Self-consumption is exempt from renewable levies.
- *Malta*: The Government awards since 2019 grants on the purchase of batteries by individuals who have already installed solar panels.
- *Netherlands*: Dynamic tariffs in the retail market have been introduced. Net metering will be phased out by 2023. The Open Charge Alliance has developed a protocol for the provision of flexibility by electric vehicles with input from the Dutch parties.
- *Slovakia*: There are incentives to create new EV charging stations.
- *Slovenia*: The purchase of electric vehicles is subsidized.
- *Sweden*: The installation of storage systems by individuals to store self-generated electricity has received financial support in Sweden from 2016 to 2020. Owners of energy storage systems are allowed to participate in the system's balancing services in Sweden. The system's TSO and the DSOs can share their generation and storage resources so as to guarantee the security of the electricity supply. In Sweden, storage units with a capacity lower than 1500 kW are exempted from paying the FiT for the electricity delivered to the grid. Storage owners receive a compensation from the DSO for the grid value of the supplied electricity. Storage owners can apply for tax refund on the electricity consumed, stored and then fed back into the grid.

3.6.5 Summary

To achieve the planned energy transition, it is important with efficient energy markets that provide a playing field for all involved stakeholders. This also includes energy communities, which need the right to produce, consume, store and sell renewable energy. These communities also should be able to exchange, within the same community, the renewable energy produced by them and access all the appropriate electricity markets, directly or through aggregation, in a non-discriminatory way.

To pave the way for this transition, the EU requires that the Member States shall ensure participation of consumers, including through demand response, as well as through investments into, in particular, variable and flexible energy generation, energy storage, or the deployment of electromobility. Recent European legislation requires that the ENTSO for Electricity (ENTSO-E) and a new EU DSO entity must involve more active citizens and energy communities in the generation, consumption, storage, and sell-off of electricity without facing disproportionate burdens.

3.7 Storage characteristics and cost forecast

The topic looks at energy storage, which will be a key factor to empower electrification. The screening considers the main characteristics and costs evolution, which will determine the future deployment of different storage technologies. The screening is not limited to a single storage technology, but considers any kind of storage e.g., thermal storage, electrical storage, etc.

3.7.1 The Pan-European perspective

Energy storage systems have the potential to provide valuable services throughout the energy chain: from power generation, transportation and distribution to the final consumer [15] examples in which electrical energy storage will add value to the electric chain are shown in Table 3.2.

The "Renewable Energy Prospects for the EU" [11] underlines the importance of storage, by stating that energy storage should be promoted to keep the value of PV energy generation and to grow the demand-side flexibility. Storage is among the options to reduce VRE integration costs and avoid curtailment.

Table 3.2 Energy Storage segmentation. Source: [15].

Conventional Generation	Transmission	Distribution	Customers Services
Black start	Participation in the primary frequency control	Capacity support	End-user peak shaving
Arbitrage	Participation in the secondary frequency control	Dynamic, local voltage control	Time-of-use energy cost management
Support to conventional generation	Participation to the tertiary frequency control	Contingency Grid Support	Particular requirements in power quality
Renewable Generation	Improvement of the frequency stability of weak grids	Intentional islanding	Continuity of energy supply
DG Flexibility	Investment deferral	Reactive power compensation	Limitation of upstream disturbances
Capacity firming	Participation in angular stability	Distribution power quality	Compensation of the reactive power
Limitation of upstream perturbations		Limitation of upstream perturbations	
Curtailment minimisation			

ETIP-SNET places several storage technologies as a binding element of its "Vision 2050" [1]. 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.

Energy transition will be facilitated by integrating storage with the various energy carrier grids using the electricity system as its “backbone”: electricity enables for a switch of energy carriers through PtG, PtH and PtL technologies and to transport large amounts of energy all over Europe, between distant and strategically interconnected hubs in the energy systems.

Other examples of energy storage include centralised and distributed stationary batteries as well as a plethora of batteries on board of EVs that can deliver services to the network. Besides these longer-term balancing needs, conversion between energy carriers will occur to meet short-term (minute, hourly and daily) energy system needs. The document defines that in 2050 coupling of different energy networks, stationary or mobile gas infrastructure and storage will play a key role in the sustainable, circular energy systems. In the ENTSO-E's RD&I roadmap [2] storage is only addressed from a cross-vector point of view (system integration).

The Pan-European Strategic Energy Technology Plan (SET-Plan) defines specific performance targets for each storage technology towards 2050 (for details, see [15]).

3.7.2 Electric vehicles as a part of storage system

"The EV and Power system integration" [25] points out that EVs can be used as distributed (and mobile) storage systems. It is forecasted that in 2030 in IEA Sustainable Development Scenario (SDS) the total energy storage capacity due to EVs will be 16 TWh.

Following this possibility, it is relevant to refer to the Global EV outlook [9], since it analyses two IEA scenarios:

- Stated Policies Scenario (SPS) (current government policies)
- Sustainable Development Scenario (SDS) (where it is ensuring universal energy access by 2030, bringing sharp reductions in Green House Gases (GHG) and meeting global climate goals in line with Paris Agreement.

The first scenario will increase the global battery capacity of EVs from 170 GWh (2019) to 1,5 TWh in 2030. In the second scenario, the global battery capacity will double the first one (3 TWh) in 2030.

Average battery sizes for new BEVs (Battery Electric Vehicles) range from 48 kWh to 67 kWh for cars in 2019, and the trend with increasing battery capacity is expected to continue. The next generation of battery technology will have lower nickel content and will use NCA (Nickel Cobalt Aluminium oxide) or NMnCo cathodes. With these technologies, battery densities will increase (325 Wh/kg per cell or 275 Wh/kg at pack-level). New battery technologies will be commercially available after 2030, improving the main characteristics of Li-ion batteries (reducing cost, increasing density and cycle life): Lithium-metal solid-state batteries, lithium-sulphur, sodium-ion or lithium-air.

3.7.3 Technical parameters of the storage

The “Study on Energy storage” [27] report assesses the optimal capacity of a set of flexibility solutions in three different future scenarios. The flexibility solutions considered in the study are pumped-hydro energy storage, batteries, electrolysis and methanation plants. The main characteristic of these solutions as well as their cost in 2030 and 2050, are shown in the document, while a selection related to the storage-based flexibility is presented in Table 3.3.

Table 3.3 Technical parameters for storage-based flexibility solutions. Source: [27].

	Investment Costs (EUR/kW)	**Fixed Operation and Maintenenace (FOM) costs (% CAPEX)**	**Efficiency**	**Lifetime**
Pumped Hydro	1 212 EUR/kW	1,20 %	81 %	60

Batteries	120 EUR/kW + 120 EUR/kWh	4,30 %	90 %	10

In addition to this, a comparative overview of different storage characteristics is presented in Table 3.4. The table shows the costs, lifetime, and efficiency values, which were applied for the storage technologies in study [38].

Table 3.4 Characteristics* of storage technologies. Source: [38].

	Round-trip efficiency	**Overnight Cost**	**FOM* (%/a)**	**Lifetime (years)**
Pumped hydro storage (PHS)	0,87·0,87 = 0,76	2000 EUR/kWe	1	80
Battery	0,9·0,9 = 0,81	144,6 EUR/kWhe	0	15
Battery inverter	0,9	310 EUR/kWe	3	20
Hydrogen storage	0,8·0,58 = 0,46	8,4 EUR/kWhe	0	20
Hydrogen electrolysis	0,8	350 EUR/kWe	4	18
Hydrogen fuel cell	0,58	339 EUR/kWe	3	20
EV batteries	0,9·0,9 = 0,81			
Individual thermal energy storage (ITES)	0,9·0,9 = 0,81	860 EUR/m3	1	20
Long-term thermal energy storage (CTES)	0,9·0,9 = 0,81	30 EUR/m3	1	40

*(FOM) costs are given as a percentage of the overnight cost per year.

"The European Energy Storage Development Roadmap" [15] makes a thorough evaluation of the key energy storage technologies and targets for 2020-2030 and 2050 for the different technologies (see the document [15] for the details). The roadmap describes the first and major application fields for energy storage necessary for the European electricity and energy systems. These storage assets are expected to be applied within the generation, transmission and distribution of electricity as well as at the end consumers. The roadmap also describes the main future challenges for storage technologies and points out how we have identified the technologies we believe to be the most promising technologies for the next decades.

General conclusion is that various battery technologies have different characteristics which should be aligned with particular service and value-added propositions. The document also refers to the trend of cost decline, especially when it comes to lithium-ion batteries. This type of electro-chemical storage has seen a fall in costs by over 70% between 2010 and 2016. With costs also projected to fall to below 200 USD/kWh by 2020, it seems likely that this will help to drive the greater deployment of electro-chemical storage moving forwards.

3.7.4 Hydrogen storage

Hydrogen storage is mentioned in several documents because of its specific properties, and in general is considered as a natural component of PtG scheme.

"The Hydrogen Roadmap Europe" [14] highlights the properties of hydrogen storage. Hydrogen can be stored for long periods of time and at a large scale at competitive costs, compared to conventional large-scale energy storage, such as pumped hydro. Hydrogen storage form can be as gaseous/liquid hydrogen or bound to carrier molecules (ammonia, methanol, etc.). The storage capacity of hydrogen can be exploited not only for long-term unbalances but also to provide grid services or flexibility, despite the lower round-trip conversion efficiency. Hydrogen can become a favourable storage option for high VRES penetration regions, characterised by grid congestion, allowing to defer the upgrade of costly grid infrastructure. By 2030, power companies could store approximately 25 TWh of surplus renewable electricity in the form of hydrogen for use in other end-use segments. By 2050, this number could more than double to about 58 TWh.

Another view on hydrogen storage is given in the "Hydrogen Strategy for a climate-neutral Europe" [21], where hydrogen is planned to store the excess of energy and balanced a renewable-based energy system. In addition, hydrogen can provide seasonal storage to help covering peak demand and make flexible the operation.

3.7.5 National Roadmaps and Plans

The Spanish PNIEC NECP [6] acknowledges the need to increase energy storage but it does not refer to the associated costs per technology. In February 2021, Spain Government approved a National Storage Strategy. This strategy quantifies the storage needs to contribute to the decarbonization of the Spanish Energy System in line with NECP, including the distributed use of batteries from EV fleet (26 GWh per year by 2030), the additional storage capacity behind the meter (with a minimum of 400 MW in 2030) as well as large-scale thermal storage by solar power plants. The document proposes a total storage capacity of 20 GW in 2030 (from the current 8.3 GW available today) and about 30 GW in 2050. These values consider both large-scale and distributed storage, which will be provided by different systems, both daily and seasonal time periods. This document includes 10 lines of actions and more than 60 measures such as promoting storage in the energy system, energy communities, promotion of renewable hydrogen, development of new business models based on circular economy, such as second life batteries, etc. [37].

The Italian NECP [12] points out the importance of the development of storage systems, indicating hydroelectric technology as the most mature option. In addition, over the next few years, it will also be necessary to pursue considerable development of electrochemical storage. The document further describes the relevance of storage systems for the system flexibility and security and their relevance in order to keep over-generation to minimum, emphasizing the role of hydroelectric and electrochemical technologies. Finally, the document defines as priority the development of storage systems, including thermal, electrochemical and PtG to guarantee high levels of penetration for non-programmable renewables and to store the excess production.

The Spanish Hydrogen Roadmap [21] aims to establish a roadmap for the production and later use of green hydrogen. The production of green hydrogen allows to store excess renewable electricity for its later use to produce electricity and/or heat for diverse purposes (delivery to the electric power system, e-mobility, in the industry, etc.). The document summarizes the existing methods that use renewable electricity for the production of green hydrogen and provides information about some performance parameters of the methods, such as efficiency, pressure, temperature, etc., and the projection of some of these parameters to 2030 and beyond. Hydrogen is characterized by being easily storable, and depending on the process of obtaining, transport and storage, you must take into account various factors. This document provides an overview of the existing storage possibilities.

3.7.6 Summary

Storage technology in its various forms is foreseen as a key enabler of the energy transition and a binding element of different energy vectors. However, it has been concluded [15] that today only few energy storage applications can justify market-based business cases, and this is why many energy storage technologies have not spread into the market yet. There is a strong expectation that the short-term electricity balancing market is where energy storage will be first applied based on commercial business cases and we believe the need for additional balancing power will be substantiated already within the next five years. From a longer-term perspective (15-20 years) energy storage will become an even more significant part of the electricity system, providing more services.

Apart from electricity storage, heat storage will become increasingly important. Today more than 50 % of the final energy demand in the EC is used for generating heat and already now heat storage is utilised in water-based systems for domestic and district heating. In terms of energy heat storage is by far the largest single energy storage application field in Europe.

3.8 EV forecast

This section gives an overview of the trend related to the electrification of transport (mainly, road transportation). EV penetration will affect the total energy consumption and the amount of storage capacity available to support the electric grid. The forecast covers several factors penetration of EVs, load, number and location of charging points etc.

3.8.1 The Pan-European dimension

Transport remains the sector with the lowest penetration of renewable energy in the EU energy system [11], and in 2015, the share of renewable energy in transport was below 7 %. Liquid biofuels were the main sources of renewables in the transport sector. In 2015, electric passenger cars accounted for 1,2 % of new sales, accumulating a 0,15 % share on the overall active car fleet [11].

