eneuron

optimising local energy communities

Limitations and shortcomings for optimal use of local resources

Date of document – January/2022 (M15)

D2.3: Limitations and shortcomings for optimal use of local resources
WP2, Task 2.3

Authors: Jesús Fraile-Ardanuy, Giuseppe Conti, Daniel Fernández-Muñoz, Álvaro Gutiérrez, Sandra Castaño, David Jiménez-Bermejo, Juan Ignacio Pérez Díaz, María Corrales, Victor Gago **(UPM)**, Marialaura Di Somma, Amadeo Buonanno, Martina Caliano, Viviana Cigolotti, Valeria Palladino **(ENEA)**, Chrysanthos Charalampous, Christina Papadimitriou **(FOSS)**, Andrés Felipe Cortés Borray, Maider Santos-Mugica, Eduardo García **(TECNALIA)**, Hanna Lewandowska, Iwona Kosmela **(COB)**, Peter Richardson, Alessio Coccia **(EPRI)**, Ata Khavari **(DERLAB)**, Andrei Morch, Hanne Sæle **(SINTEF)**, Gabriele Comodi, Mosè Rossi, Andrea Monforti Ferrario **(UNIVPM)**, Victoria Rebillas Loredo, José Luis Domínguez García, Cristina Corchero García **(IREC)**, Carlos Cardoso **(EDP)**.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

Technical References

Project Acronym	eNeuron
Project Title	greEN Energy hUbs for local integRated energy cOmmunities optimizatioN
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
Project Duration	November 2020 – October 2024 (48 months)

Deliverable No.	D2.3
Dissemination level [1]	PU
Work Package	WP 2 - Limitations and shortcomings for optimal use of local resources
Task	T 2.3 - Identification of limitations and shortcomings, input to specification of demonstration and test programs
Lead beneficiary	10 (UPM)
Contributing beneficiary(ies)	1 (ENEA), 2 (UCY), 4 (IREC), 5 (SINTEF), 6 (TEC), 7 (DERlab), 8 (EPRI), 9 (UNIVPM), 17 (CoB)
Due date of deliverable	31 January 2022
Actual submission date	23 February 2022

[1] PU = Public
PP = Restricted to other programme participants (including the Commission Services)
RE = Restricted to a group specified by the consortium (including the Commission Services)
CO = Confidential, only for members of the consortium (including the Commission Services)

Document history

Version	Date	Beneficiary	Author	Reviewer / Beneficiary
00	15/11/2021	UPM	All consortium	
01	13/12/2021	UPM	All consortium	
02	25/01/2021	UPM	All consortium	
03	08/02/2022	UPM	All consortium	Tecnalia, EPRI
04	17/02/2022	UPM	All consortium	
05	21/02/2022	UPM	All consortium	ENEA, FOSS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

Disclaimer of Warranties

The contents of this publication are the sole responsibility of the eNeuron Consortium (2020-2024) and do not necessarily reflect the opinion of the European Union.

“This project has received funding from the European Union’s Horizon 2020 research and innovation programme under Grant Agreement No 957779”.

This document has been prepared by eNeuron project partners as an account of work carried out within the framework of the EC-GA contract no 957779.

Neither Project Coordinator, nor any signatory party of eNeuron Project Consortium Agreement, nor any person acting on behalf of any of them:

- makes any warranty or representation whatsoever, express or implied,
    - with respect to the use of any information, apparatus, method, process, or similar item disclosed in this document, including merchantability and fitness for a particular purpose, or
    - that such use does not infringe on or interfere with privately owned rights, including any party's intellectual property, or
    - that this document is suitable to any particular user's circumstance; or
- assumes responsibility for any damages or other liability whatsoever (including any consequential damages, even if Project Coordinator or any representative of a signatory party of the eNeuron Project Consortium Agreement, has been advised of the possibility of such damages) resulting from your selection or use of this document or any information, apparatus, method, process, or similar item disclosed in this document.

Executive Summary

This deliverable is the third one in the series of three reports that have been developed in the work package (WP) 2 "Limitations and shortcomings for optimal use of local resources" from the H2020 project eNeuron. The main objective of this deliverable is to identify the main barriers, technical limitations, shortcomings and obstacles which can limit the optimal use of local energy resources.

In this work, several technologies that can be installed in micro-energy hubs and energy hubs structures have been identified and analysed in detail in order to determine any factor that could limit their practical implementation. This analysis has covered 33 different types of technologies, divided into three broad multi-energy groups:

- Generation (thermal, electricity and H_2 production).
- Storage (thermal, electrical and H_2 storage).
- Other complementary technologies that may have a direct impact on the deployment of these local energy resources. In this case, the study has focused on transportation and control systems.

The main technical limitations identified in this work are related to the low efficiency of some of these technologies used in thermal (heat and cool) generation (such as adsorption chillers or air-air heat pumps (HPs)), in distributed electricity generation (such as photovoltaic (PV) cells, wave and tidal generation or fuel cells) and in some energy storage (such as Compressed Air Energy Storage (CAES), Liquid Air Energy Storage (LAES), among others). Hydrogen production, storage and re-electrification has also a low performance.

Another technical barrier that has been found in this analysis is low flexibility. Some of the analysed technologies are designed to operate at constant regimes and have poor behaviour at partial load or have a low dynamic response (e.g., biomass boilers, steam boilers, heat pumps, fuel cells, etc.), reducing their controllability and limiting the number of applications in which they can be used autonomously. The easiest way to overcome this drawback is usually by hybridising these technologies (which operate at constant load) with others that can handle the fast variations in generation/consumption imposed by the control system (e.g., fuel cells are usually hybridised with battery packs in fuel cell electric vehicles-FCEVs).

There are some other technical limitations related to security concerns. Some technologies have explosion hazards due to the use of flammable materials or fuels (i.e., gas boilers, Li-ion batteries, H_2 handling and LAES, where there is a risk of concentration of oxygen and possible subsequent explosion).

Environmental problems due to the production of noise (e.g., steam boilers, Internal Combustion Engine Combined Heat and Power (ICE CHP), geothermal electric generation, back up generators), the emission of green house gasses-GHG (e.g., natural gas boilers, ICE/Turbine CHP, back up generator, CAES, etc.), the content of toxic materials (e.g., PV cell production, phase change material-PCM, fuel cells, different technologies of electrochemical batteries, supercapacitors, etc.), or the impact in wildlife and environmental disturbances (e.g., small hydropower plant, wind generators, wave-tidal generators) are also important limiting factors.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 957779

Other technologies require large space to produce or store energy (e.g., PV, concentrated solar power (CSP), sensible heat energy storage systems or batteries), or they have low energy density (e.g., batteries, flywheel, supercapacitors).

Finally, cost and cost-effectiveness are two of the most important limiting factors which affect several technologies. Most of them are still very expensive, having a high start-up and/or operational costs, particularly those which require civil works (such as small hydropower plants, CAES storage in caverns, etc.) or are installed in very extreme environments, such as wave-tidal generation.

From a technical point of view, not all technologies have the same level of maturity. In some cases, the analysed technology is mature and competitive in the current global market, but in other cases, further efforts are still required to develop this technology and make it competitive in the near future.

The identification of regulatory limitations has been a more complicated process due to the difficulty in identifying legislative barriers at different levels, from limitations at the European level to barriers at the national or local levels.

Considering the work performed in Task 2.1 of this WP, the main regulatory limitations at the European level have been identified and are presented in this deliverable. Additionally, country-specific regulatory limitations have also been analysed and included in Annex I. This analysis has been done in greater detail in those countries where the eNeuron project will install and operate pilot demonstrations, namely Italy, Norway, Portugal and Poland.

After a detailed description of all the encountered technical and regulatory limitations, this document presents a series of potential recommendations for different stakeholders that will help to overcome these barriers.

The main output of this deliverable will be used as input for the specification of the pilots. Once the main technologies to be implemented in these pilots have been defined in the project (in WP5 and WP6) and the main constraints associated with each of these technologies have been identified – that is the scope of this deliverable, it will be possible to anticipate the likely limitations and shortcomings that could affect the real implementation of these pilots.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 957779

Abbreviations and acronyms

Acronym	Meaning	Acronym	Meaning
AC	Alternating Current	**IPC**	Integrated Pollution Control
AFC	Alkaline Fuel Cells	**LAES**	Liquid Air Energy Storage
AFIR	Alternative Fuels Infrastructure Regulation	**LCOE**	Levelized Cost of Energy
aFRR	Automatic Frequency Restoration Reserves	**LCTES**	Latent Cold Thermal Energy Storage
AGC	Automatic Generation Control	**LEC**	Local Energy Communities
AI	Artificial Intelligence	**LHTES**	Latent Heat Thermal Energy Storage
BIPV	Building Integrated Photovoltaic	**LHV**	Low Heating Value
BMS	Battery Management System	**MCFC**	Molten Carbonate Fuel Cells
BRP	Balancing Responsible Party	**MCS**	Megawatt Charging System
BSP	Balancing Service Providers	**mFRR**	Manual Frequency Restoration Reserve
CAES	Compressed Air Energy Storage	**MGT**	Micro Gas Turbine
CAPEX	Capital Expenditure	**OCPP**	Open Charge Point Protocol
CCS	Carbon Capture Storage	**OLTC**	On Load Tap Changer
CEC	Citizen Energy Communities	**OWC**	Oscillating Water Column
CHP	Combined Heat and Power	**P2P**	Peer to Peer
COP	Coefficient of Performance	**PAFC**	Phosphoric Acid Fuel Cells
CSP	Concentrating Solar-Thermal Power	**PAT**	Pump as a Turbine
DC	Direct Current	**PCM**	Phase Change Material
DER	Distributed Energy Resources	**PEMFC**	Polymer Electrolyte Membrane Cells
DHC	District Heat and Cooling	**PHPP**	Pumped-hydro power plant
DHW	Domestic Hot Water	**PMSM**	Permanent Magnet Synchronous Machine
DSO	Distributor System Operator	**PV**	Photovoltaic
EC	Energy Community	**R&D**	Research and Development
ELV	Emission Limit Values	**REC**	Renewable Energy Community
EMF	Electromagnetic Field	**RES**	Renewable Energy Sources
EPA	Environmental Protection Agency	**RR**	Regulating Reserve
ETIP-SNET	European Technology & Innovation Platform - Smart Networks for Energy Transition	**SCTES**	Sensible Cold Thermal Energy Storage
ETS	Emissions Trading Scheme	**SHTES**	Sensible Heat Thermal Energy Storage
EV	Electric Vehicle	**SOC**	State of Charge
FC	Fuel Cell	**SOFC**	Solid Oxide Fuel Cells
GHG	Greenhouse Gas	**TCHCES**	Thermochemical Heat and Cold Energy Storage
GHV	Gross Heating Value	**TEN-T**	Trans-European Transport Network
GIS	Gas Insulated electrical Substation	**TRL**	Technology Readiness Level

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

Acronym	Meaning	Acronym	Meaning
GPDR	General Data Protection Regulation	**UNIDO**	United Nations Industrial Development Organisation
GT	Gas Turbine	**UPS**	Uninterrupted Power Systems
GWP	Global Warning Potential	**UV**	Ultraviolet
HP	Heat Pumps	**V2B**	Vehicle to building
HVAC	Heating, Ventilation and Air Conditioning	**V2G**	Vehicle to grid
ICE	Internal Combustion Engine	**V2H**	Vehicle to home
ICT	Information and Communication Technologies	**WP**	Work Package
IE	Industrial Emissions	**WT**	Wind Turbine

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

Table of content

DISCLAIMER OF WARRANTIES 3
EXECUTIVE SUMMARY 4
ABBREVIATIONS AND ACRONYMS 6
1 INTRODUCTION 11
1.1 ENEURON IN A NUTSHELL 11
1.2 STRUCTURE OF THE DOCUMENT 12
2 METHODOLOGY 13
3 DESCRIPTION OF THE ANALYSED TECHNOLOGIES 16
3.1 GENERATION 16
3.1.1 THERMAL GENERATION 16
3.1.2 DISTRIBUTED ELECTRICITY GENERATION 21
3.1.3 H_2 PRODUCTION 28
3.2 ENERGY STORAGE 31
3.2.1 THERMAL ENERGY STORAGE 31
3.2.2 ELECTRICITY STORAGE 33
3.2.3 H_2 STORAGE 39
3.3 COMPLEMENTARY TECHNOLOGIES 40
3.3.1 MOBILITY 40
3.3.2 CONTROL AND DATA MANAGEMENT AND SECURITY 41
4 IDENTIFIED LIMITATIONS AND SHORTCOMINGS 42
4.1 TECHNICAL LIMITATIONS 42
4.1.1 TECHNICAL LIMITATIONS IN GENERATION 42
4.1.2 TECHNICAL LIMITATIONS IN ENERGY STORAGE 64
4.1.3 MAIN TECHNICAL LIMITATIONS IN COMPLEMENTARY TECHNOLOGIES 72
4.2 REGULATORY-POLICY LIMITATIONS 77
4.2.1 OVERVIEW OF THE MAIN EU REGULATORY POLICIES 77
4.2.2 REGULATORY BARRIERS AT GENERATION LEVEL 78
4.2.3 REGULATORY LIMITATIONS IN ENERGY STORAGE 87
4.2.4 COMPLEMENTARY TECHNOLOGIES OF LOCAL MULTI-VECTOR ENERGY SYSTEMS 91
4.3 SUMMARIZE 94
5 IMPACT ON ENEURON PILOTS 100
5.1 IMPACT ON POLISH PILOT 101
5.2 IMPACT ON NORWEGIAN PILOT 102
5.3 IMPACT ON PORTUGUESE PILOT 103
5.4 IMPACT ON ITALIAN PILOT 105
6 POTENTIAL RECOMENDATIONS 107
6.1 POTENTIAL RECOMMENDATIONS FOR GENERATION 107
6.1.1 THERMAL ENERGY GENERATION 107
6.1.2 DISTRIBUTED ENERGY GENERATION 110

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

6.1.3 H_2 PRODUCTION 112
6.2 POTENTIAL RECOMMENDATIONS FOR ENERGY STORAGE 113
6.2.1 THERMAL ENERGY STORAGE 113
6.2.2 ELECTRIC ENERGY STORAGE 113
6.2.3 H_2 STORAGE 116
6.3 OTHER POTENTIAL RECOMMENDATIONS 116