However, the latest data shows that EVs, both BEV and Plug-in Hybrid Electric Vehicles (PHEV) sales in Europe has increased significantly in the last years. Nearly 1,4 million BEVs and PHEVs were registered in Europe during 2020, 137 % more than in 2019, in a vehicle market that was down by 20 % year-on-year. Europe has superseded China as the motor of EV growth. For the first time since 2015, EV sales in Europe have outpaced sales of so-called New Energy Vehicles (NEV) in China. (NEV is a local term, used in China, and refers to vehicles that are partially or fully powered by electricity.) Europe is further ahead in terms of EV share (BEV+PHEV) increased from 3,3 % 2019 to 10,2 % in

2020, counting the EU and EFTA countries, including UK [39]. According to [11] over 40 million of light-duty electric vehicles will be on EU roads by 2030.

EVs are crucial for improved air quality in cities, and many governments have developed EV mandates (such as Zero EV mandate in California, and New Energy Vehicle Mandate in China) or CO_2 emissions regulations (e.g., EU), boosting EV selling. To date, 17 countries have presented 100 % zero-emission vehicle targets through 2050 [9]. EU has approved new fuel economy standards for 2030 for different vehicles (cars, vans and heavy-duty vehicles), pushing the EV market in the near future, containing specific requirements or bonuses for EVs [9]. China and Europe will lead this deployment of light-duty EV (cars and vans), while two-wheelers will lead the deployment in urban areas in several developing countries such as India or China [9].

Half of the daily trips in Europe, the USA and China cover a distance of less than 10 km, so there is a great market opportunity for micro-mobility (electric bicycles, e-scooters or electric mopeds scooters). It is estimated that the number of e-scooters in 2028 will be multiplied almost by four, reaching 850 million. In very dense European cities, it is estimated that one-fifth of the routes could be carried out with micro-mobility by 2030. In the SPS, the electric two/three-wheeler fleet is projected to increase globally from 300 million (2019) to 400 million in 2030 (around 40 % of the entire two/three-wheelers stock). In the SDS, the global electric two/three-wheeler stock reaches nearly 500 million (almost 50 % of the stock). In Europe, two/three-wheelers will reach 40 % sales share in 2030 [9].

According to [29] a total of 364.000 EVs (BEV and PHEVs) were estimated sold in Europe in 2018, a number 26 % higher than for 2017, while nearly 1,4 million were sold in 2020 [39].

Around 100 new EV models are currently available. In a five-year horizon, car manufacturers will present around 200 new EV models, solving one of the entry barriers of these vehicles (immature EV product offer) [9].

The representative from the EU, European Parliament and European Council has agreed that EV sales should account for 15 % of new car sales by 2025 and 35 % by 2030 [29]. Bloomberg New Energy Finance (BNEF) has forecasted that the share of EV sales in Europe could rise to 6 % by 2040 [29]. When estimating that new car sales in Europe continue to grow at the rate they have since 2013 (5 % per year on average), new car sales in 2025 will be 22 million, and 28 million in 2030. This implies 3 million EV sales in 2025 and 8 million in 2030.

According to the IEM Directive [13], electric mobility is considered a key point for the decarbonisation of the transport sector, especially in urban areas, and an important element towards the energy transition as well. For this reason, market rules should facilitate the entrance into the market of all the electric vehicles [13].

The IEM Directive [13] has a separate section dedicated to integration of electromobility into the network, requiring the Member States to provide regulatory framework to facilitate the connection of publicly accessible and private recharging points to the distribution networks.

Policies to support EVs can indirectly or directly promote the use of renewable electricity in the transport sector [22]. The integration of EVs is one of the slowest towards decarbonisation. The main strategies for their integration are the implementation of policies to prohibit the use of fossil fuel vehicles and EV charging infrastructure. Tax incentives (and other non-economic incentives) for EVs and charging infrastructure deployment are key to accelerate the electrification of transport [4].

Policies to promote EVs must also support charging points deployment and include new codes to install these charging points in new (or refurbishment) buildings (in a similar way that have been done with disabled parking spaces in public buildings) [9].

3.8.2 Scenarios for EVs

The RED II [18] addresses EV forecast in general terms. The need of further incentives is expressed considering the swift development of electromobility and the potential of that sector in terms of growth and jobs in the Union. Since it is not possible to account for all electricity supplied for road vehicles in statistics through dedicated metering, such as charging at home, it is suggested to use multipliers in order to ensure that the positive impacts of electrified renewable energy-based transport are properly considered.

In "Electric Vehicle and Power System Integration" [25] the following two scenarios are analysed: IEA SPS and IEA SDS. In SPS, 140 million EVs are expected in 2030 worldwide, and in SDS 245 million EVs are expected. Under this second scenario, electricity demand will increase 4 % globally (1 000 TWh). Most of this demand will come from residential charging of Light-duty Vehicles (LDV). EVs could account for 4 % of global electricity demand by 2030 in the Sustainable Development Scenario. So, limited impacts are expected on the operation of bulk power systems from both a generation and transmission perspective.

The "Study on Energy Storage" [27] shows the forecast aggregate demand for electricity of electric vehicles and heat pumps in 2030 and 2050, considering the scenarios provided in the European Commission Long-term Strategy (EC LTS). In 2030 and 2050 accordingly 30 % and 70 % of the electricity demand of electric vehicles and heat pumps is assumed to be flexible. The document [27] analyses as well the sensitivity of the results to the increase up to 100 % in the electricity demand flexibility provided by these sources.

ETIP SNET R&I Roadmap 2020-2030 [28] has developed lists of research tasks that are of high relevance in the period 2020-2030, where evaluating grid constraints by employing short-term forecasting of generation and load, including EV charging and other flexible loads are one of the defined tasks.

In the ETIP SNET Vision for 2050 [1], it is estimated that the vehicle-based mobility system has shifted strongly towards electricity but continue to rely on liquid carbon-neutral fuels (PtL and biofuels) and gases. According to [3], EVs can provide large storage capacity, helping to integrate renewables (it is forecasted that 14 TWh of EV batteries will be available in 2050)

EV–power system integration requires a cross-sectoral discussion and a holistic approach, where the government needs to defend a multi-stakeholder approach [25]. In this context, infrastructure planning is a critical component to support vehicle electrification, including:

- Planning and support for adequate deployment of private charging infrastructure (currently representing the bulk of EV charging demand).
- Proper design of an ecosystem of cost-effective and convenient public charging networks.
- Planning for distribution systems considering EV loads.
- Integration with urban mobility planning

The possible impact of electric vehicles and the role of stationary batteries in integration of VREs is discussed in [11]. The document concludes that smart charging of electric vehicles (for example adjusting of charging to price signals from the power markets) and EVs acting as stationary batteries, feeding electricity back into the grid whenever it is profitable (through V2G), could contribute to cost-effective integration of variable renewable sources in the power sector in 2030. In addition to EVs, stationary batteries can also contribute towards this goal.

Simulation results in [11] show reduced curtailment of variable renewable generation across the EU, and a positive impact is observed with regards to the revenues for solar PV plants, because batteries can store electricity at times when solar power is abundant and prices are low, contributing to protection of the market value of solar PV generation.

The EU Reference Scenario [5] presents the evolution of the activity of passenger cars and vans by type and fuel for 1995 to 2050, as presented in Figure 4. The expected main technology for passenger cars and vans in 2050 will be conventional hybrid vehicles. ICE gasoline will decrease significantly, while ICE diesel vehicle still represents a high share. Natural gas vehicles will represent an insignificant share.

The developments of the battery costs assumed in the EU Reference Scenario 2016 [5] allow a decrease in capital costs of BEVs and enable their penetration, especially in the urban zones.

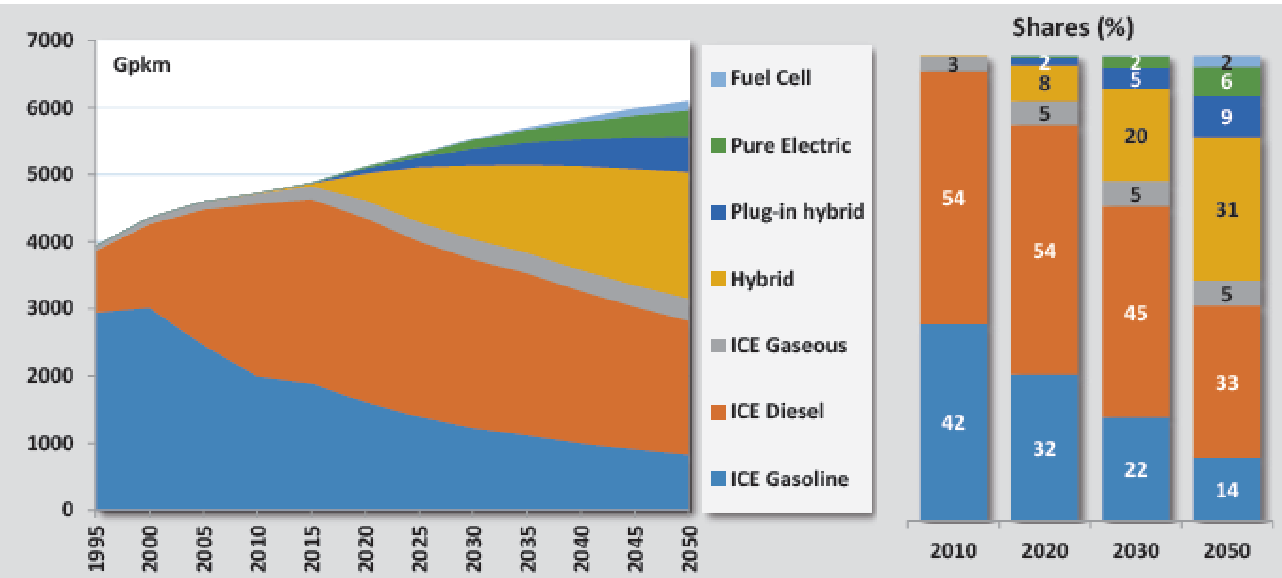

Figure 4 Evolution of activity of passenger cars and vans by type and fuel [5]

Two IEA Scenarios are analysed in [9]: SPS and SDS (reaching at least 30 % of the market share of EVs in 2030) [9]. The first scenario will reach 140 million vehicles (excluding two-wheelers) in 2030, while in the second scenario, this figure will be doubled, reaching 245 million in the same period. In the SPS, the number of Light-Duty Vehicles (LDV) increases from the current 7,5 million vehicles to almost 50 million by 2025 and 135 million by 2030 (about 2/3 of the global EV fleet will be composed of BEVs). In the SDS, 100 million additional electric LDVs will be added to this forecast by 2030. In Europe, LDVs reach 30 % of market share in 2030.

The global electricity demand of EVs (including two-three wheelers) will reach 550 TWh (in the SPS) and almost 1000 TWh (in the SDS) in 2030, reaching at least 1 % of the final electricity consumption SPS and at least 2 % in SDS. For the SPS, the electricity demand will be increased by 4 % in Europe (displacing 2,5 mb/d of oil products), while for the second scenario, this demand will increase to 6 % (displacing 4,2 mb/d of oil products globally) (in 2030) [9].

In the SPS, E-buses Buses will reach 1,4 million units in 2025 and almost 3 million in 2030, while in the SDS, the deployment of electric buses reaches almost 5 million units in 2030, starting with urban buses. In Europe, e-buses will reach 50 % sales share in 2030 [9].

Electrification of long-distance truck routes will require bigger batteries and higher power charging points (over 500 kW up to a few MW) [9]. Recharging of electric trucks in a reasonable time period, requires development of ultra-fast charging technologies. For this reason, e-trucks (with batteries) will be combined with fuel cell trucks (with lower refuelling time).

The adoption of e-trucks in Europe is driven by different regulatory frameworks (new CO2 emissions standards, urban quality restrictions, EU's Alternative Fuels Infrastructure Directive (AFID) and some additional regulations), but it is still necessary to improve the technology and increase the current offer of e-truck models in the market. (AFID does not include charging infrastructure for electric trucks and vans, but only sets targets for natural gas refuelling infrastructure for trucks) [9].

Daimler trucks (the world's largest truck manufacturer) will leave the development of natural gas-powered trucks and will only sell Zero Emission Vehicle (ZEV) truck by 2030 [9]. In the SPS, the e-truck fleet will reach 0,6 million in 2030 and 3 million in the SPS, starting with the hybridisation of ICE trucks and deployment of fuel cell trucks. In Europe, the e-truck market share will reach 2 % (2030).

EV ships are mainly focused on ferries and other short-distance ships and it will be not a feasible option for oceanic-going vessels in the near future [9].

Hybrid electric aircraft could emerge in the next generation of aircraft. Electrification of aviation should be done initially in small planes and in Landing and Take-Off Cycles (LTO), reducing fuel consumption and improving local air quality in airports (usually located near cities) [9].

EU forecast 1 million charging points in 2025 to support all the EVs expected, as the application of the different policies defined in the European Green Deal [9].

Under SPS, private chargers for LVDs, buses and trucks will reach 135 million by 2030 (0,6 TW of installed power capacity and around 400 TWh of energy consumption). Under SPS, these numbers are doubled (240 million private charging points, 1,1 TW and 770 TWh) [9]. Publicly accessible chargers will reach 11 million by 2030 (90 % of them are slow chargers) in SPS (120 TW of cumulative power capacity and 70 TWh of energy), while under SDS these figures are also doubled (20 million publicly slow chargers, 200 TW and 120 TWh).

Although electric buses (e-buses) are a simple solution to reduce pollution in urban environments, the lockdown due to the COVID-19 pandemic and the need to maintain social distance has reduced the number of users who are using public transport, increasing private transport for health reasons [9]. Local policies can directly influence e-buses deployment in urban areas and it is common that e-buses operators collaborate with governments or private sectors sharing the risk of deploying these electric vehicles. Total Cost of Ownership (TCO) is very context-specific, depending on local prices of fossil fuels and electricity, travelled daily distance and consumption (kWh/km) over each bus route, cost of finance, etc. For this reason, it is difficult to establish general conclusions applicable to all cities worldwide, although it is always true that the acquisition cost of an e-bus is currently higher than Iinternal Combustion Engine (ICE) bus. E-buses have lower O&M costs, and these vehicles also provide external benefits for citizens such as improving air quality in cities, reducing driving noise, etc. Deployment of chargers may pose additional project risks. The main limitations for e-buses are related with limited range and charging options. Most of the cities have chosen the option of depot charging, to limit the maximum daily range and they have only electrified previous shorter diesel routes. Due to the electricity demand increase in the bus depots, electric distribution utilities have had to upgrade these infrastructures to install the required charging stations. Depending on the size of the e-bus fleet, this upgrade will require more space and it has already been reported that, in many parts of the world, 90 % of the cost of charging stations corresponds to land rent to install these charging points.

3.8.3 Hydrogen demand

The "Hydrogen Roadmap Europe" [14] envisages a division of market between BEVs and FCEVs among different customers groups home charging vs urban customers. The whole process is expected to have three phases: It has been estimated that phase three will start at around 13 % electric vehicle presence, with the break-even points between BEV and FCEV coming at about 17 million zero-emission vehicles, corresponding to approximately 38 % of the passenger car fleet being electrified. Infrastructure costs will then equal approximately EUR 2 500 per vehicle for both technologies.

According to [19], the hydrogen demand for mobility is mainly driven by the development of fuel cell electric vehicles (FCEVs) and the regulatory framework for clean transport in the EU. The hydrogen demand for mobility in Europe is estimated to 10-30 TWh by 2030.

3.8.4 The national dimension

According to the INECP for Spain [6], 5 000 000 EVs will be present in Spain by 2030, represented by private cars, buses, motors and vans. The development, location and charging points for the private cars depend on another national regulation (CTE) mentioned in [6] but not fully developed. The development of the public charging infrastructure also roots in another regulation and expects one public charging point per 10 EVs. However, the business is liberalised. In [21] it is established as targets for 2030 having 150-200 fuel cell electric buses powered by green hydrogen, 5 000 -7 000 fuel cell electric vehicles powered by green hydrogen for freight transport and 150-200 hydrogen fuelling stations accessible to the public.

In the INECP for Italy [12], the target of the National Vehicle Charging Infrastructure, which is to create by 2020, 13 000 slow/accelerated charging stations and 6 000 fast-charging stations, with a prospect of having 130 000 electric vehicles in circulation are described in §1.2. Further, (in §2.1.2) it is defined that to achieve the 14 % RES in transport (2030 target), EV will be responsible for 6 % of it, with almost 6 million EV by 2030 where 4 million of them will be all-electric vehicles. Document [9] has estimated 6 million EVs by 2030, including 4 million BEVs.

In order to meet the new targets by 2030 in Ireland, there should be an increase in the number of EVs to 936 000 [26]. These are divided into: 840 000 passenger EVs, 95 000 electric vans and trucks and 1 200 electric buses.

Furthermore, it is planned to:
- install over 90 high powered chargers at key locations on the national road network, 50 new fast chargers and replace 250 standard chargers.
- install at least one recharging point for new non-residential buildings with more than ten parking spaces by 2025.
- Install a minimum number of recharging points for all existing non-residential buildings with more than 20 parking spaces by 2025.
- enlarge the charging network on garage forecourts.

In the transport sector in Croatia [24], the number of EVs and hydrogen cars is expected to rise after 2030. In the last two years, EV charging stations have been installed, and this will continue. The challenge is the affordability of electric vehicles.

In 2019, Iceland invested in infrastructure for alternative fuels at traditional petrol stations, as well as a network of EV charging stations [24].

Innovative Transport moves from Action Priority to Critical Uncertainty in Portugal [24]. This is likely in response to the shift to electric vehicles and low/zero-carbon fuels, which is proceeding at a slower pace than expected.

France plans to decarbonise land transport by 2050, and it is banned to sell vehicles that emit CO_2 by 2040 [9]. EV objectives for 2028 are: 3 million BEV and/or FCEV and 500 000 neighbourhood electrical vehicles and/or PHEV and/or FCEV LCVs.

Germany estimates 7-10 million EV cars by 2030 (extension of annual vehicle exemption for EVs to 2030) [9].

The Netherlands estimates 100 % of ZEVs in new passenger cars sales by 2030 [9]. By 2025, half of the taxi fleet must be fully electric, and by the same year the ambition is to have 15 000 FCEVs on the streets. The aim is 200 000 FCEVs by 2030, and all new buses should be electric.

3.8.5 Summary

Transport remains the sector with the lowest penetration of renewable energy in the EU energy system, and in 2015 the share of renewable energy in transport was below 7 %. The most recent figures show however a significant increase in number of sold vehicles in Europe during the recent years i.e., nearly one million BEV-PHEV vehicles were sold in Europe in 2020, representing more than 10% of car sales. The representatives from the EU, European Parliament and European Council has agreed that EV sales should account for 15 % of new car sales by 2025 and 35 % by 2030. Even if the level of adoption of EVs is small in the EU, it shows early signs of very deep transformation, close to exponential growth. Over 40 million of light-duty electric vehicles will be on EU roads by 2030.

Electric mobility is an example of a cross-cutting technology requiring a thorough holistic approach: smart charging of electric vehicles and EVs acting as stationary batteries, feeding electricity back into the grid whenever it is profitable (V2G), could contribute to cost-effective integration of variable renewable sources in the power sector in 2030.

Electric mobility is considered a key point for the decarbonisation of the transport sector, especially in urban areas, and it is a need for policies to promote EVs that must also support charging points deployment and include new codes to install these charging points in new (or refurbishment) buildings.

3.9 Expected consumer adoption of low carbon technologies

The topic relates to the consumers' adoption of several technologies, which contribute to the decarbonisation of the European economy. These include solar PV, storage, heat pumps, electric vehicles as well as willingness to participate in demand response, energy efficiency programs etc.

3.9.1 The Pan-European dimension

The RED II [18] promotes the spreading of renewable energies technologies in general. In detail, it supports deployment of RES technologies in the heating and cooling sector, leaving to the Member States the possibility to establish and make public a list of country-specific measures that can be adopted, prioritising the best available technologies, and to designate and make public the entities in charge for implementation, on the basis of objective and non-discriminatory criteria. Moreover, it supports the introduction of RES for new and renovated buildings at private and public levels.

According to the EU's "Hydrogen Strategy" [20], CO_2 emission regulation is expected to create (2025-2030) a market for hydrogen solution that will boost end-use consumption, especially for the transportation part, where electrification is not feasible, and heavy industries. "Hydrogen Roadmap Europe" [14] foresees an additional possibility to directly engage the end-users in low carbon technologies - wide use of natural gas blended with hydrogen. As a result, 52 million European households would receive either blended or pure hydrogen instead of natural gas in 2050, accounting for 58 % of all households connected to the natural gas grid. In parallel, households could switch to µCHPs instead of natural gas boilers. Their market share could grow from currently 1 % to more than 10 % by 2030 and to 50 % by 2050.

ETIP-SNET's "Vision 2050" [1] anticipates that in 2050, through digitalization, 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. Due to active local energy generation (building-integrated generation) combined with energy efficiency solutions (e.g., insulation and efficient appliances), new buildings in most cases are nearly zero-energy and possibly positive-energy buildings. 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.

Energy efficiency remains one of the main challenges in Europe. The EU Reference Scenario [5] considers policies regarding energy efficiency in the Union and the Member States, including promoting energy performance standards, which relate to individual or single technologies, improving consumer information through education, labelling, correct metering and billing, energy audits and technology support schemes aiming at inciting consumers to select more efficient technologies.

The European "Energy Storage Technology Development Roadmap towards 2030" [15] highlights positive effects of using storage by end-users, such as continuity of energy supply, limitation of upstream disturbances, Time-of-Use energy cost management, etc.

World Energy Issues Monitor 2020 [24] defines customer awareness as the back-bone of energy transition towards a more customer-centric environment. Digitalisation is leading the empowerment of consumers who will become more energy-efficient, facilitating the control of energy demand and contributing to decarbonisation.

3.9.2 Electrical Vehicles and Heat Pumps

Electrification of transport and end-users' adoption of EVs is another important low carbon technology. According to IEA [25] renewable energy will represent ¾ of the additional capacity required to meet the increasing electricity demand due to the electrification of the transportation and Heating, Ventilation and Air Conditioning (HVAC) sectors. To feel reliable using the EVs, the users must receive from the city government and transport authorities a relevant and high-quality information about charging options and associated costs.

The “European Study on Energy storage” [27] shows the forecast aggregate demand for electricity of EVs and heat pumps in 2030 and 2050, considering in the latter case two different assumptions. As it was already mentioned in Section 3.8.2, in 2030 and 2050, accordingly 30 % and 70 % of the electricity demand of EVs and heat pumps is assumed to be flexible. The document analyses also the sensitivity of the results to the increase up to 100 % in the electricity demand flexibility provided by these sources. The document uses as input the wind and solar installed capacity and capacity factors from the EC Long-term Strategy (EC LTS). The document does not specify which part of the solar PV installed capacity is owned by consumers.

According to "Power Facts Europe 2019" [29], in Europe, 1,11 million heat pumps were sold in 2017 showing an 11 % increase from 2016. The total stock of heat pumps has reached 10,6 million. The

European Heat Pump Association have forecasted that the stock of heat pumps will increase to 14,5 million by 2020, while the most recent documents indicate that the final figure was 14,8 million by the end of 2020. This is based on constant annual growth of 11,5 %. Assuming this 11,5 % growth rate remains constant until 2040, the stock of heat pumps will increase to 129 million. Under the Ten-Year Network Development Plan (TYNDP) Global Climate Action scenario, maximum heat pump deployment is 58 million by 2040. It can be argued that a growth rate of 11,5 % cannot be sustained indefinitely, and therefore a deployment level of 129 million heat pump units in Europe is potentially challenging.

3.9.3 Status in the European Member States

The Spanish NECP [6] refers to a recent study, where it was uncovered that 30,9 % of users in Spain would like to exercise their purchasing power and choose a 100 % renewable electricity supplier, owned distributed in the hands of citizens. This provision of the users encourages a better socio-economic anchor towards financing the energy transition.

The Italian NECP [12] identifies obligations to integrate energy from renewable sources in new buildings or in buildings subject to major renovation (in force from 2012). The document also describes some measures to guarantee the non-discriminatory participation of renewable energy, demand response and storage, including via aggregation, in all energy markets. In addition, the document points out that PV self-consumption could increase the awareness of the advantages of self-consumption and allows consumers to test how useful it could be in their own individual circumstances.

3.9.4 Examples of Solar Power in the Member States

According to [29], in 2017 newly installed solar PV capacity increased by 31 % to 9,2 GW. Growth was driven largely by Turkey, which added 2.6 GW of capacity, while Germany, a distant second, added 1,8 GW of capacity. Of this newly installed capacity, 26 % was attributed to residential rooftops.

Across Europe, the share of residential solar varied across Member States – Romania had a share of less than 1 %, while Belgium and the Netherlands had shares around 60 %.

Total solar PV capacity in Europe reached 114 GW in 2017 up 9 % on the year before. Germany (38 %) and Italy (17 %) operate over half of this capacity and this is unchanged from the year before.

3.9.5 Energy Communities for renewable generation

Energy Communities are expected to function as an important tool for engaging end-users in renewable generation and low carbon technologies. Therefore, [7] takes a special view on experience with Energy Communities, which have already been implemented in Spain. The barriers found in an example of a public-private-citizen community are as follows:

- There was a lot of mistrust regarding contracts to sign.
- Many users did not feel that they needed any kind of energy upgrade; there was a lack of knowledge about energy efficiency.

- Some members working in the construction sector, influenced the community according to their criteria, even if those were not the optimal ones.
- An important barrier was the previously existing conflicts. They needed to be solved before continuing in the community definition.
- It is briefly mentioned, with the growing concern of citizens for harmful damage to health as a result of air quality, the promotion and exploitation of EV charging points, could be one of the keys that could encourage the emergence of energy communities in cities.

Net-metering is one of the tools, which can be applied in Energy Communities. "Renewables 2020" [10] refers to experiences from the USA, where it stimulates the residential sector, and new community solar initiatives help encourage the commercial segment.

"Renewables 2020" [22] also elaborates on the Energy Community dimension, mentioning several incentivising schemes as:

- Feed-in tariff (FIT) schemes have been conducive to renewable energy development not only at a large scale but also at the community and residential levels, with benefits for energy democracy, citizen participation and social acceptance of renewables.
- Global climate strikes and opinion polls revealed rising public demand for a shift away from fossil fuels in 2019. But nevertheless, still face opposition from local host communities. Some of these are the noise or shadow flicker from wind energy projects, emissions from bioenergy or geothermal plants, the disruption of landscapes, land acquisitions and impacts on biodiversity. Bad perceptions of the distribution of economic costs and benefits, and unfairness of the consenting process by renewable energy project developers.
- The uptake of renewables is dependent on the three dimensions such as the views of local community acceptance, market acceptance and socio-political acceptance.
- Both governmental and non-governmental campaigns to raise awareness about renewable energy technologies are key point for a good adoption of the customers. For example, In November 2019, the EU declared a climate emergency and emphasised the need to reduce greenhouse gas emissions and phase out fossil fuel subsidies in the region by 2050.