7 CONCLUSIONS 119

8 REFERENCES 121

ANNEX I 145

AI.1 ITALY 145
AI.1.1 OWNERSHIP AND OPERATION 145
AI.1.2 GRID CONNECTION 146
AI.1.3 ENERGY STORAGE 147
AI.1.4 HYDROGEN 147
AI.1.5 MARKET AND BUSINESS MODELS 148
AI.1.6 SELF CONSUMPTION. ENERGY COMMUNITIES (ECS) 148
AI.1.7 REGULATORY STABILITY 149
AI.2 NORWAY 151
AI.2.1 OWNERSHIP AND OPERATION 151
AI.2.2 GRID CONNECTION 152
AI.2.3 ENERGY STORAGE 152
AI.2.4 HYDROGEN 152
AI.2.5 MARKET AND BUSINESS MODELS 153
AI.2.6 SELF CONSUMPTION. ENERGY COMMUNITIES (ECS) 153
AI.2.7 REGULATORY STABILITY 154
AI.3 POLAND 155
AI.3.1 OWNERSHIP AND OPERATION 155
AI.3.2 GRID CONNECTION 156
AI.3.3 ENERGY STORAGE 156
AI.3.4 HYDROGEN 157
AI.3.5 MARKET AND BUSINESS MODELS 157
AI.3.6 SELF CONSUMPTION. ENERGY COMMUNITIES (ECS) 158
AI.3.7 REGULATORY STABILITY 159
AI.4 PORTUGAL 160
AI.4.1 OWNERSHIP AND OPERATION 160
AI.4.2 GRID CONNECTION 161
AI.4.3 ENERGY STORAGE 161
AI.4.4 HYDROGEN 161
AI.4.5 MARKET AND BUSINESS MODELS 162
AI.4.6 SELF CONSUMPTION. ENERGY COMMUNITIES (ECS) 162
AI.4.7 REGULATORY STABILITY 163
AI.5 CYPRUS 164
AI.5.1 OWNERSHIP AND OPERATION 164
AI.5.2 GRID CONNECTION 165
AI.5.3 ENERGY STORAGE 165
AI.5.4 HYDROGEN 166
AI.5.5 MARKET AND BUSINESS MODELS 166
AI.5.6 SELF CONSUMPTION. ENERGY COMMUNITIES (ECS) 166

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

AI.5.7 Regulatory stability 167
AI.6 Germany 168
AI.6.1 Ownership and operation 168
AI.6.2 Grid connection 169
AI.6.3 Energy Storage 169
AI.6.4 Hydrogen 169
AI.6.5 Market and business models 170
AI.6.6 Self consumption. Energy Communities (ECs) 170
AI.6.7 Regulatory stability 171
AI.7 Ireland 172
AI.7.1 Ownership and operation 172
AI.7.2 Grid connection 172
AI.7.3 Energy Storage 173
AI.7.4 Hydrogen 173
AI.7.5 Market and business models 174
AI.7.6 Self consumption. Energy Communities (ECs) 174
AI.7.7 Regulatory stability 175
AI.8 Spain 176
AI.8.1 Ownership and operation 176
AI.8.2 Grid connection 177
AI.8.3 Energy Storage 178
AI.8.4 Hydrogen 178
AI.8.5 Market and business models 179
AI.8.6 Self consumption. Energy Communities (ECs) 179
AI.8.7 Regulatory stability 180
AI.8.8 Regulatory barriers in the Spanish legislation related to the participation of LECs in the balancing services 181

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

1 Introduction

This deliverable D2.3 ends the series of three reports that were 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 (MS). The next step is to 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 of this activity have been 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 present study.
- D2.2 Technical solutions for multi-carrier integrated systems under the LEC concept: A review (the present document).
- 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 (DER) 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 energy systems in order to optimise their architecture and operation. To ensure both the short- and the long-term sustainability of this new energy paradigm and thus support effective implementation and deployment, economic and environmental aspects will be considered 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

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 957779

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 Technology Readiness Level (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, 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

Following the Executive Summary and the list of acronyms and abbreviations, this document is structured in seven main parts. The first section provides an introduction of the current Work Package 2 (WP2) and Task 2.3. Section 2 describes the methodology for the development of this task, describing in detail the steps followed for the achievement of the planned goals. Section 3 presents a description of the different technologies that have been analysed in this task, seeking to identify the main barriers that may limit the use of local energy resources. Since many of these limitations and shortcomings found are technical, a brief description of the operating principles of the analysed technologies has been included beforehand.

The fourth section constitutes the main core of the work carried out in this task. This section identifies the main technical and regulatory constraints and shortcomings that may affect the deployment of local energy resources. The analysis is carried out in three categories: **generation**, both thermal and electrical, and hydrogen production; **storage**, both thermal and electrical, and hydrogen storage; and other **complementary technologies** that may affect local energy consumption, such as the electrification of transport.

The fifth section analyses the possible impact of these limitations on the four eNeuron pilots in order to identify at an early stage the possible barriers that may be encountered before the pilots are rolled out for real-world testing in WP6.

The sixth section presents potential recommendations to be considered to overcome the identified barriers and constraints. The current document ends with a conclusion section.

2 Methodology

For the purpose of identifying the existing limitations and shortcomings which may prevent the intended transformation of the European energy landscape towards local multi-vector energy systems, a methodology based on the one developed for T2.1 was utilised. The work has been structured in this way:

Firstly, based on the crossed analysis performed in the previous tasks of this WP (*Task 2.1 Preliminary scoping of the study based on the Pan-European de-carbonisation targets, regulatory acts and roadmaps* and *T2.2 Status for the deployment of integrated local multi-vector energy systems and corresponding enabling technologies and solutions*), different technologies were identified to be analysed in detail.

Within these technologies to be analysed, there were two sets; those technologies which were initially described in the previous deliverable D2.2 [1] and other additional technologies that could be used in very specific application energy hubs (such as wave/tidal electric generation or pumped-hydro power plants).

It is important to highlight that not all these technologies are applicable to all possible scenarios that will be covered in the eNeuron project, but they are widely applicable and cover from small domestic micro-energy hubs to much larger multi-energy systems, such as energy island hubs. As a result of this first assessment, it was determined among all the partners to focus the limitation analysis on 33 different types of enabling technologies, which support the interaction between energy carriers and networks. Table 1 presents the complete list of the different technologies to be analysed.

Table 1. List of the technologies analysed

VECTOR GENERATION		
Num. of Technolog.	Category	**Technology**
1	**Thermal Generation**	Heat pump
2		Hybrid heat pump
3		Natural gas boiler
4		Electric boiler
5		Micro-CHP (including electricity generation)
6		CHP (including electricity generation)
7		Steam boilers
8		Adsorption chiller
9		Biomass boiler
10	**Local Electricity Generation**	PV
11		Wind
12		MicroHydro / Hydro
13		Wave/Tidal

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

VECTOR GENERATION		
Num. of Technolog.	Category	Technology
14		Solar Thermal (CSP)
15		Geothermal
16		Backup diesel generator
17		Fuel Cells (electricity/heat)
18	**H2 Gen.**	Electrolyzer
19	**Electricity Storage**	Batteries (including EV as Vehicle to Building-V2B and V2G)
20		Supercap
21		Flywheel
22		Compressed Air Energy Storage (CAES)
23		Liquid Air Energy Storage (LAES)
24		Pumped-Hydro power plants
25	**Thermal/Cold storage**	Sensible heat
26		Latent heat
27		Thermochemical heat
28		Cold storage
29	**H2 Storage**	H2 storage
30	**Mobility**	EVs and their charging infrastructure
31		Heavy vehicles (vans, buses, trucks)
32		Electric Ferries / Boats
33	**Control**	Research /Commercial platforms

Each technology has been addressed by considering the following information:

- A table with the main limitations/shortcomings identified.
- A brief summary of these limitations/shortcomings.
- Identification of the type of encountered limitations, focusing on three fundamental issues: technical limitations, regulatory limitations and other additional limitations, such as economic limitations, environmental limitations, etc.
- Identification of the geographical scope of the limitation (whether this limitation affects at European level or only to a specific EU country).
- An analysis of the potential impact of these limitations on the 4 eNeuron pilots (Italian, Norwegian, Polish and Portuguese pilots).
- A detailed description of the identified limitations.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

Different types of documents were selected for the screening: technical limitations were evaluated from scientific publications, while the regulatory limitations were extracted by documents issued by several stakeholders such as European Commission (mainly, Directives and Regulations), National Governmental organisations and National Regulating Authorities, International Interest Organizations (such as WindEurope, European Heat Pump Association, etc.) and other worldwide international organisations.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

3 Description of the analysed technologies

In this section, a brief description of the different technologies which have been analysed in this task is presented. Although some of these technologies have been previously described in more detail in the deliverable D2.2 [1] and other technologies will be analysed in detal in a subsequent deliverable (D3.2) within WP3, the inclusion of these short descriptions in this document is intended for completeness to facilitate further understanding of the (mainly technical) limitations encountered in this analysis.

The technologies associated with the local energy resources have been grouped in three different sets:

- **Generation technologies** cover thermal generation, electricity generation and hydrogen production
- **Storage technologies** cover different types of thermal and electrical storage systems and also H_2 storage
- **Complementary technologies** which have a fundamental impact on the energy consumption of local energy communities has also been included

3.1 Generation

This section briefly describes the operation of the different technologies associated with the thermal generation, electric power generation, and H_2 production commonly used in micro-energy hubs and energy hubs.

3.1.1 Thermal Generation

Micro-energy hubs and energy hubs are key elements in the future European energy transition, as they generate, distribute and consume energy collectively, using renewable energies whenever possible.

An important part of the total energy consumed in the buildings of these communities is thermal loads required to provide comfortable conditions and acceptable indoor air quality for their occupants through different applications such as heating, cooling and domestic hot water (DHW) production. This thermal load can be produced by different technologies described below:

3.1.1.1 Boilers

A boiler is a closed vessel in which water or another liquid is heated and used in heating applications. Boilers are commonly used in domestic applications to produce DHW and heating in buildings, or steam for industrial processes. The type of boiler can differ based on the energy source used for combustion.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

Electric boilers. Electric boilers consist of electric resistors (shown in Figure 1), which are heating elements that transform the electric energy into thermal energy. Common applications of these devices include space heating, water heating, and industrial processes. The practise of using electricity for heating is becoming increasingly popular in both residential and public buildings. Although electric heating generally costs more than the energy obtained from the combustion of a fuel, the convenience, cleanliness, and reduced space needs of electric heat often justify its use [2].

Furthermore, electrical boilers are very flexible and can be used in demand response programs.

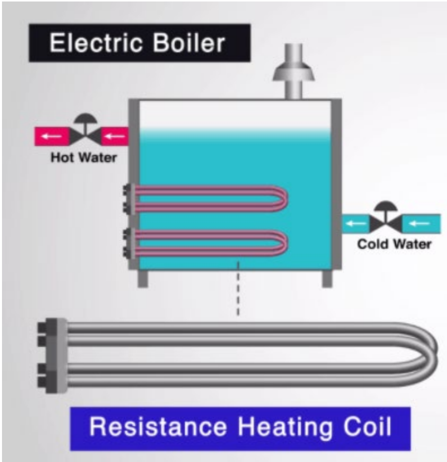

Figure 1. Electric boiler [3]

Biomass boilers are a technology to produce thermal energy from the combustion of biomass fuels (see Figure 2). This biomass fuel (e.g., wood, pellet, agricultural and manufacturing waste etc.) usually has a high moisture content, which leads to low boiler efficiency. The boiler efficiency can be increased by using heat recovery devices to decrease the temperature of flue gas before it is exhausted from the boiler. The heat recovery devices typically used in a biomass boiler are the following: economizer that increases feed water temperature, air heater that increases air temperature before combustion, and flue gas dryer that decreases the moisture content of fuel [4].

Figure 2. Biomass boiler [5]

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

Natural gas boilers are fuelled by natural gas burning in a combustion chamber to heat water to a temperature around 70°C. This hot water is then pumped through pipes and radiators to warm buildings and also pumped directly to showers and taps to provide DHW. These boilers can be connected to on-grid gas infrastructure or bulk LPG stored on the side. Additionally, these boilers can include a water tank to store hot water for future usage.

Natural gas boilers are a source of considerable NOx emissions which are harmful for the environment. As a result, the number of natural gas boilers installations is expected to fall from 30% (contribution of the total number of heating equipment stock) to less than 0.5% in 2050 as shown Figure 3). To be precise, sales of gas boilers will fall by more than 40% from current levels by 2030 and by 90% by 2050.

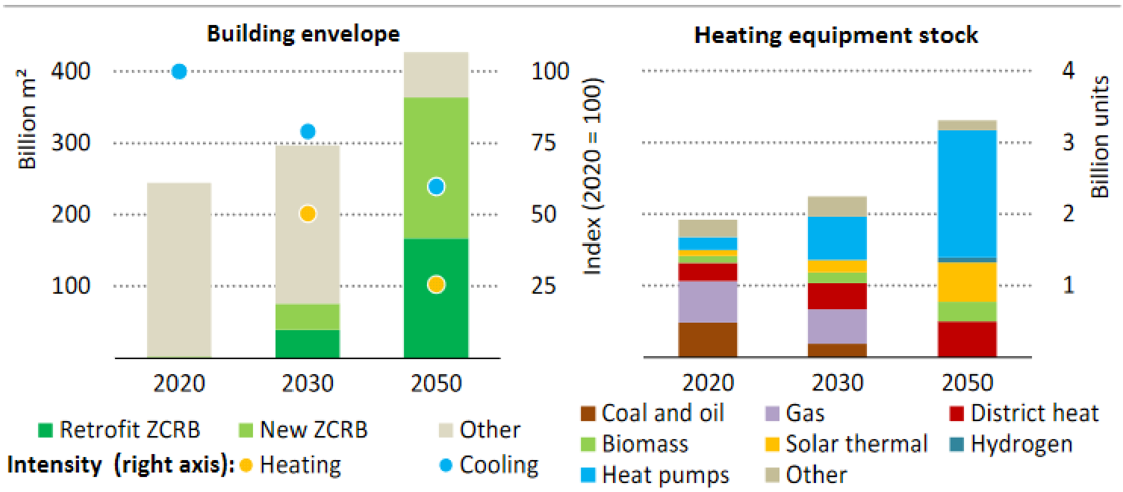

Figure 3.Global building and heating equipment stock by type and useful space heating and cooling demand intensity change [6]

Steam boilers produce steam by applying heat energy to water. Although the definitions are somewhat flexible, it can be said that older steam generators were commonly termed boilers and worked at low to medium pressure (7–2,000 kPa or 1–290 psi). At pressures above this, it is more usual to speak of a steam generator [7].

Steam boilers are used in those applications where heat cannot be transferred directly to the desired destination. The heat is often obtained from a cogeneration plant burning fossil fuels (such as oil or natural gas) or biomass. In heat-only boiler stations, other technologies can be used, such as geothermal heating or heat pumps. Even the heat waste from nuclear power electricity generation can be used to generate steam in district heating applications.

The generated steam is then distributed by insulated pipelines to the final customers. The reason behind the use of steam is its high mobility rate and ability to carry high amounts of energy with it. Unlike water, steam moves faster and needs no external propelling force to move from A to B within a pipe [8].

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

The use of steam boilers in HVAC systems include space and water heating, cooling, sanitation, cooking, waste energy utilization. Fire-tube boilers are used to warm the air, which is transferred to the rooms of a house or a warehouse. Many big cities, like New York, run on steam.

3.1.1.2 Heat pumps

A heat pump (HP) is a device that extracts thermal energy from a low -temperature source (such as the outside air or underground layers) and transfers it to a higher-temperature sink (such as the heated indoors of a building).