3.9.6 Summary

The screening creates an impression that despite a multitude of technologies, which can contribute to decarbonisation, the present situation of consumers' adoption of technologies is shaped by several technology-specific interest organisations. It appears that these organisation tend to emphasise their "own" technologies, sending the consumers information, which is not aligned or sometimes even contradicting. The situation is worsened by the complexity of the problem and variety of the available solutions and combination of these both on a single consumer level as well as on an energy community level. This highlights the necessity of holistic approach with dedicated and tailorable optimisation tools, which allow evaluating several decarbonisation technologies.

3.10 Existing local energy market mechanisms

This section describes the status of local energy market mechanisms, based on the screening documents, and is important for the eNeuron project since awareness of existing local market mechanisms is a critical input for business models in WP3 (needs for new markets/trials/tested models).

The main focus is on electricity market access for all consumers and their possibility to trade flexibility and self-generated electricity (from distributed generation such as PV panels etc.), and alternative business models for local energy communities where flexibility is available from both demand response and energy storage.

3.10.1 The Pan-European dimension

The IEM Directive specifies that all customers groups should have access to all electricity markets, both to trade their flexibility and self-generated electricity [8]. Further, the Directive specifies that consumers should be able to consume, store and sell self-generated electricity to the market and participate in all electricity markets by providing flexibility to the system. Examples of flexibility services are demand response, energy efficiency schemes or energy storage (in electric vehicles).

Additionally, [17] mentions the 'Clean energy for all Europeans' package, including the electricity market design rules adopted in 2019, which has paved the way to better cope with the new realities of energy markets, dominated by renewable energy production. The rules have given better conditions to foster consumer participation in energy markets and a level playing fields for new market entrants. The markets in the discussion are on a higher level than local markets.

Local energy market mechanisms are addressed in general terms in RED II [18]. According to Article 24 in this directive, DSOs will be required to assess at least every four years, in cooperation with the operators of district heating or cooling systems in their respective area, the potential for district heating or cooling systems to provide balancing and other system services, including demand response and storing of excess electricity from renewable sources, and whether the use of the identified potential would be more resource- and cost-efficient than alternative solutions.

Deep electrification requires a new market design and additional ancillary services suitable to the new resources. In this respect, an assessment of the value of peer-to-peer transactions for energy and an assessment of the flexibility potential provided by sector coupling, e.g., PtG solutions are essential steps [2]. According to [3], digitalized peer-to-peer energy trading based on blockchain and artificial intelligence will help to create energy communities.

3.10.2 The national dimension

Distributed generation is deployed in an increasing amount in Europe and is also one of several enablers for local energy communities. It is important to develop new methodologies for integrating distributed generation in different types of electricity markets. In the NECP for Italy [12] it is described in §2.4.3 how the current central dispatch model might not be fully appropriate with the increasing penetration of distributed generation. Further, the document underlines the importance of introducing negative prices in the Italian market to permit a profitable integration with the European electricity market (§3.4.3), which provides that market rules must not constrain pricing in any way.

To establish local energy communities where distributed generation, demand response and/or energy storage are available, relevant business models need to be developed. In [7], the following business models are considered for the creation of energy communities in Spain:

- *Cooperative*: Company created expressly for this purpose with members of the community. A strength with this alternative is that the participation is voluntary, but a weakness can be that it is difficult to get investments.
- *Hybrid community/government*: In this business model the local government participates in the consortium. A strength with this alternative is that the local government can provide economic inputs, but a weakness is that the local government varies depending on the region.
- *Hybrid community/private*: One or several companies participate in the consortium. A strength with this business model is that the investment capacity increases with increasing number of participants, but a weakness is that there might be differences in operational objectives between the participants.
- *Segregated property*: In this business model there are different parts of the networks owned by different actors. A strength with this business model is that each individual will focus on its own interests, but a weakness can be related to difficulties related to organization and problems of investments on every part of the community.

3.10.3 Summary

According to IEM all consumers should have access to all electricity markets, where they can both trade flexibility (from demand response, energy storage) and self-generated electricity (from distributed generation) [8]. With this specification, the directive opens up for all consumers to get the actual market price for both electricity and flexibility services. This is a first step towards an open market, where the consumers also pay the actual electricity price.

However, there is a limited description of existing local energy market mechanisms, mainly because this is a new trend in the power system and not deployed in large scale. To handle these changes, and study the consequence for stakeholders involved, it is important to evaluate possible business models (some examples are presented in [7]).

3.11 Integration of local energy markets into the Energy Market

This section considers limitation and shortcomings of the integration of local energy markets with the "main" conventional Energy Market. It also addresses any policy related with the different carrier's integration market.

3.11.1 The Pan-European prospective

In the short-term horizon, ETIP SNET R&I 2020-2030 Roadmap [28] defines that integrating local markets as a process, where final customers and small enterprises will be enabled to buy electricity generation from aggregated, multiple power-generating facilities or load from multiple demand response facilities to provide joint offers on the electricity market and be jointly operated in the electricity system.

The ETIP SNET Vision 2050 [1] defines a separate market layer allowing exchanges between generators, retailers, aggregators, consumers, grid operators, conversion and storage managers, as a key element of the future "system of systems" vision. Reliability and resilience for the pan-European, regional and local systems will be ensured (among others) by peer-to-peer transactions integrated with centrally- and locally-controlled electricity networks, supported by automated local grids together with network operator actions .

In addition to local trade of electricity, local markets are needed for trading flexible resources for different purposes. The IEM Directive [13] points out that DSOs should be capable of purchase ancillary services from distributed energy resources to operate their networks and avoid costly network expansions. Therefore, the Member States should create common regulations and provide incentives to DSOs with the aim of increasing flexibility and improving the efficiency of the grid. At the same time, they should also introduce network development plans for distribution systems to support the integration of RES, deploy the energy storage and electrify the mobility sector by supporting system users with adequate information related to future expansion or upgrades of the network. It is worth noticing these procedures do not exist in the majority of the Member States yet.

Looking at the local markets from the prospective of Energy Communities [16], the citizens and local energy communities should be defined as distinct entities that differ from other market participants. Numerous disadvantages can arise for energy communities from the regulatory market frameworks designed for a centralised energy system with large energy companies (e.g. principles of equality and non-discrimination can result to contradictory treatment and possible exclusion of energy community projects from the energy market). State aid guidelines should focus on addressing specific barriers for non-traditional market actors. An example is reported in the text where there should be the exemption of citizens and small renewable energy producers from some tasks.

Another aspect of local energy market is related to the sector coupling. The EU Market Outlook for Solar Power [3] further mentions that sector coupling will entail significant regulatory changes. Primarily, the EC should adapt the market design and regulatory frameworks adopted with the "Clean Energy for all Europeans"[32] for electricity to the gas sector by aligning the rules in this latter towards a zero-net emissions pathway.

3.11.2 Emerging technologies on the local markets

Apart from electricity, regional bioenergy markets are supposed to be created and integrated through the necessary trade infrastructure [11]. The European Roadmap for storage technology development [15] mentions that energy storage can participate in the ancillary market, providing primary, secondary and tertiary frequency control, allowing variable renewable energy to integrate into this market. According to [3] digitalisation will allow that local energy markets can provide flexibility to the electric system.

The Climate Action Plan [26] underlines that in order to enable the participation of micro-generation into the grid, change of electricity market rules and design of market mechanisms are required.

Referring to [20], hydrogen infrastructure should be accessible to all on a non-discriminatory basis to allow the creation of a transnational open competitive market open to newcomers and integrated with other energy carriers.

3.11.3 Summary

From the screened documents, it appears that the establishment of well-functioning local markets is a compulsory attribute of the successful energy transition. Several functions are required:

- Local trading of renewable electricity.
- Trading of flexible resources necessary for ancillary services securing operation reliable system operation.
- Cross-sector market arrangements for sector coupling.

It is likely that the process will happen stepwise and require a certain maturing time.

3.12 V2G integration mechanisms

This section gives an overview of relevant mechanisms for enabling vehicle to grid, where EVs are treated as energy storage with the possibility to feed electricity back into the grid. The focus is on opportunities associated with the provision of aggregation and other control-related services to manage the energy supply to/from vehicle batteries and to use this to deliver services to customers (e.g., DSOs, energy companies) when required. This includes technologic, legal (support schemes) or a combination of these.

3.12.1 The Pan-European dimension

In the IEM Directive [13] it is mentioned in Section (41) that demand response is pivotal for enabling smart EV charging, followed by (42) consumers should be able to consume, store and sell self-generated electricity to the market and to provide flexibility to the system. In this context, electric vehicles are mentioned as a potential storage for demand response application [13], but V2G is not directly mentioned. However, according to [8], EVs will help to accelerate the development of self-consumption schemes, enabling Vehicle-to-Grid applications.

A lot of V2G initiatives technology for the demand- and supply-side response was enabled in 2019, and this fact gives EVs the potential to support the integration of VRE as their market share grows [22]. By the end of the year 2019, around 65 V2G projects and initiatives were in progress across 15 countries [22]. In 2030, V2G could provide around 600 GW of flexible generation capacity [25].

In addition to the growth in household battery deployment, increasing demand for EVs creates opportunities for customers and system operators to derive value from an increasing number of behind-the-meter batteries – both second-life batteries from old vehicles and idle EVs [29]. V2G technology allows for smart charging and discharging of the vehicle's battery. This can allow control of a bi-directional flow of electricity between the vehicle battery and the grid. Future market structures and pricing regimes could therefore align consumers charging behaviour with network requirements.

Vehicle charging may cause a substantial increase in electricity demand but using different charging options (as promoting workspace charging and dynamic time-of-use residential tariffs) and with a solid infrastructure, it will be possible to encourage alignment between EV load and VRE generation [25]. With an optimal strategy combining the time/power level at which EVs are charged, a co-ordinated charging and V2G can unlock the full flexibility potential of EVs.

For SOs, the smart charging capability creates the opportunity for idle EVs to provide valuable grid services. Additionally, it can mitigate against the network challenges caused by the increasing EV-charging requirements, which may otherwise require investment in infrastructure. This allows for "smart" sector-coupling between transport and power [29].

EVs with V2G technology can serve as power service providers [29], and the G2V and V2G capabilities can be exploited on distribution grid operation, especially for load flattening, system balancing and voltage support [28]. However, batteries from EVs, used as balancing component (G2V and V2G), cannot solve the grid issue alone [15]. Several challenges must be solved: improve battery technology to increase the energy density, reduce the charging times and avoid battery degradation when it is used for additional services as V2G.

The sensitivity of the optimal flexibility portfolio to whether or not electric vehicles can inject back the energy stored in their batteries into the electric grid has been analysed in "Study on Energy Storage" [27], and according to this study, enabling the V2G capability will reduce the need for pumped-hydro storage and gas-fired installed capacities in the optimal flexibility portfolios in both 2030 and 2050.

The "Global EV Outlook from 2020" [9] identifies and discusses recent developments in electric mobility worldwide, including scenarios for further developments. In the SDS, 250 million EVs are forecasted in 2030. If these vehicles are dummy recharged in the evening, the peak demand could increase 4-10 % in the main vehicle markets. Promoting off-peak hour charging during the daytime could move 50 GW, coinciding with PV generation. Promoting recharging during off-peak night hours will displace an additional 110 GW (in particular, in Europe the peak load will fall from 8-12 % to 4 %). Smart dynamic controlled charging, also known as V1G, could cut these figures in half, charging at night in response to real-time price signals (allowing better integration of intermittent renewable energy and the demand

V2G is the next step in the SDS scenario [9]. In the SDS, 16 TWh of storage capacity would be available globally. Taking into account that vehicles remain idle most of the time and assuming a small percentage of their available battery capacity to offer V2G services (around 5%), 800 GWh/600 GW of flexible capacity would be available to support the electric system.

Assuming EV participation in V2G services under demand response programmes, around 600 GW of flexible capacity would be available to split across China, EU, USA and India [9]. This flexible capacity could compensate variability of renewable sources during peak periods and could contribute to meet part of the additional capacity generation required during these peak periods. In 2030, V2G could avoid generating 380 TWh during peak periods in these four regions, avoiding the emission of 330 Mt CO_2. To charge this amount of energy in the EVs' batteries, around 470 TWh of electricity should be previously supplied at off-peak hours.

Dynamic controlled charging (One-directional power flow, V1G) and vehicle to grid services (bi-directional power flow, V2G) can be a solution for the increase of electric demand, generated by the electrification of the transportation sector and can contribute to integrate a higher share of variable renewable energies, but these technologies will require to adapt current regulatory and market policies [9].

3.12.2 The national dimension

The NECP for Italy also describes V2G [12]. According to the European Delegation Law 2019, self-consumption systems will be proposed, including EVs as storage systems (§1.2). Further, the National Plan for Electric Vehicle Charging Infrastructure aiming to create infrastructure networks for charging electric vehicles and activities for the restoration of buildings is also mentioned (§3.1.3).

In the context of EVs, new measures will be provided to integrate V2G into the electricity network, first with trial experiments and then extensively applied (§3.4.3 (ii)). Moreover, a Ministerial Decree setting out the rules for the functioning of vehicle-to-grid is currently being finalised. In a previous public consultation, recommendations were made for solutions or incentives to foster V2G technology or smart recharging (e.g., encouraging the installation and proliferation of photovoltaic equipment to power electric vehicle recharging points).

Further, [12] also mentions the Legislative Decree No 102/2014, defining new possibilities of systems aggregation; in particular for the EV batteries, and there will be as soon as possible another decree to approve specific V2G projects.

3.12.3 Summary

According to IEM Directive, all consumers should be able to consume, store and sell self-generated electricity to the market and to provide flexibility to the system. EV is a potential storage for demand response application and will also help to accelerate the development of self-consumption schemes, enabling Vehicle-to-Grid applications.

EVs with V2G technology can contribute with flexibility services to the power system, and especially G2V and V2G capabilities for load flattening, system balancing and voltage support. Some of the relevant technology for this is available today, and some are under development, the challenge is to develop business models and incentives to realise the benefits from V2G/G2V.

3.13 Energy Communities - different actors and operations

The present topic is intended to cover different actors, which may be involved and their roles in energy communities. The topic further aims at future alternative models for the operation of integrated energy systems as for example, Web-of-Cells [33] (see the Glossary), which will be addressed in the the next (D2.2) deliverable of the present (WP2) activity of eNeuron project.

The issue of energy communities will be covered in more details in another activity/WP of eNeuron project – "WP3 Identification of the “Local Integrated Energy Community” subject and definition of the Use Cases".

3.13.1 Energy Communities in the Pan-European Regulation: terms and definitions

There are several terms describing energy communities, which are in circulation for the moment. This study refers to the official terms, defined in the European legislative acts and documents. Two formal definitions of Energy Communities were introduced in two separate Directives included into the "Clean Energy for all Europeans" package:

- The main framework for RECs was introduced by and defined in RED II [18]
- The concept of CECs was introduced in the IEM Directive [13]

It is important to mention that both documents had several amendments, while the most recent versions are in force. Definitions of the terms are not presented in a similar manner, while some of the points are scattered in the documents.

Table 3.5 Main terms and definitions for Energy Communities

Renewable Energy Community	**Citizen Energy Community**
Definition of the legal entity:	
Section (16) in [18]	Section (11) in [13]
• which, in accordance with the applicable national law, is based on open and voluntary participation, is autonomous, and is effectively controlled by shareholders or members that are located in the proximity of the renewable energy projects that are owned and developed by that legal entity. • the shareholders or members of which are natural persons, Small and medium-sized enterprise (SMEs) or local authorities, including municipalities.	(a) is based on voluntary and open participation and is effectively controlled by members or shareholders that are natural persons, local authorities, including municipalities, or small enterprises.

The common understanding is that *REC is a legal subset of a broader CEC* term. Term LEC is in practice obsolete, and it does not appear in the recent official documents but is still used in research projects. In its package "Clean Energy for all Europeans", the EC started the formalisation process of several new actors, including active customers, RECs and CECs, by introducing the concepts and defining the main functions, roles and responsibilities associated with this term. The intention is to provide Energy Communities with an enabling framework, fair treatment, a level playing field and a well-defined catalogue of rights and obligations.

Table 3.6 Energy Communities in the Pan-European regulation: roles and responsibilities

Renewable Energy Community	**Citizen Energy Community**
• Roles and Responsibilities:	
	Section (11) in [13]
(not present in the document)	• may engage in generation, including from renewable sources, distribution, supply,

	consumption, aggregation, energy storage, energy efficiency services or charging services for electric vehicles or provide other energy services to its members or shareholders;
Article 22 in [18]	Article 16 in [13]
The Member States **shall ensure** that renewable energy communities are entitled to: • produce, consume, store and sell renewable energy, including through renewables power purchase agreements. • share, within the renewable energy community, renewable energy that is produced by the production units owned by that renewable energy community, subject to the other requirements laid down in this Article and to maintaining the rights and obligations of the renewable energy community members as customers. • access all suitable energy markets both directly or through aggregation in a non-discriminatory manner.	Member States **may provide** in the enabling regulatory framework that citizen energy communities: • are open to cross-border participation. • are entitled to own, establish, purchase or lease distribution networks and to autonomously manage them subject to conditions set (see the last two bullet points below). • are subject to the exemptions from certain duties of DSOs (see Art. 38 (2)). Member States **may decide** to grant citizen energy communities the right to manage distribution networks in their area of operation and establish the relevant procedures. If such a right is granted, Member States **shall ensure** that those citizen energy communities: • are entitled to conclude an agreement on the operation of their network with the relevant distribution system operator or transmission system operator to which their network is connected. • are subject to appropriate network charges at the connection points between their network and the distribution network outside the citizen energy community and that such network charges account separately for the electricity fed into the distribution network and the electricity consumed from the distribution network outside the citizen energy community.

For the scope of the present study, it is not necessary to go deeper into the legal aspects of the ECs, while a deeper comparative evaluation of the ECs can be found in [31]. In addition, as altready mentioned, there is a dedicated activity in eNeuron project, which will explore this issue further.

There is also a common understanding that ECs is not an activity as such, but a type of organisation and governing, involving schemes in which citizens are highly involved in decision-making or where there is an emphasis on local benefits such as energy access, job creation, community regeneration and education [16]. Membership in the energy communities should be opened to all categories of entities. However, the decision-making should be limited to the members, which are not engaged in large-scale commercial activity and the energy sector is not the primary area of operation.

It is also important to mention that the present definition of CECs presumes technology neutrality, meaning that it can be using different sources of energy, even including fossil fuels.

3.13.2 Examples of National implementations

There are several existing organisational schemes of local energy communities in Europe [16] in which citizens are highly involved in decision-making, or where there is an emphasis on local benefits such as energy access, job creation, community regeneration and education. Such projects can be owned completely by a community and/or its citizens (e.g., a RE cooperative) or represent a hybrid model of partnerships between citizens, public or private organisations).

In practice, the organisational structures of community energy initiatives vary, and include different legal forms such as partnerships (including public-private partnerships (PPPs) with local authorities), cooperatives, community trusts and foundations, limited liability companies, non-profit customer-owned enterprises, housing associations and municipal ownership.

Following the European regulations, the Spanish government seeks to promote citizens' role to conform to the energy communities as the engine of the energy transition. The NECP [6] settles tools and mechanisms for the development of energy communities (ECs) and aligned with the "Clean Energy for all Europeans" package. However, it is currently being developed in Spain now a specific regulation for ECs, to fulfil the objectives of the NECP but as a separate law.

The concept of energy communities is under development, requiring efforts from several stakeholders which pursue their goals. This is described in [7] defining three main stakeholders:

- **Public administrations:** Generate awareness, create adequate regulations to allow diverse initiatives, design and make available means of support (legal and financial), legislate according to emerging and technological needs, put the different parties in contact, ensure the final objectives, develop and promote new financial schemes, limit risks for stakeholders, both citizens as private companies, educate in the energy transition, promote and support technical, financial and social innovation, promote the formation of alliances, clusters, etc.
- **Private sector:** Offer technological and financial solutions, develop new business models cooperate with other entities for integrated offers, integrate the citizen in the processes of design and decision making, offer new financial schemes, promote operations with a positive impact on society.
- **Citizens:** Be a tractor of the initiative, Request offers, requirements and help from the public and private sector, create demand aggregation, to get informed about the technological and financial benefits.

When it comes to Italy, the Italian NECP [12] document introduces the Renewable Energy Communities as fundamental entities to support the economies of the smaller regions and that help in situations where self-consumption is technically difficult. The same document points out that the current dispatching model is not suitable to favour the energy communities and suggests a new model based on efficiency and security, and that a ‘self-dispatching’ model, currently prevailing in Europe, could be a better solution.

3.13.3 The future role of CECs

The ETIP SNET's R&I Roadmap for 2020-2030 [28] foresees that by 2030 energy communities contribute with their flexibility to the resolution of congestion management and local balancing issues, with the proper DSO coordination. They support the operation of the electricity system by controlled charging and discharging of batteries and demand response, optionally combined with heating/cooling energy systems, thus allowing their participation to the regional energy market and their contribution by their flexibility to the handling of regional balancing and distribution system constraints.

3.13.4 Summary

Following the Pan-European legislation for CECs, an array of possibilities appears to be open (for details see Art. 16 in [13]) e.g., it can undertake roles of final customers, producers, suppliers or DSOs, engaging in energy generation, distribution, supply, ownership and management of batteries, EV charging points etc. The IEM Directive also empowers the Member States to allow citizen energy communities to become DSOs either under the general regime or as "closed distribution system operators". Once a citizen energy community is granted the status of a DSO, it should be treated as, and be subject to the obligations as a DSO, with certain exemptions. At the very same time while undertaking these roles, CECs may have several exemptions form the responsibilities required from the full-scale operators. For the time being, it is up to Member States to define national regulatory regimes and there is an indication of considerable diversity among the forthcoming national models. However, simple inheritance of different roles as, for example, DSO does not necessarily open all necessary functions for CECs, simply because these are none-existing at the DSO level.

3.14 Energy vectors integration and coupling technologies (Policies)

This section gives a policy view of the operation of energy vectors, including policies regarding the integration of different energy vectors and the implementation of coupling technologies.

3.14.1 Market regulation

ENTSO-E Research, D&IR Roadmap 2020-2030 [2] gives the recommendation to define regulatory guidelines for topics such as flexibility markets, sector coupling, off-shore wind integration and hybrid DC/AC girds.

According to [13], consumers should be able to consume, store and sell self-generated electricity (see Section (42)), and it is DSOs’ responsibility to cost-efficiently integrate new electricity generation, especially installations generating electricity from renewable sources, and new loads such as loads that result from heat pumps and electric vehicles (61). In [17] the focus is on the internal energy market for electricity and gas. For electricity, the market coupling is mentioned as a contribution to increased efficiency of electricity trading in Europe, but this is on a Member State level and not local.

3.14.2 Power system and flexibility services

According to ETIP SNET's Vision 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[1].

Power system flexibility involves the integration of strategic market design; generation, demand and energy storage; forecasting of electricity demand and of VRE generation and demand; and the implementation of physical linkages between VRE sources and demand centres [22].

3.14.3 Electric Vehicles

Demand response of vehicle charging is also mentioned in the document as a means to couple the electricity and transport sectors [27]. Interoperability standards for communication between different electric vehicle brands and charging stations must be developed so as to enable the provision of flexible services by electric vehicles to the electricity system.

3.14.4 Energy Storage

The "Study on Energy Storage" [27] warns about potential conflicting definitions of energy storage in the primary legislation of different energy sectors (e.g., electricity and gas). Specifically, in the electricity sector, the legislation in most EU Member States requires the re-conversion of the energy stored into electricity. This may have a negative impact on the business case of PtG projects aimed to inject hydrogen or methane into the natural gas network.

3.14.5 Sector Coupling

To achieve energy transition in 2050, it is needed to 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 [1]. Also [27] mentions sector coupling as a mean to provide services to the electricity system and to increase the security of the electricity supply.

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 the conversion from and to electricity) as well as through new infrastructures for mobility (charging stations and refuelling stations) [1].

The report [4] clearly recognises the importance of sector cross-coupling and, in particular PtG technologies, but at the very same side it points out there are several missing points, when it comes to PtG, including some open regulatory questions and gaps (ownership, roles and responsibilities), lack of proved business cases and need for methods for traceability of hydrogen's origin. Therefore, it points out that large-scale, direct renewables-based electrification should be preferred whenever it is available and wherever it is possible across all sectors in the economy. Indirect electrification with renewables should be used only where necessary, like in the hard-to-abate sectors of the economy. This is because using directly renewable electricity is more efficient than converting it into other energy carriers, like hydrogen or hydrogen-based fuels.

3.14.6 Variable Renewables (VRE)

A transition to a more system-friendly integration of variable renewables is needed to cut peaks in VRE generation, for example, by complementing policy support schemes with exposure to competitive market outcomes, since there is little incentive for assets with fixed prices and prioritised dispatch to control outputs [10].

3.14.7 Hydrogen

Current policy supports hydrogen vector in the chemical sector via the short-term implementation of blue hydrogen production with Carbon Capture, Utilisation and Storage (CCUS) technologies from fossil fuels (i.e., Steam Methane Reforming (SMR)) in order to produce extreme low-cost hydrogen to provide to hard-to-abate and highly CO_2-emissive sector (i.e., refineries, chemical plants, etc.) [14].

In the medium-long term, the sector coupling between power and other networks via hydrogen is expected, achieving the possibility to reach a vast range of applications (gas, buildings, mobility, power generation, storage) [14]. Such sectorial integration will benefit all sectors, providing flexibility and balancing capacity from both the technical and economic scale.

There are different ways to produce hydrogen with different CO_2 emissions (and other environmental associated impacts). Therefore, it is important to have a commonly agreed definition and classification for hydrogen at EU-level (particularly green hydrogen), in order to determine its role in the decarbonisation pathway in Europe [4].

3.14.8 Origin of energy carriers

The "Study on Energy Storage" [27] mentions the importance of guarantees of origin for the different energy carriers and cites an interesting project undertaken by the Association of Issuing Bodies under a contract to the DG ENER of the EC. The FastGo project developed a text proposal for a revised EN16325 standard on guarantees of origin.

3.14.9 Power to Gas

The Danish TSO considers in its energy system outlook for 2035 that PtG will provide seasonal flexibility to the electricity system. In Germany, electricity used for PtG is exempted for charges and levies, provided that the gas is converted back into electricity [27].