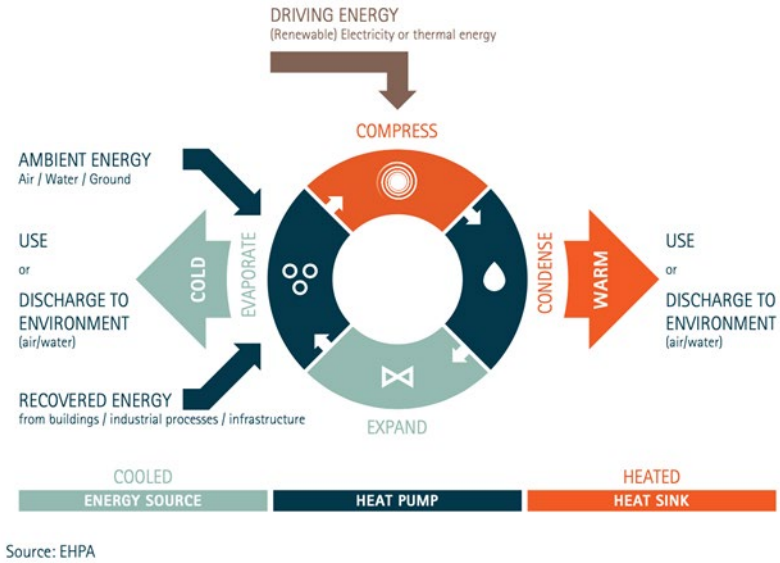

Figure 4. Heat pump operational diagram [9]

The HP operational process diagram is shown in Figure 4. The HP has four main components: an evaporator, a compressor, a condenser, and an expansion device. It essentially operates like a refrigerator, where a mechanical heat pump performs compression and expansion of a fluid, or 'refrigerant'. The evaporator is the heat exchanger between the low-temperature heat source and the refrigerant.

The refrigerant enters the evaporator as a low-pressure liquid, and the outside air/waste heat source (from the underground layers) evaporates the refrigerant. The refrigerant leaves the evaporator as a low-pressure gas, which then enters the compressor, where it is compressed. The compression process turns the cool, low-pressure gas from the evaporator into a hot, high-pressure gas. This gas enters the condenser, which is another heat exchanger that serves to deliver this heat to the consumer at a higher temperature level. Electric energy is required to drive the compressor, and this energy is added to the heat that is available in the condenser [10].

Heat pumps are classified based on the source of heat. It is possible to distinguish three main types of HPs:

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

- **Air Source HPs** use outside/indoor or exhaust air as energy sources.
- **Ground Source (or Geothermal) HPs** use energy from the underground layers, extracted via a closed-loop horizontal or vertical collector.
- **Water Source HPs**, which, in principle, are identical to ground source units that use water directly. These HPs can be connected to aquifers, rivers, lakes or the sea, and to wastewater, cooling water from industrial systems, or a district heating system.

Other types of HPs consist of a combination of these three main types [9] [10] [11], and are described in the following subsection.

3.1.1.3 Hybrid heat pumps

Hybrid devices are composed of two systems: a heat pump, which is predominantly used for meeting the heating demand, and a gas boiler that covers peak demand during winter days. During these periods, the efficiency of the HP is considerably reduced due to unfavourable ambient conditions and/or the HP does not have the capacity to cover the entire demand.

Unlike conventional HP systems, hybrid HPs do not require buildings to have a minimum requirement for insulation. However, the higher the insulation and thermal efficiency of the dwellings, the higher the percentage of demand covered by the HP.

In the case of DHW, it is usually the gas boiler that covers the entire demand, although it is also possible to find systems with an air-to-water heat pump that covers the DHW demand.

For best overall system performance, HPs should be used with a low-temperature heating system of 45 to 55°C, such as underfloor heating, low-temperature radiators or wall heating, as opposed to conventional heating systems, which typically work with temperatures between 60 and 80°C.

The main advantage of hybrid systems is that the installed capacity is considerably reduced compared to an all-electric system and, therefore, also the cost of the installation. In addition, peaks and overloads in the electricity grid are also avoided.

3.1.1.4 Combined Heat and Power (CHP)

Combined heat and power (CHP) technology represents an efficient approach to generating electric power and thermal energy from a single fuel source by using a prime mover such as internal combustion engines (ICE), micro gas turbines (MGT), gas turbines (GT), and fuel cells (FC), which represent the most used options in the context of local integrated energy systems. For more details, please refer to D2.2 [1].

3.1.1.5 Adsorption chiller

Although they are not yet competitive comparted to the traditional vapor compression cooling systems, adsorption refrigeration technology has been developing in recent years, due to its quiet, non-corrosive and environmentally friendly operation.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

An adsorption cycle for refrigeration does not use any mechanical energy, but only thermal energy, using a thermal compressor operating with heat input instead of conventional compressors. These chillers use water as the refrigerant and silica gel as adsorption material, having four chambers that operate at nearly a full vacuum.

The water goes through an evaporator, two adsorption heat exchangers, and a condenser cycle, as shown in Figure 5. This cooling cycle is driven by the evaporation and condensation of the water rather than electricity. There is a small electrical consumption in the unit for pumping the water.

The silica gel creates an extremely low humidity condition inside the unit that causes the water refrigerant to evaporate at a low temperature. This process is further helped by keeping the atmospheric pressure inside the adsorption chiller low to further reduce the evaporation point of the water. These devices work using an inlet hot water temperature of around 65°C to 100°C [12].

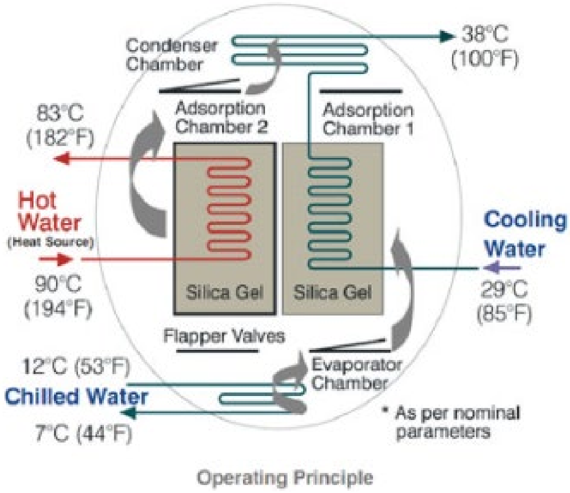

Figure 5. Adsorption chiller scheme [13]

This equipment is ideal to be combined with cogeneration systems, where there is a heat source available, and it has a very low energy consumption (most of it comes from the electric pump) [14].

Adsorption chillers provide an energy-efficient alternative to conventional refrigeration and air conditioning. The energy used to drive the cooling system comes from water warmed by waste heat, such as exhaust or steam from industrial processes, or heat directly generated from solar collectors or other devices. The intensive development of adsorption cooling technology in recent years is driven by the growing public interest in green energy sources. Unfortunately, there are technological and economic impediments to the widespread adoption of adsorption chillers, as will be discussed in subsection 4.1.1.1.4 of this document.

3.1.2 Distributed Electricity Generation

The current electric power system is a complex network of different types of electrical components used to generate, transmit and use electricity. This electricity is generated at large centralized power

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

plants located very far away from where it is consumed, requiring a large economic investment in high voltage infrastructures. Additionally, the energy transmission over these long distances generates power losses, with overall losses between the power plants and the consumers in the range of 8-15%.

On the contrary, local distributed electricity generation reduces these transmission losses and extends the life of the existing transmission-distribution infrastructure by bringing the generation closer to consumption. Additionally, distributed generation creates electric systems more resilient to both natural disasters (such as hurricanes, floods, etc.) and potential attacks on the electric grid. This section presents a brief description of the main technologies used in local electricity generation.

3.1.2.1 Photovoltaic (PV) systems

Solar photovoltaic (PV) panels are composed of cells containing silicon material to convert solar radiation into electricity. PV cells have two layers of semiconductor materials (p-n junction), and when they are illuminated by the sunlight, the electric field across the junction causes electricity to flow, generating Direct Current (DC). To boost the power output, individual PV cells are connected together, forming larger units known as modules. These modules can also be connected to form arrays, meeting almost any power requirements. Inverters convert the DC electricity generated by the PV modules into Alternating Current (AC) electricity,which can be used to power appliances within buildings or can be connected to the main electric grid.

In some other applications, PV systems operate autonomously (off-grid) without needing a connection to the main grid. In this case, these systems typically require a battery pack to store the excess energy generated by the PV panels and deliver it when needed. Also, a charging controller is used to supervise the charging/discharging processes, avoiding possible damages due to overcharging/over-discharging the battery.

3.1.2.2 Wind power generation

Wind energy can be converted into electrical energy using wind turbine technology. Several different wind turbine technologies exist and can be either vertical or horizontal in orientation. The horizontal layout is the most common configuration for large wind turbines whereas for low power applications, the share is more balanced. Another classification is made depending on the generation capacity of a turbine, which is mainly affected by the blade size. Table 2 shows the different classifications of wind turbine according to rated power output.

Table 2. Types of Wind Turbines (WT)

Wind Tubine	Sub-division	Rated Power
Small Wind Turbines	Pico-Wind	<1 kW
	Micro-Wind	1 kW – 7 kW
	Mini-Wind	7 kW – 50 kW
	Small-Wind	50 kW – 100 kW
Utility Scale Wind Turbines	Medium Wind	100 kW – 1 MW
	Large Wind	>1 MW

Examples of different wind turbine models for isolated applications, such as onboard ships, farms, as well as large power plants or building-integrated, are shown in Figure 6.

Typically, small wind turbines have little or no control capability, reducing their ability to provide services to the grid.

Figure 6. Examples of different wind turbine applications

3.1.2.3 Small-scale hydropower

Small-scale hydropower is defined by the United Nations Industrial Development Organisation (UNIDO) as hydroelectric power stations with a capacity of less than 10 MW. In addition, the category includes the following classification: small – up to 10 MW, mini – less than 1 MW, micro – less than 100 kW and pico – less than 5 kW [15]. It is typically developed in areas with suitable landscapes such as in Italy, Portugal, Spain, Norway, Austria and Switzerland.

Small-scale hydropower is an important energy source, especially in countries with available resources and favourable landscape conditions.

Smaller "run-of-river" installations utilise the natural downward flow of rivers, where a part of a river's water is diverted to a channel, pipeline, or pressurised pipeline (runner) that delivers it to a waterwheel or turbine. Installations in mountain or areas with considerable height differences (so-called head[1]) normally have a water reservoir and water pipes (runners) delivering water to the turbine.

---

[1] Head is the vertical distance between the upper and lower water levels of a hydro system, and it is usually measured in metres or units of pressure. Head also is a function of the characteristics of the channel or pipe through which water flows.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

There are several turbine types, which are used [16]:

- Pelton turbine for higher heads (50-800 m) and small flows.
- Francis turbine for medium heads (15-300 m) and medium flows.
- Kaplan turbine for low heads (1-40 m) and high flow rates.

Normally the output from the small-scale hydropower is not dispatchable but can vary according to the local seasonal water flow and environmental limitations (e.g., required least water flow). Small-scale hydropower normally feeds electricity into the distribution network.

Much smaller hydropower facilities are also possible at the village or building levels. In these installations, pico-turbines and electric generators are installed in the existing water infrastructures (see Figure 7).

Figure 7. Conduit pico hydro power generation in existing water infrastructure [17]

3.1.2.4 Wave and tidal energy generation

Wave energy converters obtain energy from the kinetic and potential energy associated with ocean waves or from wave motion [18], [19]. Unlike other renewable energy systems, there is a wide variety of wave energy technologies, but none of them have demonstrated a clear higher performance compared to others.

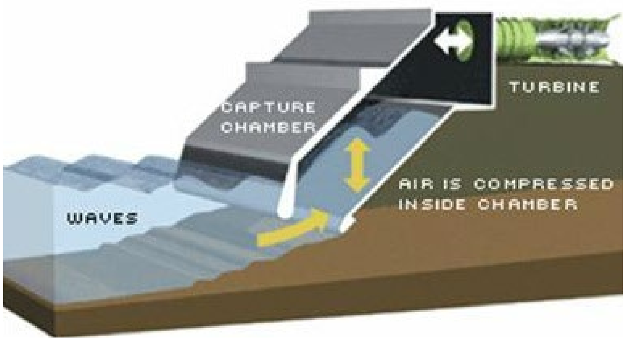

Figure 8. Oscillating Water Column (OWC) technology [20]

One of the most promising technology is the Oscillating Water Column (OWC), in which the energy is extracted from pressure variation caused by waves inside a chamber (see Figure 8). OWC technology can be used onshore, in fixed structures on the coast, or floating.

A typical wave energy plant will consist of multiple small floating devices connected with dynamic cables between them and a static cable that transmits the electricity to the shore.

Tidal energy generation is the technology that obtains energy from tidal currents or tides which are produced from the gravitational pull from both the moon and the sun, which pulls water upwards, while the Earth's rotational and gravitational power pulls water down, thus creating high and low tides [21]. A tidal energy converter normally obtains the energy when the water goes through a turbine or tidal fence [18], [19].

3.1.2.5 Concentrating solar-thermal power (CSP)

A concentrating solar-thermal power plant is a large power plant that uses a mirror configuration to concentrate the sunlight onto a receiver, which contains a high-temperature fluid that stores heat. This heat can be used to generate steam to drive a steam turbine and an alternator producing electrical power, or it can be used directly as process heat for heavy industries to produce steel, cement, etc. [22] [23].

There are four types of CSP technologies currently available in the market [28]:

- **Power Tower Systems.** This system uses several sun-tracking mirrors (heliostats) to focus the sunlight onto a receiver installed at the top of a central tower. A heat transfer fluid, heated in this receiver up to around 600°C, is used to generate steam, which is then used in a conventional turbine-generator to produce electrical power (see Figure 9).
- **Parabolic trough CSP system.** In this system, the sun's energy is concentrated by utilising parabolically curved, trough-shaped reflectors to reflect sunlight onto a receiver pipe – the heat absorber tube – running along about a meter above the curved surface of the mirrors, as shown in Figure 10. The temperature of the heat transfer fluid (usually thermal oil) flowing through the pipe is increased from 293°C to 393°C, and the thermal energy is used to produce steam and to generate electricity in a conventional steam turbine- generator system.
- **Linear Fresnel CSP system**. In this power plant, a linear concentrating collector field consists of a large number of collectors in parallel rows. These rows are typically aligned in a north-south orientation to maximize annual and summer energy collection. The mirrors are laid flat on the ground and reflect the sunlight to the pipe above, as shown in Figure 11. These collectors heat up a fluid which is used to produce steam and generate electricity in a conventional steam turbine-generator system.
- **Parabolic Dish CSP system**. This CSP system consists of a parabolic-shaped point focus concentrator in the form of a dish that reflects sunlight onto a receiver mounted at the focal point (see Figure 12). These concentrators are mounted on a structure with a two-axis tracking system to follow the sun. The collected heat is typically utilized directly by a heat engine mounted on the receiver moving with the dish structure.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

Figure 9. CSP Power Tower Systems [24]

Figure 10. Parabolic trough CSP system [25]

Figure 11. Linear Fresnel CSP system [26]

Figure 12. Parabolic Dish CSP system [27]

Solar thermal power stations is a renewable source of energy which can operate round the clock, (storing thermal energy in the insulated molten salt tanks and being used at any other time to produce electricity during the night), but also have some important drawbacks as well [29] [30]. These limitations will be described in subsection 4.1.1.2.5.

3.1.2.6 Geothermal electricity generation

Geothermal energy is defined as the energy stored in the form of heat beneath the surface of solid earth [31]. Geothermal energy can be utilised also for electricity generation through the use of steam produced from geothermal reservoirs.

There are three geothermal power plant technologies being used to convert hydrothermal fluids to electricity—dry steam, flash steam and binary cycle (see Figure 13). The type of conversion used depends on the state of the fluid (steam or water) and its temperature.

- **Dry steam plants** use hydrothermal fluids that are primarily steam. The steam travels directly to a turbine, which drives a generator that produces electricity.
- **Flash steam power plant** uses fluid at temperatures greater than 182°C. It is then pumped under high pressure into a tank at the surface held at a much lower pressure, causing some of the fluid to rapidly vaporize, or "flash." The vapour is then expanded in a turbine, which drives a generator.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

Binary cycle power plants use geothermal fluid to heat up, through a heat exchanger, a closed-loop system. The heat from the geothermal fluid causes the secondary fluid to flash to vapour, which then drives the turbines and subsequently, the generators [32].

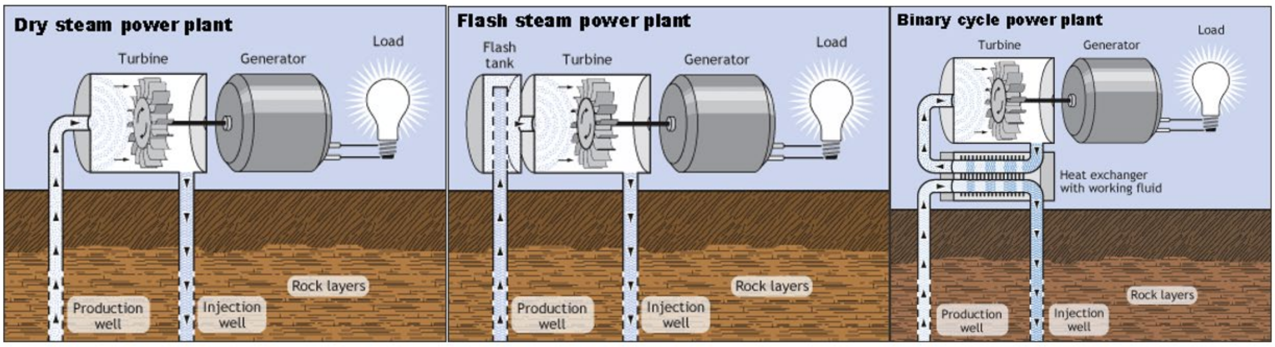

Figure 13. Geothermal power plant technologies [32]

3.1.2.7 Backup generators

A backup generator is a device that can provide instantaneous and uninterruptible power. Backup generators typically utilize an ICE and electric generator to generate electrical energy [33] and are usually fed by fossil fuels (diesel or natural gas). These types of technologies are usually used to meet the electricity demand in isolated or off-grid systems, or function as a backup source of electricity for critical consumers, e.g. hospitals, airports, etc.

3.1.2.8 Fuel cells

A fuel cell is a device that generates electricity through an electrochemical reaction, not combustion. In a fuel cell, hydrogen and oxygen are combined to generate electricity, heat, and water. This device is composed by an anode, a cathode and an electrolyte membrane, as it is shown in Figure 14. Hydrogen is injected through the anode and a catalyst splits the hydrogen molecules into protons and electrons. The protons pass through the porous electrolyte membrane, while electrons are forced to move through an external circuit, generating an electric current and excess heat. At the cathode, these protons and electrons are combined with oxygen to produce water. As there are no moving parts, these devices are very reliable and quiet.

Stationary fuel cells are a distributed generation technology, i.e., they produce power and heat at the site of the consumers and for the purpose of immediate energy supply. The produced electricity can be used to cover the customers' own demand or can be injected into the electricity grid and sold. The main applications in Europe are Micro-CHP for single households up to small residential or commercial buildings, using hydrogen, biogas, natural gas or other gaseous hydrocarbons to produce heat and electricity (Figure 14).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

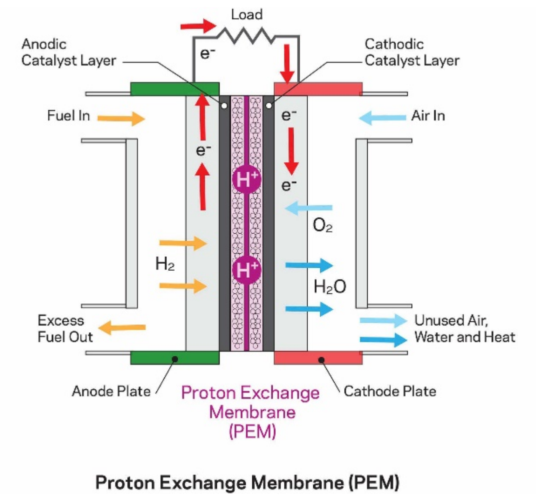

Figure 14. Fuell Cell [34]

3.1.3 H_2 Production

Hydrogen is an energy carrier and not a source of energy, however it can be produced from a wide variety of energy sources (see Figure 15). Currently, hydrogen is primarily produced by reforming hydrocarbon fuels such as natural gas (predominant method), crude oil, coal and alcohol. The process includes conversion of these materials to hydrogen with water vapour, carbon monoxide and carbon dioxide as common by-products of this process.

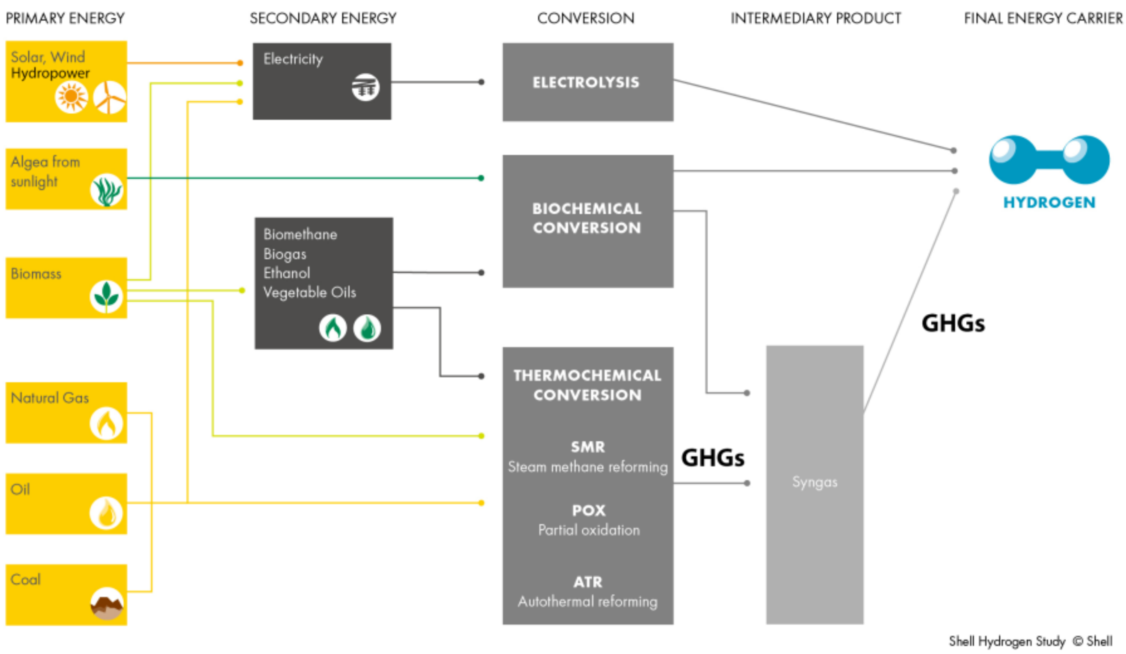

Figure 15. Diagram showing the different origins and steps to produce hydrogen [35]

Hydrogen production pathways can be categorised into various processes [36]:

- Electrolysis of water - This process splits water into hydrogen and oxygen.
- Biochemical conversion - using micro-organisms or through biomass (currently negligible).
- Thermochemical conversion - reforming of fossil hydrocarbons (usually natural gas). In addition to the raw material, the reforming requires an oxidant that supplies the necessary oxygen, providing three basic methods:
  - Steam Methane Reforming (SMR)
  - Partial Oxidation (POX)
  - Auto Thermal Reforming (ATR).

Hydrogen can be produced from fossil fuels such as natural gas and coal, biomass, nuclear energy, and renewable energy sources such as wind, solar, geothermal and hydroelectric energy. Each of these production pathways are associated with differnet levels of emissions, based on the technology and source of energy source. The diversity of possible sources of energy supply for hydrogen production is the most important reason why hydrogen is such a promising energy carrier.

"Electricity-based hydrogen" means hydrogen produced by the electrolysis of water (in an electrolytic cell supplied with electricity), regardless of the source of the electricity. For electricity-based hydrogen production, the amount of GHG emissions in the full life cycle depends on how the electricity is generated.

"Renewable hydrogen" means hydrogen produced by the electrolysis of water (in an electrolytic cell supplied with electricity) and by the use of electricity derived from renewable sources. The GHG emissions during the full life cycle of renewable hydrogen production are almost zero [37].

In a low-carbon energy future, hydrogen offers new pathways to maximise renewable energy utilization [38].

The production of hydrogen, which is based on reforming of natural gas or other hydrocarbons with emitting CO_2 into the atmosphere, is commonly called "grey hydrogen". A similar process with the application of Carbon Capture Storage (CCS) is commonly called "blue hydrogen", and renewable energy-based is called "green hydrogen".

Broadly speaking, hydrogen can contribute to a resilient, sustainable energy future in two ways:
- Existing applications of hydrogen can use hydrogen produced using alternative, cleaner (greener) production methods and from a more diverse set of energy sources.
- Hydrogen can be used in a wide range of new applications as an alternative to current fuels and inputs, or as a complement to the greater use of electricity in these applications. In these cases, hydrogen can be used in its pure form or converted to hydrogen-based fuels, including synthetic methane, synthetic liquid fuels, ammonia and methanol.

Hydrogen can help to lower the cost of electrification, allowing hard-to-electrify sectors such as industrial heat, transportation(e.g., cars, trucks), trains (where renewable hydrogen can be used a s feedstock in fuel cells) or as a feedstock for synthetic fuels for ships and aeroplanes.

Moreover, hydrogen can also be used to store the excess of renewable energy production or for the transportation of this renewable energy using the current natural gas infrastructure. Hydrogen is

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement N° 957779

currently considered to be one of the key enabling technologies allowing future large-scale and long-term storage of renewable electricity production through the now well established Power-to-Gas concept.

3.1.3.1 Electrolysers

An electrolyser is a device which uses electricity to split water into its components, i.e., hydrogen and oxygen. The anode and cathode are typically separated by a membrane, as is shown in Figure 16.

An alternative to reforming from natural gas for hydrogen production is water electrolysis, which involves separating water into hydrogen and oxygen by passing electricity through an electrolyte. The electrolyser uses DC power and two noble-coated electrodes separated by an electrolyte.

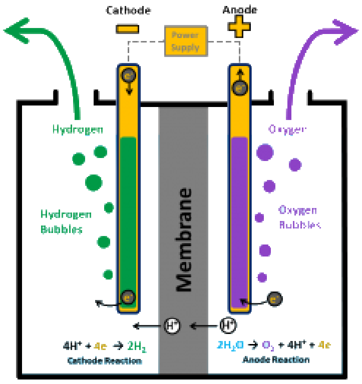

Figure 16. Electrolyser [39]

The following types of electrolysers are the most widespread:

- **Alkaline electrolysis** (AE), is the most mature electrolyser technology currently available on the market.
- **Proton Exchange Membrane** (PEM) works at high current density, reducing operating costs and requiring less area (as it uses solid electrolytes) and it is more sustainable compared to AE.
- **Anion-exchange membrane** (AEM) is a new technology on the market, which is a combination of PEM and alkaline electrolyser.

These electrolyser types vary in chemical composition and temperature, making them applicable in different environments.

Electrolysers offer a flexible load that can provide low-cost balancing services (up and down) to the power system while producing hydrogen for mobility applications, industrial uses, or injection into the gas grid. The built-in storage capacity of downstream sectors (gas infrastructure, hydrogen supply chain etc.) can be used as a buffer to adjust hydrogen production (and hence electricity consumption) in real-time depending on the needs of the power system [38] [40] [41].

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

3.2 Energy Storage

Energy consumption, whether thermal or electrical, can be time-decoupled from generation, storing by excess energy and using it later on, increasing the flexibility in local multi-energy systems.

3.2.1 Thermal energy storage

Additionally to electric storage, thermal storage is also becoming very important at the European level. Currently, heat storage is widely used in the water-based system for domestic applications and for that reason, thermal energy storage is the largest single energy storage application in Europe [42].

Thermal energy storage systems, in general, can play a fundamental role in improving the efficiency and reliability of energy systems when heat supply and heat demand do not match in time or space. Typical thermal storage applications concern the storage of solar energy, the heat recovery in industrial processes and power systems, and the operation optimization of industrial and residential poly-generation systems.

In recent years, due to the electrification of air conditioning systems, distributed thermal storage systems are being increasingly adopted in the development of demand-side management programs, as they allow the peak demand management by the load shifting of the electricity demand for air conditioning.

In CHP district networks, thermal storage can be much more cost-effective than the direct storage of electricity if the CHP system is operated according to the electricity demand [43].

There are currently three main technologies for thermal energy storage.

3.2.1.1 Sensible Heat and Cold Energy Storage

Sensible Heat Thermal Energy Storage (SHTES) and Sensible Cold Thermal Energy Storage (SCTES) systems allow absorbing and releasing thermal energy (heat/cold) due to the variation of the temperature of a storage medium that can be liquid (water, oil) or solid (rocks, sand, soil, etc.), without a phase transition. For SHTES, the stored energy is proportional to the temperature difference of the used materials. The higher the storage medium temperature, the higher the amount of accumulated thermal energy (heat). Similarly, for SCTES, the lower the storage medium temperature, the higher the amount of accumulated thermal energy (cold). They are typically composed of a cylindrical storage tank filled with the storage medium but also include lake and water basins. These ones are typically used for seasonal thermal energy storage.

SHTES and SCTES are generally the most economical and simplest thermal energy storage systems to be designed and built compared with the other two available technologies for thermal energy storage (latent and thermochemical thermal energy storage systems).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

3.2.1.2 Latent Heat and Cold Energy Storage

Latent Heat Thermal Energy Storage (LHTES) and Latent Cold Thermal Energy Storage (LCTES) systems are based on the absorption and release of heat when a phase change material (PCM) undergoes a phase transition. There are many materials that are capable of storing a large amount of thermal energy when changing state. These materials that store latent heat energy are called PCM (Phase Change Material). They have the advantage of higher thermal storage densities compared to conventional sensible heat storage systems and of absorbing and releasing thermal energy at a nearly constant temperature.

The change of state is a process that occurs with the absorption of heat (endothermic). In the most common phase change (solid-liquid) case, the material begins its process of state change and energy storage when it reaches its melting temperature. Until the melting process is complete, its temperature remains almost constant. Change-of-state cycles are reversible and depend on whether the temperature to which the material is subjected is lower or higher than its change-of-state temperature.

LHTES-LCTES can be achieved by solid-gas, liquid-gas, solid-liquid and solid-solid state changes, the last two being the most interesting. This is because solid-gas and liquid-gas state changes have very complex and impractical containment systems, which severely limits their use. At present, solid-liquid PCMs are the most common thanks to many advantages, such as small volume variations during freezing, compactness, multiple forms of containment and encapsulation for such a state change, ease of use and construction, etc. while solid-solid is the main candidate to give more flexibility to latent heat thermal storage in buildings in the immediate future [44] [45].