3.14.10 The national dimension

For Spain, document [6] specifically mentions electrical/gas coupling to promote demand response and the need to develop an adequate framework for the participation in the markets of renewable energy, storage and demand response (creating the figure of the independent aggregator).

Further, document [21] mentions several measures that the Spanish Government intends to take so as to promote the production and use of green hydrogen. None of the measures is specifically focused on the operation of installations using hydrogen as an energy vector. Notwithstanding, certain measures are listed below since they are somewhat related to the integration of different energy vectors:

- Regulatory measures simplifying and making easier the deployment of specific power lines for the production of green hydrogen and of a hydrogen pipe network.
- Establishment of a National Statistic System about consumption and production of hydrogen in Spain, classified by type of hydrogen and consumption sector.
- Financial support for the manufacturing of FCEVs powered by hydrogen.
- Promotion of studies and tests about the feasibility of replacing diesel powered trains by fuel cell electric trains powered by green hydrogen.
- Development of specific regulations for building and operating hydrogen fuelling stations, for both cars, buses, trains and ships.
- Foster the development of plants for the production of synthetic kerosene from green hydrogen to decarbonize the aviation sector.
- Establish a legal framework for Power-to-X plants.
- Allow the participation of electrolysers in the ancillary services of the electric power system.
- Revise the technical, regulatory and quality issues of the injection and use of hydrogen in the natural gas pipe network.
- Analyse the needs for the adaptation of devices using gas in the industrial and residential sectors so as to allow higher concentrations and penetrations of green hydrogen.

3.14.11 Summary

Relevant topics related to policies for integrating energy vectors and coupling technologies are for example market regulation so that all consumers can have access to all markets and can sell flexible services to the power system, which can defer the needs for grid upgrades and increase the security of supply. Electric vehicles, charging stations, and their potential for demand response are additional examples of resources that can offer services to the power system.

For the energy transition towards 2050, it is needed to deploy power conversion units enabling the optimal coupling (integration) among all energy carriers. Coupling different energy networks occurs on all scales according to the most cost-effective way. In the medium-long term the sector coupling between power and other networks via hydrogen are expected, achieving the possibility to reach a vast range of applications (gas, buildings, mobility, power generation, storage).

4 Conclusions

The EU has set the ambition to reduce greenhouse gas emissions to the point of becoming climate neutral by 2050 and prevent the negative and irreversible effects of climate change. Reaching this goal will require shifting the energy system to a renewable-based system and radical technological, behavioural and organisational changes in the economy and society.

The present screening draws a rather complicated picture, based on a selection of legal documents, roadmaps, position papers etc. from several types of stakeholders. It is once again necessary to reming the scope and objectives eNeuron project i.e. development of innovative tools for the optimal design and operation of local energy communities (LECs), integrating distributed energy resources and multiple energy carriers at different scales. In view of this, several important things were learned, as for example:

The ETIP SNETS's vision of the 2050 power system located the electricity grid in the centre of the integrated power system to transport huge amounts of energy across Europe and enable switching between the energy carriers. The present study shows that now, several years after its publication, the Vision becomes more strengthened, elaborated in more details and substantiated in several roadmaps.

Achieving the Pan-European goals for decarbonisation of the energy sector requires several radical steps following the energy transition path. Storage technology in its various forms is foreseen as a key enabler of the energy transition and a binding element of different energy vectors. Different types of energy storage will meet different needs and applications in decarbonised power sector. Introduction of RES brings a need for more efforts in balancing of the power system, what may become a major driving force for deployment of grid-connected energy storage, while other technologies as pumped hydro and heat storage will become more important. Hydrogen storage has unique technical properties and may become a favourable storage option for high VRES penetration regions. However, very high costs, lack of infrastructure and even more importantly lack of regulation is likely to postpone full scale-implementation of hydrogen as a storage and as an energy vector in general. Uncertainty and especially the absence of clear regulatory provisions are possibly two of the most significant barriers to establishing new services, since this uncertainty could strongly discourage potential investors from developing the necessary infrastructure assets. Furthermore, to establish an operational environment, it can be equally important to indicate roles and responsibilities as well as any possible limitations of these in order to draw unambiguous legal borders.

Apart from electricity storage, heat storage will become increasingly important. Today more than 50% of the final energy demand in the EU is used for generating heat, and already now heat storage is utilised in water-based systems for domestic and district heating. In terms of energy, heat storage is by far the largest single energy storage application field in Europe.

Transport remains the sector with the lowest penetration of renewable energy in the EU energy system. Electric mobility is considered a key point for the decarbonisation of the transport sector, especially in urban areas, and there is the need for policies to promote EVs that must also support charging points deployment and include new codes to install these charging points in new (or refurbishment) buildings.

Successful implementation of the new technologies and the energy transition process depend upon support and engagement of the end-users. Several important steps in this direction have been recently made, more specifically introduction of Citizen and Renewable Energy Communities, Active Customers and other innovative concepts in the "Clean Energy for all Europeans" package. From the screened documents, it appears that the establishment of well-functioning local markets is a compulsory attribute of the successful energy transition.

The screening creates an impression that despite a multitude of technologies which can contribute to decarbonisation, the present situation of consumers' adoption of technologies is shaped by technology-specific interest organisations. The situation is complicated by the complexity of the problem and variety of the available solutions and combination of these both on a single consumer level as well as on an energy community level. This highlights the necessity of holistic approach with dedicated and tailorable optimisation tools, which allow evaluating several decarbonisation technologies and proves again the necessity and correct timing of eNeuron project.

Finally, it is also necessary to mention the uncertainty arising from the future consequences of COVID19 worldwide. For the time being it is difficult to foresee both its duration and the whole magnitude of aftereffects. Some of the planned timelines and roadmaps can be adjusted accordingly.

5 References

5.1 List of the main documents screened in the study

[1] R. Bacher, M. de Nigris and E. Peirano, "ETIP-SNET Vision 2050," 27 June 2018. [Online]. Available: https://www.etip-snet.eu/wp-content/uploads/2018/06/VISION2050-DIGITALupdated.pdf. [Accessed 30 April 2020].

[2] ENTSO-E, "Research, Development & Innovation Roadmap 2020–2030," 14 October 2020. [Online]. Available: https://www.entsoe.eu/2020/10/14/entso-e-research-development-innovation-roadmap-2020-2030/.

[3] M. Schmela and et al, "EU Market Outlook for Solar Power 2019-2023," 2019. [Online]. Available: https://www.solarpowereurope.org/eu-market-outlook-for-solar-power-2019-2023/. [Accessed 28 February 2021].

[4] WindEurope, "Wind-to-X: a postion paper an how to achieve net-zero emissions through a renewables-based electrification," October 2019. [Online]. Available: https://proceedings.windeurope.org/biplatform/rails/active_storage/disk/eyJfcmFpbHMiOnsibWVzc2FnZSI6IkJBaDdDRG9JYTJWNVNTSWhkVEIzTm5ZM2VqWnBhR050TWpGNk5HbHBhbmg1YVdOeFoyTjBjUVk2QmtWVU9oQmthWE53YjNOcGRHbHZia2tpZVdsdWJHbHVaVHNnWm1sc1pXNWhiV1U5SWxkcGJtUkZkWEp...

[5] European Commission, "EU Reference Scenario 2016 - Energy, transport and GHG emissions Trends to 2050," 2016. [Online]. Available: https://ec.europa.eu/energy/sites/ener/files/documents/20160712_Summary_Ref_scenario_MAIN_RESULTS%20(2)-web.pdf. [Accessed 26 02 2019].

[6] Ministerio para la Transición Ecológica y el Reto Demográfico, "Plan Nacional Integrado de Energía y Clima (PNIEC) 2021-2030," 31 March 2020. [Online]. Available: https://www.idae.es/informacion-y-publicaciones/plan-nacional-integrado-de-energia-y-clima-pniec-2021-2030. [Accessed 28 February 2020].

[7] IDAE, "Guía para el desarrollo de instrumentos de fomento de Comunidades Energéticas Locales," March 2019. [Online]. Available: https://www.idae.es/sites/default/files/documentos/publicaciones_idae/guia_para-desarrollo-instrumentos-fomento_comunidades_energeticas_locales_20032019_0.pdf. [Accessed 28 Febraury 2021].

[8] Interreg Europe, "Renewable energy self-consumption: A Policy Brief from the Policy Learning Platform on Low-carbon economy," September 2020. [Online]. Available: https://www.interregeurope.eu/fileadmin/user_upload/plp_uploads/policy_briefs/Energy_self-consumption__Policy_brief_final.pdf. [Accessed 28 February 2021].

[9] Clean Energy Ministerial, Electric Vehicles Initiative, "Global EV Outlook: Entering the decade of electric drive?," 2020. [Online]. Available: https://webstore.iea.org/download/direct/3007. [Accessed 28 February 2021].

[10] IEA, "Renewables 2020: Analysis and forecast to 2025," 2020. [Online]. Available: https://webstore.iea.org/download/direct/4234. [Accessed 28 February 2021].

[11] International Renewable Energy Agency (IRENA), "Renewable Energy Prospects for the European Union," February 2018. [Online]. Available: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Feb/IRENA_REmap_EU_2018.pdf. [Accessed 28 Febraury 2021].

[12] Ministry of Economic Development (Italy), "Integrated National Energy and Climate Plan," December 2019. [Online]. Available: https://ec.europa.eu/energy/sites/ener/files/documents/it_final_necp_main_en.pdf. [Accessed 28 February 2021].
[13] The European Commision, "Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019," 5 June 2019. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2019.158.01.0125.01.ENG&toc=OJ:L:2019:158:TOC. [Accessed 24 September 2019].
[14] Fuel Cells and Hydrogen 2 Joint Undertaking, "Hydrogen Roadmap Europe," January 2019. [Online]. Available: https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf.
[15] European Association for Storage of Energy, "EASE/EERA Energy Storage Technology Development Roadmap towards 2030," [Online]. Available: https://ease-storage.eu/publication/easeeera-energy-storage-technology-development-roadmap-towards-2030/. [Accessed 28 February 2021].
[16] European Committee of the Regions, Milieu Ltd, "Models of Local Energy Ownership and the Role of Local Energy Communities in Energy Transition in Europe," 25 September 2018. [Online]. Available: https://op.europa.eu/en/publication-detail/-/publication/667d5014-c2ce-11e8-9424-01aa75ed71a1. [Accessed 28 February 2021].
[17] The European Commission, "2020 report on the State of the Energy Union pursuant to Regulation (EU) 2018/1999 on Governance of the Energy Union and Climate Action," 14 October 2020. [Online]. Available: https://ec.europa.eu/energy/sites/ener/files/report_on_the_state_of_the_energy_union_com2020950.pdf. [Accessed 28 Febraury 2021].
[18] The European Commission, "Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources," 11 December 2018. [Online]. Available: https://eur-lex.europa.eu/eli/dir/2018/2001/2018-12-21. [Accessed 28 Febraury 2021].
[19] Directorate-General for Energy (European Commission), "The role and potential of Power-to-X in 2050," 30 April 2019. [Online]. Available: https://op.europa.eu/en/publication-detail/-/publication/1e6b9012-6bbc-11e9-9f05-01aa75ed71a1/language-en/format-PDF/source-96288622. [Accessed 28 February 2021].
[20] The European Commission, "EC COM (2020) 301 final. A hydrogen strategy for a climate-neutral Europe," 8 July 2020. [Online]. Available: https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf. [Accessed 28 February 2021].
[21] Gobierno de España, "Hoja de ruta del hidrógeno," [Online]. Available: https://www.miteco.gob.es/es/ministerio/hoja-de-ruta-del-hidrogeno-renovable.aspx. [Accessed 28 February 2021].
[22] REN21, "Renewables 2020 - Global Status Report," June 2020. [Online]. Available: https://www.ren21.net/wp-content/uploads/2019/05/gsr_2020_full_report_en.pdf. [Accessed 28 February 2021].
[23] Council of European Energy Regulators (CEER), "Report on Regulatory Frameworks for European Energy Networks 2019," 28 January 2020. [Online]. Available: https://www.ceer.eu/documents/104400/-/-/27978c4f-4768-39ad-65dd-70625b7ca2e6. [Accessed 28 Febraury 2021].

[24] World Energy Council, "World Energy Issues Monitor - 2020," 2020. [Online]. Available: https://www.worldenergy.org/assets/downloads/World_Energy_Issues_Monitor_2020_-_Full_Report.pdf. [Accessed 28 February 2021].

[25] 21st Century Power Partnership Initiative, Electric Vehicles Initiative, International Smart Grid Action Network Initiative, Power System Flexibility campaign, "Electric Vehicle and Power System Integration: Key insights and policy messages from four CEM workstreams," September 2020. [Online]. Available: http://www.cleanenergyministerial.org/sites/default/files/2020-09/2020-9-15%20CEM%20Horizontal%20Accelerator%20FINAL%20FOR%20POSTING.pdf. [Accessed 28 February 2021].

[26] Governmment of Ireland, "Climate Action Plan 2019," 2019. [Online]. Available: https://www.gov.ie/pdf/?file=https://assets.gov.ie/25419/c97cdecddf8c49ab976e773d4e11e515.pdf#page=null. [Accessed 28 February 2021].

[27] Artelys, Directorate-General for Energy (European Commission), Enerdata, Trinomics, "Study on Energy Storage: Contribution to the security of the electricity supply in Europe," 08 May 2020. [Online]. Available: https://op.europa.eu/en/publication-detail/-/publication/a6eba083-932e-11ea-aac4-01aa75ed71a1/language-en?WT.mc_id=Searchresult&WT.ria_c=37085&WT.ria_f=3608&WT.ria_ev=search. [Accessed 28 February 2021].