3.2.1.3 Thermochemical heat (and Cold) Energy Storage

Thermochemical heat and cold energy storage (TCHCES) occurs through a chemical reaction in which the products of the reaction must be stored. In addition, the reaction must be reversible to allow storing and releasing the heat as needed.

This energy storage refers to two main processes, thermochemical reactions and adsorption processes. Thermal adsorption reactions can be used to store heat or cold in the binding of a substance to another solid or liquid, with water vapour adsorption being one of the most common processes. During loading, water is desorbed from the inner surface of the adsorbent and is adsorbed again when the stored energy is discharged from the system.

Alternatively, heat can be stored by directing the energy to an endothermic chemical reaction. In this reaction, a thermochemical absorbs the energy and splits into separate substances, which can be stored until the energy is needed again. When this happens, these substances recombine, and the thermal energy is released in an exothermic reaction.

Due to high energy storage density, TCHCES systems emerge as an attractive alternative for the design of next-generation power plants, which are expected to operate at higher temperatures [45].

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

3.2.2 Electricity storage

Self-consumption using local renewable energy gives final consumers the possibility of generating their own energy, increasing their autonomy and resilience and reducing energy costs. The problem arises with the intermittency of these renewable sources and with the hourly mismatch between consumer demand and local generation, which produce continuous power flows between buildings and the electric grid. Electric storage can provide flexibility at an individual household and aggregated community level, increasing the self-consumption rate and supporting the grid.

This section describes different electrical storage technologies that can be used at the micro-energy hub level as well as at higher levels such as energy hub. As it will be shown, there is no single one-size-fits-all solution, and therefore each of these technologies has a specific field of application.

An overview of technical parameters and cost forecasts for different types of electric storage technologies was presented in Section 3.7 of eNeuron deliverable D2.1 [42].

3.2.2.1 Electrochemical batteries

A battery is an electrical accumulator that stores electrical energy through electrochemical processes. Its operation is based on an oxidation-reduction reaction in which electric current flows from the anode to the cathode. Batteries are constantly being upgraded due to the ever-increasing need to store energy and specially to manufacture long-life storage systems.

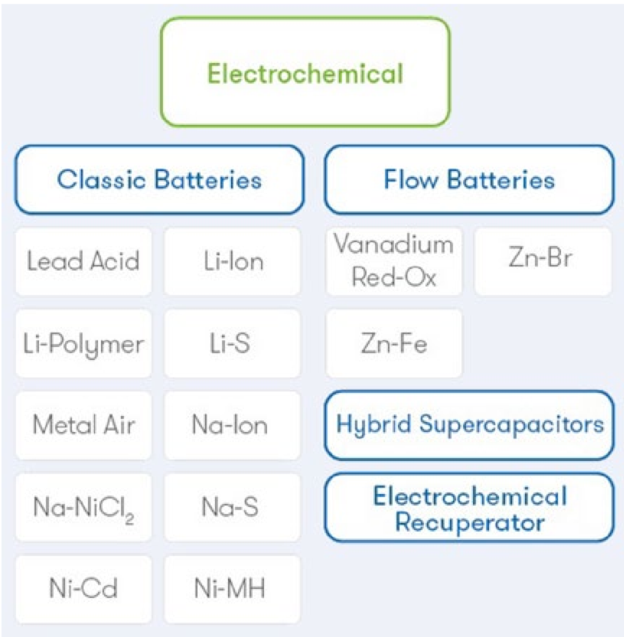

Figure 17. Electrochemical storage technologies [46]

Depending on what these elements are, different types of batteries are found, such as Li-ion batteries, Lead-Acid batteries, nickel-metal hydride, aluminium-air, zinc-air, Sodium Sulphur batteries, Vanadium redox flow batteries, etc. A summary of electrochemical storage technologies is shown in Figure 17.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

Some characteristics of the main types of electrochemical batteries for power system applications are the following [46]:

- **Lead-acid batteries**: the positive electrode of the battery contains lead dioxide (PbO_2), and the negative contains spongy lead (Pb). The electrolyte is aqueous sulphuric acid. There are two main subtypes: flooded (VLA), which require maintenance, and Valve-regulated (VRLA). The cells are produced in different designs and sizes (from 1 Ah to 16000 Ah). They can be connected in large battery arrangements without sophisticated management. They have a low cost per kWh to install and a low cost per kWh throughput. It is used in nearly all applications except small portable and mobile systems.
- **Lithium-ion battery**: the charge/discharge reactions occur between a positive electrode (cathode) that contains some lithiated metal oxide and a negative electrode (anode) that is made of a carbon material or intercalation compounds. The electrodes are separated by porous polymeric materials immersed in an electrolyte made of lithium salts dissolved in organic liquids. This is a family of batteries that includes different electrochemistry: $LiCO_2$, LiNCA, LiNMC, $LiFePO_4$, LiT0, etc. Their main application field was the small mobile phone market (since the beginning of the '90s), but their use in the stationary market is increasing and has benefited from their deployment in the automotive sector. They are used in all the areas of the electricity sector: demand, distribution & transmission grids, renewable generation, etc.
- **NaS**: the cathode is typically made of molten sulphur (S) and the anode of molten sodium (Na). The electrodes are separated by a solid ceramic, sodium beta alumina, which also serves as an electrolyte. This makes that the battery should be kept at high temperatures, 300-360˚C, to maintain the molten state of the electrodes, through an independent heater. This technology has been demonstrated at over 200 sites and it permits 6-7 hours of operation for peak shaving. Because of the operating temperature and the corrosive nature of the sodium polysulphides, NaS batteries are primarily suitable for large-scale non-mobile applications: firming of renewable plants, peak shaving, time-shifting, etc.
- **Flow batteries**: they are rechargeable batteries with two electrolytes as energy carriers, one positively charged, and one negatively charged. The electrolytes are separated using an ion-selective membrane. Its main singular characteristic is the total decoupling between power and energy ratings providing great flexibility: power is defined by the active surface of the membrane and by hydraulic pumps management; energy depends on the capacity of the tanks. Different redox couples for flow batteries are available: vanadium, zinc-bromine (Zn-Br), polysulphide-bromide (PSB), etc. Modularity can be used to provide redundancy and reliability. Because of the relatively low energy density of the vanadium electrolyte, big storage tanks are necessary, which limits their applicability to large scale non-mobile energy storage.

The main characteristics of each type of electrochemical battery storage are presented in Table 3.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

Table 3. Key performance data of different electrochemical storage technologies [46]

Key perfromance data (KPI)	Lead-Acid	Li-ion	NaS	Flow
Power Range	Some MW	1 kW-400 MW	200 kW-50 MW	some kW-some MW
Energy Range	<10 MWh	<10 MWh	1.2-400 MWh	0.1-some MWh
Discharge time	<20 h	10 min-4h	6 h	Some h
Cycle life (cycles)	500-3000	2000-10000	>4500	<12000
Life duration (years)	5-15	15-20	15-20	44105
Reaction Time	some ms	somes ms	some ms (if hot)	some ms
Round Efficiency (%)	75-85%	90-98%	70-80%	50-60%
Energy (power)density	25-35 Wh/kg	120-300 Wh/kg	206 Wh/kg	10-25 Wh/l
CAPEX: energy(€/kWh)	100-200	300-700	300-450	100-400
CAPEX: power (€/kW)	100-500	100-1200	2000-3000	500-1300

3.2.2.2 Supercapacitors

Supercapacitors or ultracapacitors are a promising energy storage technology that has attracted the attention of many researchers due to their significant advantages. The most important advantages of supercapacitors are the high power density in a small volume and weight, a long life cycle with high stability, extremely high round-trip efficiency (around 95%) and rapid charge-discharge rates.

There are two types of supercapacitors, the electrical double-layer capacitor (EDLC) and the pseudocapacitor. Double-layer electrical capacitors store electrical energy by intercalating charges at the electrode-electrolyte interface forming the double layer of charges, while the pseudocapacitors use faradaic reactions to store electric energy.

Until now, the most common use of these devices in grid applications have been in uninterruptible power systems (UPS) in microgrids (see for example [47]), and also they have been used for peak shaving applications in industrial services, improving the global efficiency [48].

3.2.2.3 Flywheels

The flywheel energy storage consists of a composite flywheel in combination with a motor-generator and arms (often magnetic) with a low-pressure housing to reduce self-discharge losses. Its origin dates back to the 1950s when it was used to make gyroscopes. It stores electricity in the form of rotational kinetic energy. As an electric energy storage system, it operates in the charging and discharging phase. During the charging phase, electricity is used to accelerate the motor connected to the rotor via a shaft, transmitting an angular momentum to the rotor, which acts as the energy storage part. During the discharge phase, the rotating mass transfers the kinetic energy as it slows down back to electricity using the generator connected to the same shaft.

Flywheels are classified based on the rotation speed. Low-speed flywheels have a rotational speed <10000 rpm, and high-speed flywheels have a rotational speed> 10000 rpm. Low-speed flywheels

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

provide a shorter storage period but high-power capability, while high speed flywheels do the opposite.

In terms of operating costs and functionality, the flywheels are considered a perfect storage system due to low maintenance costs, long life cycle, high efficiency, free from the effects of deep discharge, environmental friendliness, wide operating temperature range and capacity to survive in harsh conditions.

However, due to friction loss, the flywheels are not suitable for long-term energy storage due to the frictional forces that occur, reducing the efficiency of the flywheel assembly during operation.

3.2.2.4 Compressed Air Energy Storage (CAES)

Compressed air energy storage system (CAES) uses off-peak electricity to compress air and store it in a reservoir, either an underground cavern (underground hard rock caverns, salt caverns, depleted gas fields or an aquifer) or aboveground pipes or vessels. This air is released during peak period, heated, expanded and used in a turbine-generator to produce electricity. The process diagram of a CAES is shown in Figure 18.

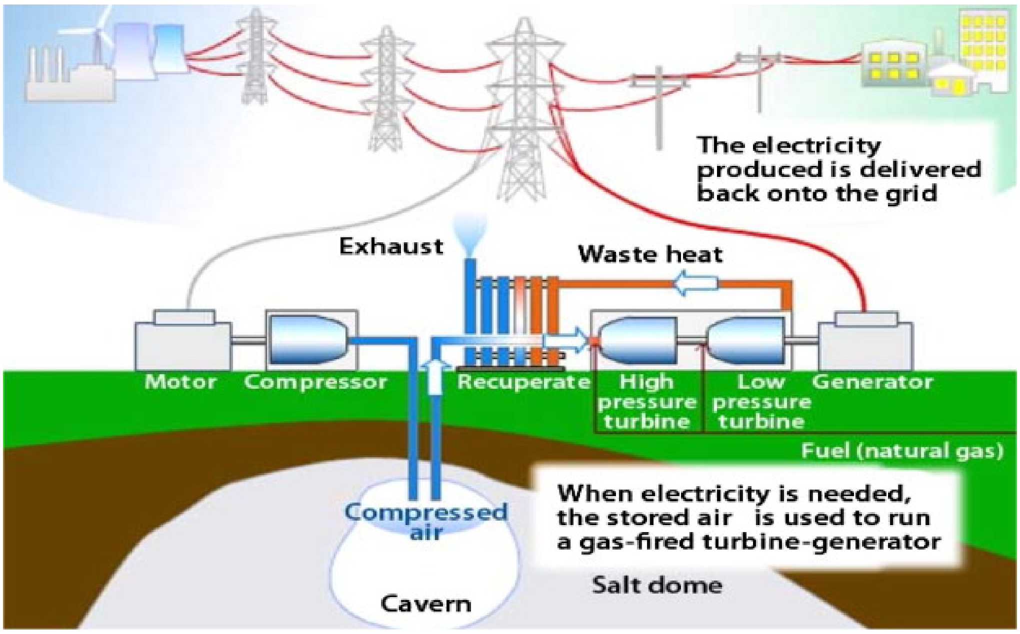

Figure 18. Process diagram of CAES [49]

CAES is a large-scale, commercialised energy storage technology that can provide more than 100 MW of power from a single unit [50]. The two existing large-scale CAES facilities have an efficiency <40% and around 55%. There are two other small CAES plants in Canada that have an efficiency of 60%.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

3.2.2.5 Liquid Air Energy Storage (LAES)

Liquid air energy storage (LAES) is an evolution of CAES that uses liquefied air as a storage medium, thus being considered cryogenic energy storage (see Figure 19) [51] [52].

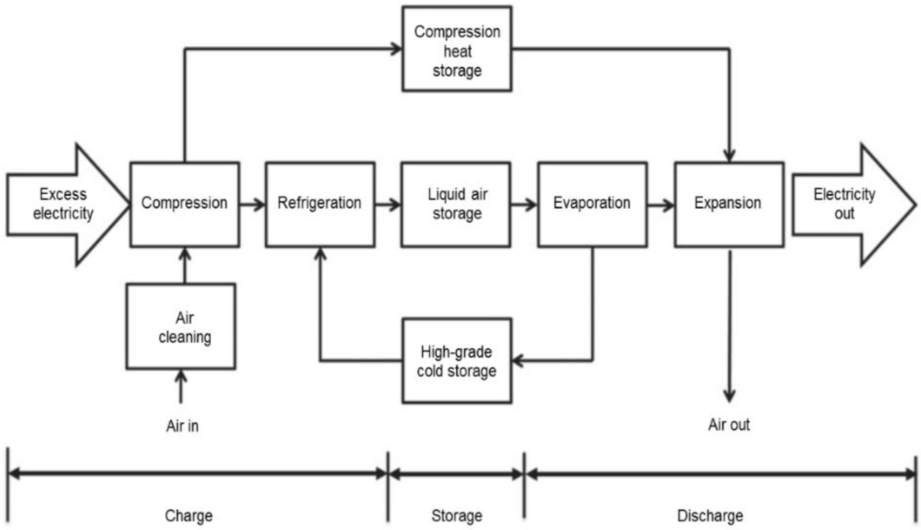

Figure 19. Liquid Air Energy Storage (LAES) process scheme [53]

The first step is the charging process, where excess electrical energy is used to compress and liquefy air. The second step regards the storing process of the liquid air that is insulated in a tank at approximately -196°C and ambient pressure. The third step is the discharging process that recovers the energy through pumping, reheating, and expanding to regenerate electricity during peak hours when electrical energy is in high demand and expensive.

Possible energy recovery can be performed in both the second and third steps, namely the storage of heat from the air compression process and the high-grade cold energy during the re-heating process, respectively. The stored heat and cold energy can be used to increase the power output and reduce the energy consumption of the liquefaction process or in other end uses.

However, this storage technology presents different limitations that could affect both exploitation and deployment in different applications. For instance, the advantages in terms of both energy and economic analyses are anyhow important, but the viability of this solution is not always affordable, depending on the plant sizes. These aspects will be further discussed in detail in subsection 4.1.2.2.4.

3.2.2.6 Pumped-hydro power plants (PHPP)

Pumped hydroelectric energy storage is a technology that uses water to store and produce electric energy. PHPPs comprise a lower-level water reservoir and a high-level water reservoir, which acts similar to a huge battery. When a high energy demand level is required, the water flows from the high-level reservoir to the lower one through a hydro turbine generating electric power. During the off-peak time, the water is pumped back from the lower to the upper reservoir using low-cost energy, such as nuclear, wind or solar energy [54] (see Figure 20).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

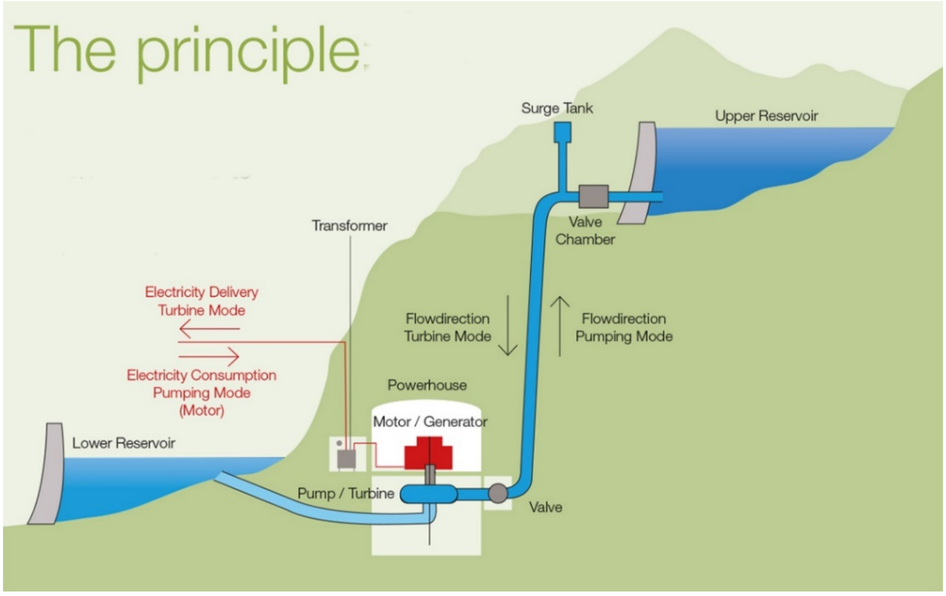

Figure 20. Pumped-Hydro Power Plant [55]

Pumped storage is a reliable and mature storage technology. It is the most widely used electrical energy storage technology when considering large-scale energy storage [56] and is considered as a driver to help isolated power systems to increase their renewable energy penetration level [57].

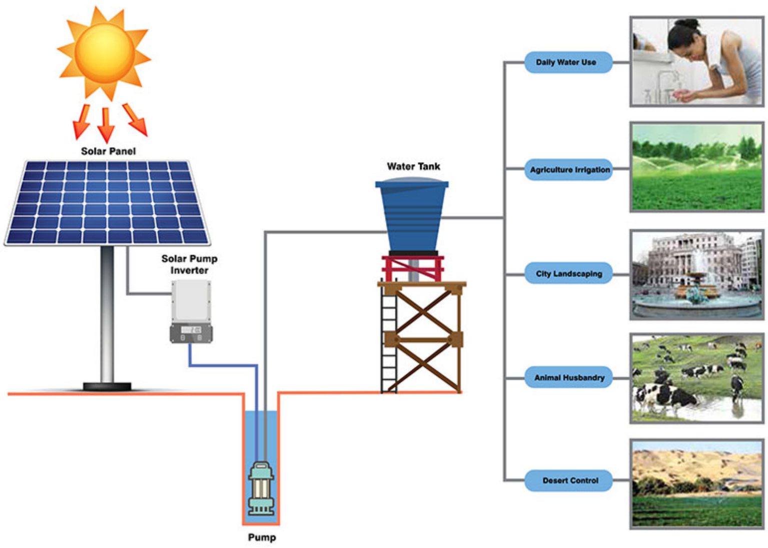

Figure 21. Small scale pumped energy storage [58]

In the last years, the implementation of small-scale PHPPs in different sites such as residential buildings, water distribution networks, etc., has attracted the interest of the scientific community [59] [60] [61]. Water can be pumped to an upper water tank taking advantage of the local PV excess energy, and that stored water can be later used for other uses such as irrigation, water supply or electricity generation, installing pico electric generators in the existing water infrastructures.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

3.2.3 H_2 storage

Table 4 shows the main methods for hydrogen storage. The physical storage methods appear to be the most mature and frequently applied. This normally includes compression, cooling or a combination of these. Different pressures are used from intermediate (50 bar) to high pressure up to 1000 bar. For industrial applications, salt caverns are considered to be suitable for long-term storage and have been tested in the US and Europe. The number of salt caverns suitable for this purpose is limited. For more common end-uses such as transport, pressures of 350 bar or 700 bar have become the most common norm.

Table 4. Storage methods for Hydrogen [36]

Physical		Material-based	
Compressed Gaseous Hydrogen CGH_2 (350, 700 bar)	Liquefied Hydrogen LH_2	Metal Hydrides	
Crio-compressed Hydrogen CcH_2	Slush Hydrogen SH_2	Liquid Organic Hydrogen Carriers LOHCs	Sorbents (MOFs, Zeolites, Nanotubes)

Hydrogen is most commonly transported in pressurised or liquid form (-253°C) by lorries or tank vessels (see Figure 22). There are also several dedicated hydrogen pipelines in US and Europe, but it is also possible to have a limited injection of hydrogen into the existing pipelines for natural gas.

Slush hydrogen is cooled further beyond its melting point to the consistency of slush or gel.

Storage methods in materials such as metal hydrides are still under development and unlikely to be available for commercial use within the near future.

Figure 22. H_2 Storage [62]

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

3.3 Complementary technologies

This section describes other complementary technologies used in local energy communities, which are not energy generation or energy storage but can interact with different energy carriers/networks and can directly influence the final energy consumption and controllability.

3.3.1 Mobility

The transportation sector is responsible for a third of the final energy consumed in the EU. Most of this energy is produced by fossil fuels, which means that transport represents more than a quarter of the EU's GHG emissions, contributing to global warming and climate change. Within the transportation sector, road transport is the biggest GHG emitter (70% of the total), and the rest comes from maritime and air transport. The electrification of transport is an essential step for reducing the environmental impact of this sector, and for that reason, the EU is promoting low emission transport modes and the infrastructure and fuels to support them [63].

An electric vehicle (EV) uses one (or more) electric motors instead of an ICE. These vehicles can be from small e-scooter and city cars to vans, buses, trucks, trains, ferries and planes. An EV can be powered through a collector system by electricity from off-vehicle (like trains and trams) or self-contained using a battery or a generator to convert compressed H_2 to electricity.

Figure 23. Renewable energy sources for charging EVs [64]

Currently, there are two types of fully EVs:

- **Battery electric vehicles (BEVs)**: These vehicles are powered by a rechargeable Li-ion electric battery pack, producing zero tailpipe emissions while driving.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

- **Fuel cell electric vehicles (FCEVs)**: use a fuel cell instead of a battery pack, where through an electrochemical reaction, that combines oxygen and hydrogen, generates electricity to power their electric motors. Additionally, these fuel cells also produce water.

These types of vehicles require an adequate charging infrastructure at a reliable network across Europe (see Figure 23). For that reason, EU countries will have to ensure a sufficient charging (and H_2 refuelling) capacity on cities and main motorways [65]. The existing forecasts and scenarios for the deployment of EVs are presented in section 3.8 of eNeuron deliverable D2.1 [42].

3.3.2 Control and data management and security

Nowadays, integrated energy systems are more eminent due to the development of efficient energy conversion and multi-generation systems. The combination of different energy carriers led to a more efficient and sustainable solution to satisfy the increasing energy demand in a friendly environment form.

In order to achieve the optimal management of the different energy carriers, it is necessary to develop advanced control management tools which are able to provide precise decisions in order to coordinate technical, regulatory, economic and environmental issues.

These control management tools are composed of different parts such as databases, monitoring tools, graphical interfaces, etc., but the core of this system is a mathematical optimization model that integrates the considered technologies (electric and thermal generation and storage).

A completed description of the different control management tools was presented in a previous deliverable of the eNeuron project (see deliverable D2.2 [1]).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

4 Identified limitations and shortcomings

This section describes the main **limitations** and **shortcomings** found in the analysis of the different technologies for optimal use of local resources. The section has been divided into two different parts:

- An initial analysis of the **technical limitations**, subdividing this section into technical limitations in **generation** (heat and cold generation, electricity generation and hydrogen production), **storage** (heat and cold storage, electric storage and hydrogen storage) and other technical limitations related to **complementary technologies** involved in local energy communities such as mobility and control management systems.
- A second analysis regarding the **regulatory limitations** for the same categories (generation, storage and complementary technologies). The country-specific existing regulatory limitations found during the identification process are presented in Annex I.

4.1 Technical limitations

4.1.1 Technical limitations in generation

Local energy communities have different multi-energy requirements to fulfil, such as electricity demand, heat and cold demand, etc., which have to be produced locally. In conjunction with these needs, different generation technologies will have different technical barriers which can limit their future deployment.

4.1.1.1 Technical limitations in thermal generation

Heating, ventilation, and air conditioning in local energy communities are necessary to provide thermal comfort conditions and acceptable indoor air quality for their occupants. In this section, the technical limitations of the main heating and cooling technologies are identified.

4.1.1.1.1 Technical limitations for Boilers

The major barriers regarding the technical feasibility of installing **electric boilers** are here discussed [66]:

Internal temperature: higher expectations or requirements of internal temperatures compromise the ability of an electric boiler to deliver a sufficient level of thermal comfort at coldest winter times.

Colder winter temperatures: if electric boilers are designed based on colder minimum winter temperatures, the electrical requirements are likely to be greater and fewer houses may be suitable. However, if the design minimum temperature remains the same, but winter temperatures regularly fall below this minimum, it is likely that they will fail to deliver sufficient thermal comfort during peak winter times and may develop an unsatisfactory reputation which would pose a barrier to

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

uptake. For instance, a 2°C colder design winter temperature would not affect the number of homes suitable for the installation of electric boilers, but the most suitable type of system may change.

Lower heat capacity and hot water production: an electric boiler struggles to meet the higher hot water demand. Generally, 1.5 kW of thermal power is allocated for every radiator in a house.

Available current (Amperes per phase) for electrical boilers: this barrier depends on the house's fuse rating and existing wiring. A lower available current has the greatest effect on direct electric heating but also has a significant reduction (around 5%) on the number of houses that can adopt electrical heating systems across all heating systems.

Additionally, **electric boilers** have low upfront costs but high operating costs. Installing an electric boiler is cheaper than traditional gas boilers; however, the electricity price in some European countries is higher than the natural gas price, and this could be one of the major concerns regarding the deployment of this technology.

On the other hand, maintenance costs are lower, and there is no problem with gas leaks. Electric boilers are safe and can be installed in more areas inside the buildings, but it is recommended to install an automated shutdown switch to prevent overheating. Older electric storage heaters might be contaminated with asbestos.

The main technical challenges when installing a **biomass boiler** are the following:

Delivery and storage of fuel: Natural gas is delivered via the gas transmission and distribution network. LPG and oil are delivered in tankers and are stored in on-site tanks. Biomass will nearly always have to be delivered by road as wood chips or pellets. The consequences will therefore be infrequent delivery by very large vehicles or more frequent delivery by smaller vehicles. Hence, access and the volume of road traffic in the vicinity of the boiler installation have to be considered. Seasonal delivery of biomass as wood chips or pellets requires substantial storage areas.

Physical size of boiler: With respect to the equivalent fossil-fuel-fired boiler, a biomass boiler will be physically much larger. This is due mainly to the inherent combustion characteristics of solid, organic materials, which require a large volume combustion chamber. Biomass boilers also require more space in the boiler house for access for fire-tube cleaning and feed and ash-extraction systems.

Boiler responsiveness and ability to modulate: Biomass boilers are less responsive to changes in heat demand with respect to conventional gas or oil boilers in which ignition is instantaneous, and it can also be shut down instantaneously with little residual heat remaining.

Waste and cleaning: Biomass boilers produce ash, and more cleaning is required than for gas or oil-fired boilers. The mineral content of biomass, and so the amount of ash depends on its source. There are two types of ash to consider as by-products from biomass combustion: bottom ash and fly ash. Bottom ash is formed on the grate and is pushed off the grate into the ash pan when new fuel is introduced. Fly ash is very fine. It is carried on the thermal currents inside the boiler, deposited in the fire tubes, and captured by abatement systems in the flue or released to the environment. This means that biomass boilers require boiler tube cleaning (unnecessary for oil and gas boilers). It is

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

also necessary to collect and dispose of bottom ash. Furthermore, melted ash can form an unwanted clinker on the grate that will reduce the efficiency during the heat exchange [67].

The main technical limitations regarding **natural gas boilers** are:

Security. Natural gas boilers are more unsafe compared to other heating technologies (i.e. electric boilers or electric heat pumps) due to the use of a fuel that is flammable. Gas leaks can generate fires and explosions, causing fatal injuries and serious damages to zones nearby natural gas boilers installation.

Furthermore, several problems such as agglomeration, slagging, fouling, caustic embrittlement, fatigue failure, and high-temperature corrosion can be faced while using natural gas boilers, thus affecting their performance [68].

Regarding the performance of natural gas boilers, the influence of the **gas quality** change affects it and thus the emissions from the natural gas boilers as well. The Wobbe number W, one of the most important characteristics of combustion gases, is defined to describe the variation of the load Q with changing gas quality [69].

So for the Wobbe range defined in EASEE Gas CBP [70], and considering as reference the natural gas Low Heating Value (LHV) of 50.7 MJ/kWh, the following maximum and minimum load variation is possible:

$$\Delta Q: +6\% \text{ for LHV} = 54\ kWh/m^3 \tag{1}$$

$$\Delta Q: -9\% \text{ for LHV} = 46.4\ kWh/m3 \tag{2}$$

This load variation is not an issue for most heating appliances, like boilers, since the load is modulated due to the actual demand, but reduced load might be an issue for instantaneous water heaters. The air factor is also important for the proper combustion of the fuel, as well as for flame stability, efficiency, and emissions of CO and NOx; certainly, the air factor changes together with the Gross/Low Heating Value (GHV/LHV) of the used fuel.

To summarise, the ambient conditions strongly affect the performance of natural gas boilers, and this factor is crucial for selecting those zones where this technology can perform better or worse.

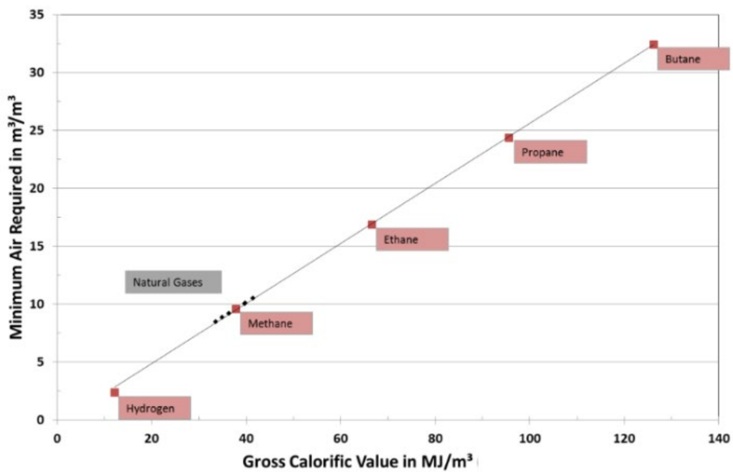

Figure 24. Minimum combustion air requirement of different hydrocarbons, natural gases included [69]

In the last years, **natural gas prices have been consistently increasing**, most recently observed in November and December 2021. the primary reason for the rise in the natural gas price was due to a strong recovery in demand, extreme weather events, and unplanned supply outages. Furthermore, there is an increase in the global demand for natural gas for transportation, HVAC, and power generation [71]. The high natural gas prices also have ripple effects on electricity markets, pushing prices up and driving fuel substitution in favour of coal and oil, thus also impacting higher levels of emissions of CO_2 and local pollution [72].