[28] ETIP SNET, "ETIP SNET R&I roadmad 2020-2030 (updated)," June 2020. [Online]. Available: https://www.etip-snet.eu/wp-content/uploads/2020/02/Roadmap-2020-2030_June-UPDT.pdf.

[29] ENTSO-E, "PowerFacts Europe 2019," 2019. [Online]. Available: https://eepublicdownloads.entsoe.eu/clean-documents/Publications/ENTSO-E%20general%20publications/ENTSO-E_PowerFacts_2019.pdf. [Accessed 28 Febraury 2021]

5.2 List of the supporting documents (not a part of the screening study)

[30] The European Commission. EUCO scenarios. https://ec.europa.eu/energy/data-analysis/energy-modelling/euco-scenarios_en

[31] J. Roberts, D. Frieden and S. d'Herbemont, "Energy Community Definitions," May 2019. [Online]. Available: https://www.compile-project.eu/wp-content/uploads/Explanatory-note-on-energy-community-definitions.pdf

[32] The European Commission, "Clean energy for all Europeans package," May 2019. [Online]. Available: https://ec.europa.eu/energy/topics/energy-strategy/clean-energy-all-europeans_en.

[33] T. I. Strasser and e. al, "D7.1 Report on the evaluation and validation of the ELECTRA WoC control concept," AIT Austrian Institute of Technology, December 2018. [Online]. Available: https://www.researchgate.net/publication/329947540_Report_on_the_evaluation_and_validation_of_the_ELECTRA_WoC_control_concept

[34] C. Nolden, J. Barnes and J. Nicholls, "Community energy business model evolution: A review of solar photovoltaic developments in England," Renewable and Sustainable Energy Reviews, vol. 122, 202

[35] EU 2030 Climate Target Plan, 2020 [ONLINE] https://ec.europa.eu/clima/policies/eu-climate-action/2030_ctp_en

[36] The European Commission. News: Energy efficiency first, 2019 [ONLINE] https://ec.europa.eu/info/news/energy-efficiency-first-accelerating-towards-2030-objective-2019-sep-25_en

[37] Estrategia de Almacenamiento Energético (in Spanish): https://www.miteco.gob.es/es/prensa/estrategiaalmacenamiento_tcm30-522655.pdf

[38] M. Victoria, K. Zhu, T. Brown, G. B. Andersen, M. Greiner, " The role of storage technologies throughout the decarbonisation of the sector-coupled European energy system" Energy Conversion and Management, Elsevier. Volume 201, 2019-12-01. https://doi.org/10.1016/j.enconman.2019.111977

[39] https://www.ev-volumes.com/

[40] https://www.ehpa.org/market-data/

[41] The European Commission. Communication from the Commission: "Annual Sustainable Growth Strategy 2021" COM(2020) 575, 2020 [ONLINE] https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX:52020DC0575

[42] https://www.certifhy.eu/

[43] The European Commission, EU Biodiversity Strategy for 2030. COM(2020) 380 final. 2020. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0380

6 Annex I: Glossary

Abbreviation	Term	Explanation	Source / Reference
AC	Active customer	a final customer, or a group of jointly acting final customers, who consumes, or stores electricity generated within its premises located within confined boundaries or, where permitted by a Member State, within other premises, or who sells self-generated electricity or participates in flexibility or energy efficiency schemes, provided that those activities do not constitute its primary commercial or professional activity	“Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU
-	Ambient Energy	Naturally occurring thermal energy and energy accumulated in the environment with constrained boundaries, which can be stored in the ambient air, excluding in exhaust air, or in surface or sewage water	Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources
CEC	Citizen Energy Community	a legal entity that: (a)is based on voluntary and open participation and is effectively controlled by members or shareholders that are natural persons, local authorities, including municipalities, or small enterprises (b)has for its primary purpose to provide environmental, economic or social community benefits to its members or shareholders or to the local areas where it operates rather than to generate financial profits; and (c)may engage in generation, including from renewable sources, distribution, supply, consumption, aggregation, energy storage, energy efficiency services or charging services for electric vehicles or provide other energy services to its members or shareholders	“Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU
CDS	Closed Distribution System	a distribution system, which distributes electricity within a geographically confined industrial, commercial or shared services site and does not supply household customers, without prejudice to incidental use by a small number of households located within the area served by the system and with employment or similar associations	European Commission, “Commission Regulation (EU) 2016/1388 of 17 August 2016 establishing a Network Code on Demand Connection,”
DR	Demand Response	the change of electricity load by final customers from their normal or current consumption patterns in response to market signals, including in response to time-variable electricity prices or incentive payments, or in response to the acceptance of the final customer's bid to sell demand reduction or increase at a price in an organised market	“Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU
-	Energy Carrier	Either a substance or a phenomenon that can be used to produce mechanical work or heat or to operate chemical or physical processes	ISO13600 (Technical energy systems — Basic concepts)

Abbreviation	Term	Explanation	Source / Reference
ESS	Energy storage facility	the electricity system, deferring the final use of electricity to a moment later than when it was generated, or the conversion of electrical energy into a form of energy which can be stored, the storing of such energy, and the subsequent reconversion of such energy into electrical energy or use as another energy carrier	"Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU
-	Energy Vector	A tool that allows the transportation and/ or storage of energy is called energy vector. An energy vector allows to transfer, in space and time, a quantity of energy.	Orecchini F. The era of energy vectors. Int J Hydrogen Energy 2006;31(14):1951–4.
-	Guarantee of Origin	An electronic document which has the sole function of providing evidence to a final customer that a given share or quantity of energy was produced from renewable sources	Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources
IES	Integrated Energy System	An integrated infrastructure for all energy carriers, with the electrical system as a backbone, and characterised by a high level of integration between all networks of energy carriers, coupling electrical networks with gas networks, heating and cooling, supported by energy storage in several forms and types including electric vehicles and conversion processes.	ETIP SNET Vision 2050
ILEC	Integrated Local Energy Community	A set of energy users deciding to make common choices in terms of satisfying their energy needs, in order to maximize the benefits deriving from this collegial approach, thanks to the implementation of a variety of electricity and heat technologies and energy storages and the optimized management of energy flows	eNeuron definition
	Renewable Energy	Energy from renewable non-fossil sources, namely wind, solar (solar thermal and solar photovoltaic) and geothermal energy, ambient energy, tide, wave and other ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas, and biogas;	Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources
WoC	Web-of-Cells	The Cell is a portion of the power grid able to maintain an agreed power exchange at its boundaries by using the internal flexibility of any type available from flexible generators/loads and/or storage systems. The total amount of internal flexibility in each cell shall be at least enough to compensate the cell generation and load uncertainties in normal operation. The Cell is not a microgrid and does not have to be energy self-sufficient or able to operate in islanded mode.	FP7 project ELECTRA IRP, "The Web-of Cells Concept - an architecture for decentralized balancing and voltage control in the future power system," ELECTRA Consortium, 2018.

7 Annex II: Summaries of the screened documents

7.1 Document 01: ETIP SNET Vision 2050 [1]

The Vision is a common document of the research and industry experts, European and national public authorities, European associations and others, which supports long-term decarbonisation strategy for the EU and where 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. The main message of the document is that electricity distribution and transmission grids are 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.

7.2 Document 02: ENTSO-E Research, Development & Innovation Roadmap 2020 – 2030 [2]

The Innovation Roadmap for 2020–2030 (RDI Roadmap) has been developed by ENTSO-E following the requirements defined by the Clean Energy Package. The document is based on a use-case approach to target challenges which need to be solved before 2030. The RDI Roadmap integrates the opportunities provided by technological trends, the needs of TSOs arising from system operations and market evolution, policy objectives of the European Commission (EC) and inputs from external stakeholders. The roadmap differs from its previous version by shifting focus from technologies to a problem-solving approach and innovation activities with higher TRLs. The document puts stronger focus on three prioritised RDI Areas/Clusters and 6 flagship projects and goes far beyond the transmission system, "system integration" & "deep electrification" are important keywords in the document.

7.3 Document 03: EU Market Outlook for Solar Power 2019-2023 [3]

This document describes the development of the photovoltaic industry in Europe. It describes the main reasons for this development and presents the main trends for the coming years, showing a forecast of the European market in 2023 (and beyond)

7.4 Document 04: Wind Power to X [4]

The paper presents WindEurope's position towards achieving net-zero emission by 2050. It puts forward renewable generation as the most cost-effective approach to reach the climate neutrality with direct use of renewable energy whenever it is possible in power generation, light-duty, pulp and paper, railway etc. and conversion into zero-carbon gases and fuels only when necessary. The document puts a lot of weight on regulatory work and removing regulatory barriers.

The paper discusses the present status and limitations related to production of hydrogen. It also clearly defines the areas of priority for sector decoupling process:

1. The taxonomy to classify the different routes to produce hydrogen, particularly when produced via electrolysis with renewable electricity;

2. The traceability of the renewable electricity used for hydrogen production in a system with a mix of power generating technologies;
3. The roles and responsibilities of market and regulated players in the production of hydrogen, crucially who can own, operate and offer sector coupling and cross-vector integration services to the market;
4. The level of infrastructure needed for cross-vector integration.

7.5 Document 05: EU reference scenario 2016 [5]

This report is focused on the EU energy system, transport and greenhouse gas (GHG) emission developments, including specific sections on emission trends not related to energy, and on the various interactions among policies in these sectors for EU and individual Member States. It is initially assumed that GHG and RES targets for 2020 were achieved, and all policies agreed at EU at the end of 2014, were implemented. Taking into account these assumptions, a modelling suite to obtain a Reference Scenario was built, combining technical and economic information. This suite is based on Reference Scenario 2013, and the main improvements in this suite are initially described.

The results are based on these simulations, therefore, it is necessary to be sceptical due to it may be a bit outdated for the eNeuron project.

7.6 Document 06: Plan Nacional Integrado de Energía y Clima 2021-2030 [6]

The final objective of this National Plan is to make to Spain a carbon-neutral country by 2050, leading the way towards it in the middle term. The goals in the reduction of GHG, use of renewable energy in the final energy or in the use of electricity as well as the increase of the energy efficiency are fully aligned with the European goals. Spain is a country that has been always a leader in technology development and roll-out of renewable energy technologies. Due to this, and the principles regulating the European policies (such as sharing of CO2 reduction obligations), Spain is a good country that can serve as a reference to analyse the trends in different European Countries that will have a direct impact in the design and development of the eNeuron solutions.

7.7 Document 07: Guía para el desarrollo de instrumentos de fomento de Comunidades Energéticas Locales [7]

It is a short guide created by the Spanish Institute for Diversification and Energy Saving (IDAE). The idea is to lay the foundations to generate guidelines to modify the energy market at the urban level, increasing the participation of citizens and local companies. It bases its information in the concept of local energy community, providing different typologies and definitions. It also shows some success factors and a summary of different legislative models to be applied.

7.8 Document 08: A Policy Brief from the Policy Learning Platform on Low-carbon economy [8]

This document describes the main reasons to promote (renewable) electric energy self-consumption in Europe

7.9 Document 09: Global EV Outlook 2020 [9]

This document analyses EV sales worldwide from 2010 to May 2020, indicating the main factors that affect their demand. Policies and strategies to promote EVs and recharging points in different countries are described and an outlook by 2030 is also presented. This document also describes the current and future battery development and how to integrate EVs with the electric grid, via off-peak charging, unidirectional controlled charging (V1G) or Vehicle-to-grid (V2G), providing additional flexibility for the power system

The report also describes policy recommendations based on frontrunner markets, as input to policy makers and stakeholders that consider policy frameworks and market systems for electric vehicle adoption.

7.10 Document 10: Renewables 2020. Analysis and forecast to 2025 [10]

This document provides detailed analysis and forecasts on renewables in the electricity, heat and transport sectors through 2025 and includes the impact of the Covid-19. It is important to eNeuron project to consider the current status in renewables and the projection to next five years.

7.11 Document 11: Renewable Energy Prospects for the European Union [11]

This document describes the renewable energy prospects for the European Union. It describes the state of the art of the use of renewable energies in the different EU countries, the share in the energy mix, how they can be managed in the European electricity sector, and the forecast (by 2030) of the increasing integration of cost-effective energy from renewables and the impact in the decarbonisation (assessing the potential for scaling up renewables in the different countries).

7.12 Document 12: Integrated National Energy and Climate Plan [12]

To meet the EU's energy and climate targets for 2030, each EU Member State needs to produce a national energy and climate plan (NECP) document for the period from 2021 to 2030.
The main scope of the document is to accelerate decarbonisation with focus on energy decentralisation, security of supply, energy efficiency promotion and electrification of consumption in Italy.
The NECP also aims to transpose the Directive 2018/2001 (Directive 2018/2001), related to individual and collective self-consumption initiatives (and energy communities).

The national plan considers five dimensions defined by Energy Union, developed for objectives/targets and policies/measures:

- Decarbonisation
- Energy efficiency
- Energy security
- Internal market
- Research, innovation and competitiveness

The document is relevant to eNeuron project, since promotes the integration of multiple energy carriers at building and community levels, fosters the empowerment of final consumers, and discusses the concepts of energy community and collective self-consumption.