Natural gas boilers have **high upfront costs.** The boiler itself usually costs a lot more than an electric or oil-using model, especially if the gas boiler is a high-efficiency model. Not only is the boiler expensive, but the gas lines and hook-ups to the boiler are expensive too. For new installations, gas lines will have to be installed, and they must be inspected yearly to ensure there are no leaks or problems, which increase the maintenance costs.

Natural gas-fired boilers and furnaces emit dangerous nitrogen oxides (NO_x), carbon monoxide (CO), nitrous oxide (N_2O), as well as volatile organic compounds (VOCs), sulfur dioxide (SO_2), and particulate matter (PM) [73]. In addition to steam produced in the process of boiler operation with specific parameters (temperature and pressure), the boiler also produces by-products in the form of exhaust gases, ash and slag, which must be systematically removed from the receiver. It is necessary to take care of the proper utilization of the above-mentioned products [74].

Steam boilers are used starting from a small-scale industry that needs steam in its production process to a large electrical power plant that requires steam for its turbine glands, passing through low or high-pressure boilers and applications to recover heat from engine or turbine exhaust gases, without forgetting hybrid boilers which can operate equally with gas recovery or with a liquid or gaseous fuel burner.

The high temperature of steam leads to the heating of all elements of the system to 100°C and above. This leads to the following consequences:

- very active air circulation in the room, which can be uncomfortable and sometimes harmful (if you are allergic to dust);
- the air in the room dries out;
- hot elements of the system are hazard and must be closed, as well as pipes;
- not all building materials normally tolerate prolonged exposure to 100°C temperatures ; therefore, the choice of finishing materials is very limited (in fact, it is only cemented plaster, followed by painting with heat-resistant paints).

Steam boilers have low controllability. Simple steam heating has **very limited possibilities to regulate heat transfer**. There is only one way to change the temperature to make several parallel branches and turn them on as needed.

The second way is to turn off the boiler in case of overheating and turn it on after the room has cooled. This process is controlled by automation, but this method is far from the most convenient since constant temperature fluctuations are observed.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

Another technical limitation is **noise**. Steam is very noisy when moving through pipes. In production workshops, it does not really bother, but in domestic applications (private dwellings) this can be a problem.

The main technical limitations of the steam boiler are the following:

Priming: When the steam is produced in the boiler, some droplets of water get carried away with the steam resulting in the formation of 'wet steam'. This phenomenon is named priming.

- Deposits on the valves may cause overheating and corrosion
- Reduced product quality which affects the heat transfer rates
- Higher steam consumption for the same power output
- Life of boiler and its components are subjected to danger

Foaming: The formation of a layer of froth or stable foam on the surface of the water is termed foaming.

- The formation of soap-like structures reduces the surface tension of water significantly, thus decreasing the boiler efficiency.
- Fluctuation in water levels.
- Water hammer problem.
- This can lead to contamination and scaling.

Carry-over: Carrying away water containing soluble salts into the distribution system is termed as carry-over. The salts essentially have an alkaline nature.

- The decrease in the efficiency of a boiler as the dissolved salts and solid particles have chances of getting carried away into the turbine blades and finally getting deposited over the blades.
- The life of different parts of a boiler subjected to such water-soluble salts is at stake.
- A judgment of the actual height of the water column becomes difficult, making maintenance procedure quite troublesome.
- Carry-over poses a serious problem to the parts such as turbine blades, steam traps, valve bodies, etc.

Scale: A layer of water formed over the metal surfaces of the boiler is termed scale. Scales are salts of Calcium and Magnesium (existing primarily in the form of sulphates or carbonates), which are highly insoluble in water. If there is scaling in the boiler, then the amount of fuel required to produce the same amount of steam may increase considerably compared to a boiler without scales.

- Sodium sulphate is a strong electrolyte, so it dissociates with water. Its conductivity is about one hundredth that of steel, thus causing hindrance in the heat flow. Even a thin layer of this scale on the metallic surfaces may reduce the boiler efficiency up to 20%.
- The scaled boiler becomes increasingly hotter due to resistance in heat flow, so that this metal will become more prone to deformation and rupture.
- The heat transfer in the boiler is reduced due to the layers of scale that act as an insulator.

Corrosion: The active destruction of the boiler material through pitting action is termed corrosion. It is the process of continuous 'decay' or 'disintegration' of the boiler material due to the electrochemical action of the dissolved oxygen with the boiler metal. Corrosion leads to rusting of ferrous metals, tools that are not regularly oiled and steel windows that are not regularly painted.

- The boiler metal gets eaten up quickly due to the action of dissolved oxygen, leading to complete failure of the boiler system.
- Increase in cost of maintenance and repairs.
- Leaking of rivets and joint areas.
- Reduced boiler life and possible chances of failure of the entire system.

Other technical limitations of Steam Boiler:

- high temperature and pressure are involved.
- a well-trained employee is required.
- the boiler requires regular maintanence.
- to Effective insulation of the boiler and boiler parts is required to prevent heat burns
- Temperature regulation for space heating is difficult with steam boilers
- the high inertia of steam installations (prolonged start and stop time);
- relatively low volume of produced electric energy compared with thermal energy.
- difficult repairs of steam turbines;

In the process of cogeneration, 7-50% of the fuel energy is used for the production of electric energy; 8-20% – turns into losses, while the rest of the fuel energy is transformed to steam or hot water, used for building heating and DHW.

In the scope of the present project, the main advantage of steam boilers is that they can use a variety of energy sources for the production of overheated steam. Due to the present legislation in several countries in urban areas, it has become common to incinerate waste for district heating. For example, dumping waste in landfill sites was banned in Norway in 2009, and waste incineration is part of the national waste management system. In smaller-scale installations and rural areas, it is common to use biomass, e.g., pellets [75], scrap wood from industry, etc. (see example in [76]).

One of the key advantages of steam boilers is that they allow a combination of several alternative sources of electricity with low additional costs, e.g., electricity, natural gas, biogas.

4.1.1.1.2 Heat pumps and hybrid heat pumps

The Hybrid HPs have the same drawbacks as that of a conventional HP, but in some cases, they could have additional constraints. The main limitations and shortcomings identified in HP are the following:

Availability. Normal HPs provide temperatures up to 80°C and can use energy sources from renewable and waste sources with temperatures up to 40°C, and they are currently commercially available. More advanced high-temperature HP reaching temperatures up to 100°C, using energy sources with temperatures up to 60°C are also commercially available.

The temperatures provided by very high temperature HP provide temperatures that could reach up to 150°C, but, at the moment, the technology availability is limited to experimental solutions and prototypes and for that reason, they are not expected to be commercially available in the near future [9].

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

Integration and implementation. The HP's main obstacle in existing processes is that the steam is most often used for thermal energy distribution, resulting in high-temperature system designs. Changing this equation requires restoring most of the HVAC installation with new pipes and pumps and different process designs, a step that decision-makers are reluctant to take. In smart system designs, heat pumps help to close energy cycles by using all output to a maximum, thus reducing heating/cooling losses to a minimum [9].

Seasonal Efficiency. In the specific case of air-to-water HP systems, the annual efficiency is usually lower than the ground- or water-source HP systems as air temperatures usually vary more than ground or water temperatures. This problem is accentuated in winter when outside air temperatures are lower, coinciding with higher heat demand. Air-source HPs can be more efficient (than ground- or water-source pumps) during the summer months, but this is also a time when heat demand is low. The efficiency of reversible air-to-water heat pumps is often significantly lower when providing cooling than the efficiency of ground- or water-source versions. Air-source HPs cannot use direct cooling from the source in the way that ground- or water-source HPs can [9].

In the case of an air-to-water heat pump, an outdoor temperature lower than -5°C to -15°C decreases the efficiency of the equipment considerably [77], so its implementation would not be suitable in very cold climates. In these situations, hybrid HP with an additional gas boiler can be used, but this complementary gas boiler will be working during a high percentage of the operating hours.

In the case of a geothermal installation, suitable geological conditions, such as high underground temperature, natural hydrothermal fluid reservoirs, as well as access to the fluid and the availability of land for the installation, have to occur [78].

Hourly Efficiency. In a ground-source HP system, particularly horizontal collectors, there is a finite thermal resource that can be depleted. Systems that extract only naturally occurring (renewable) heat depend on solar gain, rainfall or geothermal energy, which may vary. As a result, ground-source HPs are more sensitive to the operating hours, the profile of heat supplied, and total heat delivered than other types of heat pumps. For example, particular care needs to be taken with delivering heat to dry out a new building after construction (e.g. if it has underfloor heating with solid floors). This can be a significant heat load that can deplete the ground energy store if it has not been allowed for [79].

Weather compensation. This is a strategy that is used in any system to improve energy efficiency and comfort. It stops the system from cycling on and off. Weather compensation in an HP system has an added bonus because the HP operates more efficiently at a lower temperature. Unfortunately, there are also disadvantages to weather compensation. The system can be slow to respond to changes in outside temperature, so if outdoor temperature changes rapidly, there is usually a lag time in the system response [79].

Use of heat pumps as a flexible load: One of the practical technical limitations is that HPs are normally operating in pre-defined cycles, making it impossible to instantly switch-off or -on the device. It has to happen in a controlled way to avoid damages to the unit. This makes it very difficult to use heat pumps as a flexible resource since changing the operational regime may take several

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement N° 957779

minutes. Furthermore, the operational cycles vary among manufacturers, meaning that a pool of heat pumps from different vendors will work in different patterns, which are difficult to predict.

Regarding hybrid HP, the first important need is access to the gas grid. If there is no access to the gas network, it will not be possible to implement this technology without investment to extend the gas network, which would imply high costs.

Equipment operation. Another technical aspect to consider related to the Hybrid HP is the equipment operation. Despite the fact that a hybrid system significantly reduces peak electricity demand compared to that which would be required using only an HP, a massive deployment of these technologies can generate peaks in electricity demand on the grid at certain moments, especially in winter, which will depend both on the operating mode of the system and the behaviour of the user. This situation will be even more accentuated in the case that the DHW demand is also supplied by the HP, so it is necessary a correct adjustment of the control systems and a good choice of the type of operation of the system for each case; switch: when the system works completely with the HP or the gas boiler or parallel: when both devices work simultaneously.

These control systems allow, on the one hand, to optimise the operation of the system to achieve lower consumption and lower costs and, on the other hand, to have flexibility when it comes to consumption, so that, if there is an overload in the electricity grid, the system stops consuming electricity and uses gas during those specific periods of time.

Heat Pumps have high maintenance costs. Additional equipment, particularly rotating equipment, leads to additional maintenance costs, which offset the benefits [80].

Hybrid heat pumps also have several economic limitations. The cost of a hybrid installation is much higher than the cost of a conventional gas boiler because it requires both the gas boiler and the heat pump.

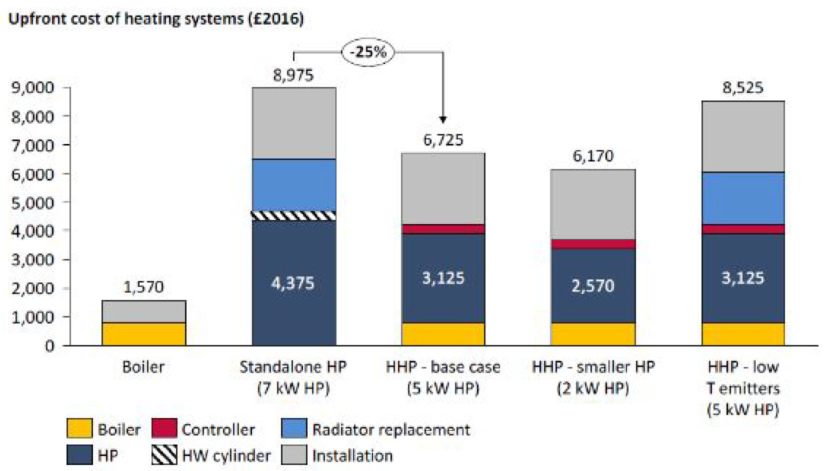

Figure 25 Upfront costs of HHP, HP and boiler heating systems for a typical semidetached [81]

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

Additionally, in some cases, it may be necessary to **replace conventional radiators** with low-temperature radiators in order to reduce the peak electricity demand, which would lead to an increase in the total upfront cost of the system, as shown in Figure 25.

Due to the large initial investment required for the installation of this kind of system, the lifetime costs of the hybrid system also exceed those of the gas boiler considerably. It would also be necessary to consider the costs of maintenance and repairs of the equipment, which would be increased as there would be two units instead of a single one. On the other hand, the fixed costs of the supply would also be increased, since, by having both electric and gas units, the user would have to assume the fixed costs of both; although the dwellings already have an electricity contract, when installing a heat pump it would be necessary to increase the power capacity contracted and therefore also the cost.

Although in some cases there are incentives or subsidies, the money is not received immediately, so the user has to pay in full when the installation is done (as is the case in the Netherlands with the *Investeringssubsidie duurzame energie ISDE subsidy* -Investment subsidy for sustainable energy and energy saving). On the other hand, this subsidy only applies to the cost of the heat pump and not to the whole system, so the user would have to pay the full cost of the gas boiler in hybrid HP installations. These types of subsidies are different for each country, and not all countries offer them.

In the case of Italy, users can benefit from the *Ecobonus* [82], which consists of a tax deduction calculated as the 65% of the investment incurred for the measures to replace an existing heating system with efficient systems, like the heat pumps driven. The deduction can amount to a maximum of 30.000 € per house or per dwelling in the case of multifamily houses, and it is split into 10 yearly instalments.

In the case of installing a heat pump, the advantage is even greater with the *Super bonus*, a tax deduction calculated as the 110% of the investment costs split over 5 fiscal years. If the heat pump installation is geothermal, the additional cost of drilling will need to be taken into account.

All of the above will vary depending on the heat produced by a heat pump in hybrid systems but varies overbuilding types, energy price regimes, climate and chosen control strategy, as well as the electricity/gas ratio used during the year, which generates uncertainty in the payback period [79].

In the case of heat pumps, in addition to complying with the regulations on noise and vibrations set out in the corresponding ordinance, the maximum levels of hot air expulsion to the outside must also be respected, which will be determined by the power of the equipment in the case this is required by municipal ordinances.

4.1.1.1.3 Combined Heat and Power (micro CHP-CHP)

Technical limitations of CHPs are discussed with reference to the three types of movers: ICE, MGT and GT, which represent the most used options in the context of local integrated energy systems. Technical limitations associated with fuel cells CHPs will be described in subsection 4.1.1.2.8 in this document.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

ICE powered by fossil fuels, such as diesel and natural gas, are among the most widely used technologies in the field of energy networks, especially in co-trigeneration applications for the combined production of electrical and thermal energy. Their sizes range from 1 kW to 10 MW in distributed generation (DG) applications.

In cogeneration, the main sources of heat potentially usable for the recovery of thermal energy are:

- The exhaust gases represent the thermodynamically most valuable source, as they are available at a rather high temperature (400-500°C). Therefore, they also allow medium pressure steam to be produced.
- The cooling water represents about 10-20% of the total thermal input. It is available at temperatures below 100°C and can be used for the production of hot water.
- The lubricating oil represents 4-7% of the total, is available at 75-90°C (only in large engines).