7.13 Document 13: Directive (EU) 2019/944 on common rules for the internal market for electricity [13]

The Directive recast is an update of the rules for the internal market of electricity. The document aims to pursue the goal of creation the internal energy market and reduce application of fragmented national rules and uncoordinated policies. The Directive covers several areas, where the following are most relevant for the present project:

- Lays down the main principles ensuring that the EU electricity market is competitive, consumer-centred, flexible and non-discriminatory.
- Reinforces the existing and introduces the new rights for the customers, including free choice of suppliers or aggregators, ability to engage in Demand Response, self-generation and self-consumption.
- Introduces new roles as Citizens' Energy Communities and Active customers and defines their responsibilities.
- Highlights the role of independent aggregators and demand response principles.
- Clarifies tasks for DSOs, especially procuring of network services to flexibility and integration of EVs and data services.
- Summarises the general rules applicable to TSOs, largely based on the existing text.
- Sets rules for unbundling as developed in the 3rd Energy Package.
- Describes rules related to establishment, powers and duties of the independent energy regulators.
- Electricity bills must contain all the information needed by the end-users in order to select the proper energy service; in particular, the costs of the electricity bills have to be divided according to: i) electric energy supply, ii) electric energy transmission/distribution and iii) taxes.

7.14 Document 14: Hydrogen Roadmap Europe [14]

The document represents the EU roadmap for hydrogen implementation and scale-up as an energy vector to support Europe's energy transition both in terms of technology and applications. The document reports on the foreseen scale-up of hydrogen deployment under 2 scenarios (BaU, Ambitious) both in terms of additional capacity and percentage (%) of final energy demand met by hydrogen subdivided by end use application sector and its consequential impact on the EU energy matrix (CO_2 reduction, economic value added). The energy source of hydrogen and repartition between green/blue/grey hydrogen is analysed and forecasted to 2030 and 2050.

Four strategic end user sector applications are presented and intermediate milestones to 2030 are defined:
1. Transport (FCEV) for light and heavy-duty vehicles
2. Buildings supplied by H_2/NG blend or local FC based µ-CHP systems
3. Industry, mainly chemical such as ammonia, refineries, DRI steelmaking, etc.
4. Power System for large scale conversion of curtailed electricity to hydrogen in a Power-to-Gas approach

Finally, recommendations are given regarding the required regulatory and policy framework in terms of yearly budgetary incentive support, required taxation/certification mechanisms, contracting schemes and potential new revenue streams (balancing markets) and R&D development budget at EU level, considering the current standpoint of the hydrogen sector in Europe.

The document is developed by companies involved in hydrogen industry and appears to express somewhat one-sided opinion and using selective reasoning. The document should be linked with WindEurope's position paper Power to X.

The document is relevant for eNeuron project with regard to the hydrogen deployment.

7.15 Document 15: European Energy Storage Technology Development Roadmap towards 2030 (EASE/EERA) [15]

European Energy Storage Technology Development Roadmap towards 2030 (EASE / EERA) describes the need for further energy storage in Europe for the period 2020 - 2030. Great emphasis is placed on electricity storage applications but other forms of storage are mentioned, such as thermal storage etc. Describes also the main stages and the next steps which are necessary for the smooth integration of the various storage technologies in the electricity system in Europe. In addition, the various technologies are analysed with the advantages and disadvantages of each technology, as well as their technical characteristics and application costs. Also, the present roadmap describes the "Market design and policy issues" that need to be addressed by authorities and system operators for the optimal integration of energy storage systems to the European Energy System.

7.16 Document 16: Models of Local Energy Ownership and the Role of Local Energy Communities in Energy Transition in Europe [16]

Following document helps to understand better the concept of a local energy community. In order to reach the decentralization of the energy system, the evolution of the role of the producers and consumers is required. The active participation of consumers could be significant in the development of sustainable and green solutions. This document analyses local energy community initiatives and the actual status in four Countries (Denmark, Germany, Ireland and Greece). Main relevance to eNeuron project is related to the explanation of the main barriers that local energy ownership models could face, socio-economic impacts and strength and weak points of the existing EU legislative that can hinder the development.

7.17 Document 17: 2020 report on the State of the Energy Union pursuant to Regulation (EU) 2018/1999 on Governance of the Energy Union and Climate Action [17]

The object of this report is based on EU's renewed ambition related to the European Green Deal. The report presents the many initiatives that EU and its Member States haves taken during the last months to shape a better Europe.

The following topics are presented in the report:

- The Energy Union (Decarbonisation, Energy efficiency, energy security, internal energy markets, research & innovation and competitiveness)
- Green recovery and a sustainable economy

7.18 Document 18: Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources [18]

The Directive 2018/2001/EU on the promotion of the use of energy from renewable sources makes a substantial revision of the regulatory framework envisaged by directive 2009/28/EC. The Directive, called RED II, is a fundamental part of the set of initiatives and directives, launched with the Clean Energy Package for all Europeans, aimed at making the European Union more competitive in the energy transition and redesigning the profile of the European electricity market. The RED II promotes the diffusion of renewable energies, in general and pays particular attention to the self-consumption of renewable energy. It promotes consumers' empowerment, providing that consumers can become consumers of renewable energy, also being able to produce, store and sell the electricity generated in surplus, both individually and through aggregators, while guaranteeing consumer's rights. The Directive introduces the "Renewable Energy Community (REC)" concept, or rather communities that must have the right to produce, consume, store and sell renewable energy, being also able to exchange, within the same community, the renewable energy produced by them and access all the appropriate electricity markets, directly or through aggregation, in a non-discriminatory way.

The document is very relevant for the eNeuron project, as it is one of the main regulatory elements in force within the European Union, and promotes the diffusion of renewable energies and the concept of REC within the entire Union and Member States.

7.19 Document 19: The role and potential of Power-to-X in 2050 [19]

The document deals with the profitability of Power-to-X technologies on both environmental and economic points of view, taking into account the electricity price variability in different European Countries. Different scenarios have been investigated considering Power-to-H2, Power-to-CH4 and Power-to-Liquids technologies, all of them being the most promising and interconnected one to each other. This latter aspect could be one of the key points for the eNeuron project.

The work is divided in 3 main core topics:

1. Definition of current Power-to-X technologies and benchmark solutions;
2. Overview and forecast of possible case studies;
3. Feasibility study of future case studies.

The main outcomes of the three case studies analysed in this report are related to the comparison between:

- Power-to-H2 vs SMR+CCS;
- Power-to-CH4 vs Biomass-to-CH4;
- Power-to-liquids vs Biomass-to-Liquids.

Not very relevant for eNeuron project because with Power-to-X (to liquids or CH4) technologies are not deployed in the project.

7.20 Document 20: A Hydrogen strategy for a climate-neutral Europe [20]

This document presents a roadmap to establish a full value chain approach for hydrogen economy in Europe; from the production from renewable and low-carbon sources to the development of the required infrastructure and the creation and regulation of the market. Investment agenda, and promoting research and innovation in hydrogen are considered as well.

7.21 Document 21: Hoja de ruta del Hidrógeno: Una respuesta por el hidrógeno renovable [21]

The document establishes the roadmap the Spanish Government intends to follow for the development of green hydrogen in Spain. The document describes the socio-economic benefits the development of green hydrogen might bring to Spain, defines a set of measures of diverse nature the Spanish Government plans to implement so as to foster the development of green hydrogen and sets target installed capacities of electrolysers in Spain and target contributions of hydrogen to the energy demand in the transport and industry sectors in different time horizons (2030 and 2050).

The document is relevant to the goal of Task 2.1 since hydrogen is expected to play a crucial role in multi-vector energy systems across Europe and the roadmap sets the framework for the development of green hydrogen in Spain.

7.22 Document 22: Renewables 2020. Global Status Report [22]

Renewables Global Status Report annual publication is a report with the current status of renewables where energy actors from science, academia, governments, NGOs and industry collaborate (through the global community Renewable Energy Policy Network for the 21st Century - REN21). The highlights related to eNeuron project are that motivates the development of power system flexibility and energy communities, as a feasible measure to extend efficiently the use of renewable energies. This, due to a growing number of jurisdictions directed policies towards ensuring greater integration of variable renewable electricity (VRE) as well as the physical technological improvement of energy devices and the connections between the devices and the electricity grid. Another crucial point for the implementation of the energy communities is that consumer adoption to participate in the decarbonisation process has been growing favourably until today.

7.23 Document 23: Report on Regulatory Frameworks for European Energy Networks 2019 [23]

This report provides a general overview of the regulatory regimes applied in 2019, the required efficiency developments and analyses the overall determination of capital costs in EU Member States, Iceland and Norway. This report also serves as a background paper to CEER (Council of European Energy Regulators) work on incentives, both in a quantitative as well as in a qualitative way. In particular, the characteristics of both TSOs and DSOs in terms of market structure, general framework, rate of return, regulatory asset base and depreciations are discussed in detail for each Country. Anyway, it is difficult (but it's not the scope of the document) to extract general/uniform information for EU.

The report could be interesting for the eNeuron project because it presents the regulatory framework in force in each country, included the ones of the pilots.

7.24 Document 24: World Energy Issues Monitor - 2020 [24]

The document provides a comprehensive high-level overview of the main driving forces and challenges in the energy domain, especially concentrating on critical uncertainties and critical priorities for each country.
The document does not distinguish between EU or none-EU countries, so only relevant countries have been selected. The document provides a summary of national energy overviews for the world's economies, based on selection of countries. The document indicates priorities (under climate-neutral aim by 2050) and uncertainties without clear division between energy vectors, technologies and support schemes.

The present screening concentrated on the EU member states only.

The screening indicated great differences in the level of energy priorities and strategies across Europe, spanning from conventional energy sources as natural gas and nuclear to hydrogen. In addition, some of the countries appear to move in opposite directions e.g., phasing out nuclear power vs. building nuclear power plants.

7.25 Document 25: Electric Vehicle and Power System Integration Key insights and policy messages from four CEM workstreams [25]

The Clean Energy Ministerial (CEM) has gathered key policy messages based on the current experience that are opportunities to the transport road and power system sectors, finding to facilitate the cross-sector collaboration between them. Electric Vehicles (EVs) charging affects both aggregate power demand and distribution systems at the local level, which are impacted by high-power or clustered loads. EV charging flexibility and the use of the batteries to balance a system with flexible demand and power infeed offer great opportunities to optimise power system planning and operation, reaping synergies with VRE generation, eNeuron project can satisfy this field with the analysis to assess local distribution-level impacts and to provide an efficient solution.

7.26 Document 26: Climate Action Plan 2019 [26]

Climate Action Plan 2019 is a strategy document that presents actions for a climate resilient and sustainable development. The alarming impact of GHG (Greenhouse gas) emissions worries the whole earth system, hence instant and sweeping interventions are required. The Paris agreement on climate change obliges different Countries to act in order to reduce the emissions and to ensure a sustainable and low-carbon world. In the following document, Ireland`s targets for 2030 and the ambition for 2050 are presented and explained. In particular, individual targets per each sector (electricity, building, transport, agriculture, enterprise and services, waste) are set out. The document is relevant for eNeuron project as it explains one current climate action plan of one Country in the European Union and supports the development of renewable energy technologies.

7.27 Document 27: Study on energy storage – Contribution to the security of the electricity supply in Europe [27]

The document focuses on energy storage and its contribution to the security of electricity supply. The document is divided into three parts. The first part provides a picture of the existing front- and behind the meter energy storage facilities in the EU (UK was Member State of the EU at the time the document was written). The second part assesses the optimal capacity of a set of flexibility options (pumped-hydro energy storage, batteries, electrolysis and methanation plants) in three different scenarios corresponding to 2030 and 2050. The third part surveys the policies, barriers and best practices in all EU Member States in relation to the deployment of energy storage (including power-to-X technologies).

The document is relevant to the goals of the three Tasks of WP2, as long as energy storage is considered an important part of multi-vector energy systems. The document summarises the policies implemented in the EU Member States as regards the deployment of energy storage, provides a picture of the existing energy storage facilities in the EU Member States and discusses the most important barriers for the deployment of energy storage and its contribution to the security of electricity supply.

7.28 Document 28: ETIP SNET R&I Roadmap 2020-2030 [28]

ETIP SNET Research & Innovation (R&I) Roadmap 2020-2030 describes and analyzes the future energy system and the energy transition required to achieve the energy goals set by the European Union but also to meet the new challenges that arise. The concept of smart electricity networks is the key element for the integration and management of more and more renewable energy sources. In addition, the interaction of different energy vectors plays an important role in the flexibility and reliable management of the system. The roadmap also includes the integration of flexibility solutions in the electricity system as well as the integration of energy storage systems.

7.29 Document 29: PowerFacts Europe 2019 [29]

This ENTSO-E report sheds light on key areas of the European energy transition. The aim is to present this transformation in a clear and concise way.
The report provides data and analysis six key areas combining the traditional energy trilemma (point 1-3) and energy transition (point 4-6):

1. Security of supply - Europe has one of the world's most reliable power grid, and the prime objective is to maintain this. The variability in the power system introduced by increasing amount of solar and wind generation, increase the focus on flexibility.
2. Sustainability - amphibious de-carbonisation targets are committed upon by European leaders.
3. Affordability/Market integration - market coupling
4. Customers - the power system should be opened up to greater customer participation. The progress has started, but more has to be done related to products, incentives and market conditions.
5. Infrastructure development - fundamental to achieve a cost-efficient energy transition, but development of the physical infrastructure is only part of the solution.
6. Cyber physical grid - Emerging digital layer supporting new services and empower customers. Open and transparent data availability is key to enabling the digital grid.

For each are relevant data points have been included in the report, showing the width of issues related to the electricity system transformation.