Ultimately, the recoverable heat is around 25% of the total compared to 35% available from the exhaust gases.

The main technical shortcomings related to **ICE CHP** are:

- Limited temperature cogeneration applications;
- Diesel-powered ICEs are characterized by high NOx and particulate emissions. Those powered by gas are characterized by significantly lower emission levels;
- Must be cooled even if recovered heat is not used;
- They are characterized by high levels of low-frequency noise.

GTs are thermal engine systems that convert the chemical energy of the fuel into mechanical energy through a Brayton thermodynamic cycle. These technologies are often used in large industrial applications, and the range of sizes available on the market goes from 500 kW to 20 MW. They are generally used for the combined production of electrical and thermal energy in the industrial sector.

The main technical shortcomings related to this technology are indicated below:

- They are characterized by a significant reduction in efficiency at partial load;
- They require high-pressure gas or in-house gas compressor;
- Their output falls as ambient temperature rises.

MGTs are thermal engine systems similar to GTs that convert the chemical energy of the fuel into mechanical energy through a Brayton thermodynamic cycle. This technology, together with internal combustion engines, represents one of the most widely adopted solutions in the field of energy networks, with sizes ranging from 30 kW to 250 kW.

The main technical shortcomings related to **MGT/GTs** are indicated below:

- They are characterized by a significant reduction in efficiency at partial load;
- Relatively low mechanical efficiency as compared with ICEs with the same sizes. The same occurs the thermal efficiency as shown in Figure 26 [83]
- Limited to lower temperature cogeneration applications

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

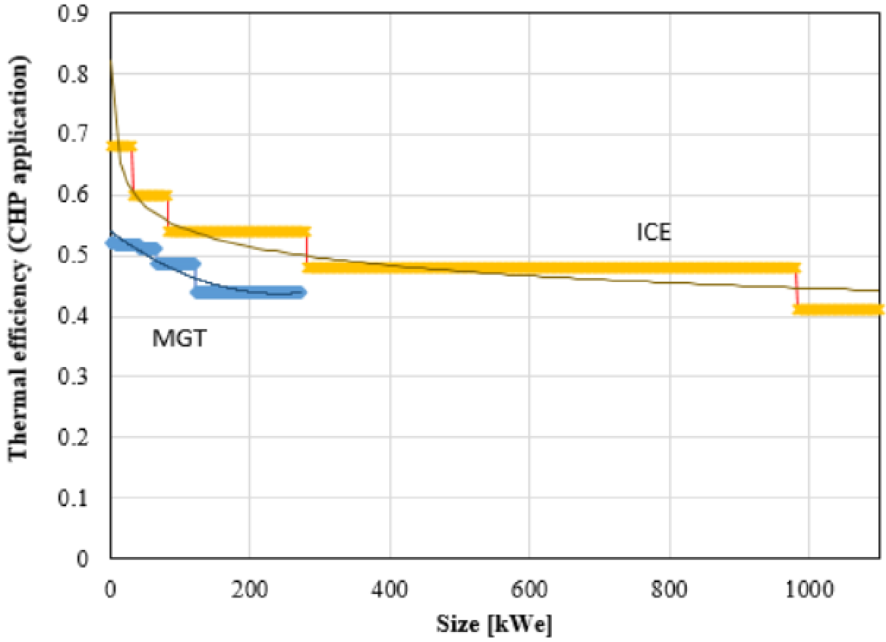

Figure 26. Variation of thermal efficiency with size (ICE vs MGT in cogeneration applications) [83]

Some general technical limitations have to be taken into account in the assessment of a CHP system:

- The necessary condition for appropriate use of CHP is the **simultaneous demand for heat and electricity**. A CHP system provides heat and electricity at the same time ; therefore, it is necessary that the users would be able to simultaneously absorb this energy.
- In general, the electricity and thermal demands relative to the utilities connected to a CHP system are time-varying. So, the CHP system should be able to vary its cogeneration ratio in order to satisfy continuously both types of energy demands. Nevertheless, the majority of CHP systems operate at a **very narrow range of the cogeneration** ratio in order to maximize the overall conversion efficiency. The presence of an adequate heat storage system and the connection to the external electrical grid allows a CHP system to operate with a practically constant cogeneration ratio and guarantees certain flexibility to the overall system.

The connection of **CHP units** to the electricity grid can be complicated or expensive due to the technical and paperwork requirements, which discourages end-users and companies from investing in this technology [84].

Often CHP operators have to pay the standby rates for having a backup electrical grid service when the CHP unit is offline (e.g. maintenance, unexpected shutdowns) or the demand exceeds the generation produced by CHP. These standby rates are calculated considering the most disadvantageous situation (in correspondence of peak demand), leading to overestimated costs compared to real applications [84]. The convenience of usage of cogeneration is directly related to gas and electricity market prices of different countries. For instance, the subsidies for fossil fuels could make such energy carriers more economically convenient than the Renewable Energy System (RES) Heat and Cooling technologies [84].

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

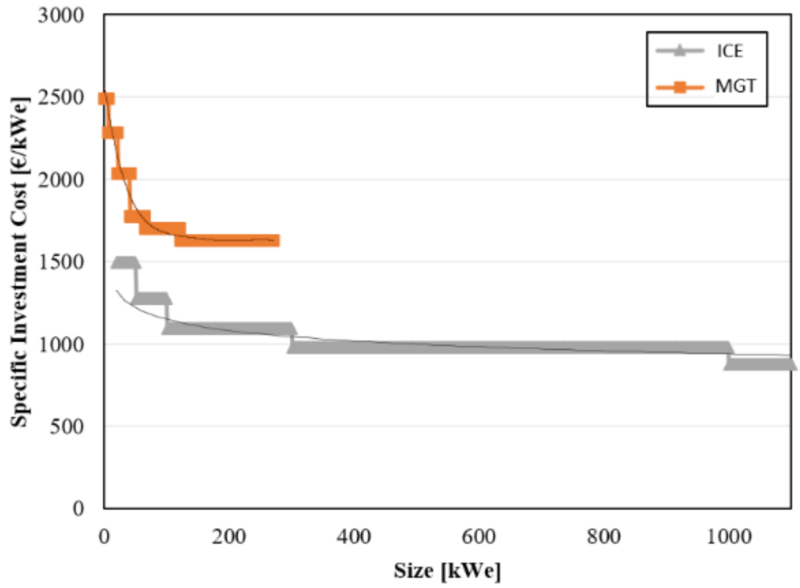

Figure 27. Variation of specific investment costs with size (ICE vs MGT in cogeneration applications)

Utility companies usually try to recover their fixed costs (e.g., new plants, distribution infrastructure, etc.) by selling energy. The energy efficiency measures (as the CHP units) reduce the amount of energy that can be sold and, in consequence, they can reduce the revenues of the company. Such a business model could discourage these companies from investing in CHP [84].

The operation and maintenance costs of ICE-based CHPs are relatively high, whereas the investment costs of MGT-based CHP systems are higher than those of ICE-based CHPs, as shown in Figure 27 [83].

4.1.1.1.4 Adsorption chillers

The main factor limiting the popularization of this technology is the **low efficiency of adsorption chillers** expressed by the coefficient of performance (COP), whose average indicated values are between 0.3 and 0.6. Conventional measures to improve their efficiency are associated with a drastic increase in the weight and size of equipment, which is a serious factor inhibiting the popularity of desiccant systems. It is also necessary to maintain high leakage due to the low-pressure operation of the cooler [85] [86].

The cost of purchasing an **adsorption chiller** is higher compared to other units. The installation cost of the adsorption plant is also high. For a single-family house, there is no chance for a quick return on investment, also due to the seasonal character of air-conditioning systems. The investment will reach its profitability threshold the fastest in buildings where a large cooling capacity is needed, and air-conditioning systems operate all year round [85] [86].

4.1.1.2 Distributed electricity generation technical limitations

There are some technical limitations and shortcomings which are common to different intermittent renewable energy sources such as PV or wind energy.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

Firstly, most of these generators are connected to the grid through a grid-tied power electronic converter, causing a **reduction in power system inertia** and increasing the risk of **stability problems**.

Harmonics produced by the high switching frequency of these power converters can also affect the power quality, producing unnecessary **extra losses** in the copper windings and torque pulsations in wind and some micro-hydro generators, and they may even excite some mechanical modes of the turbine-generator components.

These intermittent renewable energy generators are usually connected to **weak distribution networks** in remote areas with limited generation hosting capabilities.

4.1.1.2.1 Photovoltaics (PV) systems

The main technical challenges of the PV systems are the following:
Low efficiency. The record lab cell efficiency is 26.7% for mono-crystalline and 24.4% for multi-crystalline silicon wafer-based technology. The highest lab efficiency in thin-film technology is 23.4% for CIGS and 21.0% for CdTe solar cells. Record lab cell efficiency for Perovskite is 25.5% [87]. Current commercial PV panels efficiency are around 20-23% [88]. General Inverter efficiency for current state-of-the-art products is 98% and higher. The overall efficiency, combining PV modules efficiency and inverters efficiency, is around 20%.

PV modules generate direct current (DC), and therefore, the integration of these PV systems into alternating current (AC) grids tends to have low inertia and harmonics issues [89].

Another current trend in PV power stations is increasing the string DC voltage to 1500 V. At this higher voltage level is possible to implement longer strings and reduce the number of inverters as well as the cost of cables and structures, thus reducing installation and maintenance costs. However, it increases demands on the dielectric strength of modules, and higher internal electric fields may be reflected in PID -like defects and also on the personnel's qualifications (legislative restrictions over 1000 V) [90].

PV system degradation. PV and wind technologies are expected to become the world’s largest energy source by 2025, with PV representing 60% of the capacity additions [91]. For this reason, PV-module reliability and durability over a 25-30-year project life are essentials for investors to determine their expected return on their investment.

PV solar panels can be affected by high voltage, mechanical stresses, UV-radiation, humidity, and other meteorological factors such as hail, snow, dirt and temperature fluctuations, impacting various components of the PV modules such as packaging materials, adhesion, semiconductors, metallization, etc. which drive a performance loss [92], [93], [94], [95].

Storage requirements. One of the main drawbacks of PV systems is their intermittency. Solar energy can still be generated during cloudy and rainy days, but the efficiency of the solar system drops significantly. Additionally, PV systems cannot produce energy during the night period, requiring to store the excess of energy produced during the day. The cost of the electricity storage should be included in the total cost of the installations.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 957779

Space requirements. The technologies harnessing renewable energy sources are characterized by a power density several orders of magnitude lower than fossil fuels. For example, PV systems require around 2 m^2 per 400 Wp, which implies that the transition to renewable energies will intensify the global competition for land [96].

Water use. PV manufacturers require water for cooling, chemical processing, and air-pollution control. The biggest water waster is produced for cleaning solar panels during the installation and operation, but this amount is significantly lower than the water requirements for other types of power plants such as concentrating solar thermal power plants (CSP) or coal and nuclear power plants. This aspect is important at utility-scale projects. For example, according to [97] 230 to 550 MW PV power plants require up to 1.5 billion litres of water for dust control during construction and another 26 million litres annually for panel washing during operation.

Hazardous materials. PV cell manufacturing process includes a number of hazardous materials ; most of them are used to clean and purify the semiconductor surface. These chemicals include hydrochloric acid, sulphuric acid, nitric acid, hydrogen fluoride, etc. than can acidify the soil and emit harmful fumes. The amount and type of chemicals used depends on the type of cell, the cleaning requirements and the size of the silicon wafer. Manufacturing workers also face risks associated with inhaling silicon dust.

Thin-film PV cells contain a number of more toxic materials than those used in traditional silicon PV cells, including gallium arsenide, copper-indicium-gallium-diselenide, and cadmium-telluride. These technologies use compounds containing cadmium (heavy metal), which is a carcinogen.

If not handled and disposed of properly, these materials could pose serious environmental and public health threats.

4.1.1.2.2 Wind energy generation

As another intermittent renewable source, wind generators will require energy storage to increase their flexibility. There are different technologies of wind power, from small-scale (<1 kW to 100 kW) until large scale (from 100 kW up to 15 MW). In the following table (see Table 5 below), a summary of the potential cases and applications can be observed.

Also, there is the need to remark that there exist different technologies considering the grid/power take-off side of the generator. Those can be directly connected to the grid, partially connected to a grid through a converter of partial rating and full rated power converter.

Each technology presents a different option of regulation:

- **Directly connected :** can only down-regulate the power by pitching. This means that if there is the need for this type of Wind Turbines (WT) provide energy surplus, it can be only achieved by inertia request (really small amount) or by de-loaded constant operation.
- **Partially connected :** can provide a certain level of control (usually about 30%); the partial rated converter allows to control active and reactive power.
- **Full power converter** : can provide full rated active and reactive power control.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

The two latter can provide better regulation of active power (although for providing higher energy, the limitations are exactly the same as the previous one; since formally no energy storage is available), reducing the mechanical inertia of the power system. Partially connected and full power converter wind turbines can have better regulation of reactive power and voltage control.

Table 5. Summary of the applications of wind power technologies

Nominal Power / Systems					Wind-Diesel										Small Wind Farm					
			Hybrid								Single Wind Turbine									
	Residential Wind									Building Integrated								Wind Farm	
P<1kW	X	X	X	X	X	X	X			X	X	X	X	X					
1kW<P<7kW	X	X	X	X	X	X	X	X			X	X	X	X	X	X	X		
7kW<P<50kW					X	X	X	X	X					X	X	X	X		
50kW<P<100kW								X	X						X	X	X	X	
100kW<P<1MW								X	X							X	X	X	X
1MW<P																X	X	X	X
Applications	Boats	Signals	Public lighting	Isolated homes	Farms	Water pumping	Sea water treatment	Isolated village generation	Microgrid	Public lighting	Roof of buildings	Residential buildings	Public Centers	Parking	Industry	Districts	Farms	Distributed generation	Large generation
	Off-Grid									On-Grid									

Another relevant point from the technical limitations is that currently, wind power requires an electric network (ideally strong) in order to ensure the stability of the operation and control of the grid. Should the share of converter-interfaced wind generation be high in a power system, advanced controllers would be necessary so as to make some of the converters grid-forming.

Bigger wind turbines are more efficient, but larger turbines require greater investments, and these turbines can only operate in some specific windy areas.

Smaller micro wind turbines (<10 kW) can be deployed in a greater range of locations, producing energy locally, where it is demanded. Installation of wind turbines in densely populated areas is complicated due to noise and vibrations. In addition to this, wind turbines are often considered to be visually annoying for the population [98]. Most of these micro wind turbines are vertical axis wind turbines, where no wind seeking mechanism is required, and the generators are located near the ground, reducing the mechanical stress on the tower. Unfortunately, these types of turbines are not as efficient as conventional horizontal axis turbines. Some users mounted small micro wind turbines on their rooftops. But wind turbines vibrate, creating vibrations through the buildings on which they are installed. As a result, it can lead to noise and **structural vulnerability**.

It is worth noting that typically small wind turbines present reduced controllability, making complex its regulation and potential support to be provided by them.

Additionally, the technology is prepared to provide voltage and reactive power control but not frequency support. Thus, novel controllers must be implemented to do so as Synthetic Inertia, Overspeeding, Deloading, etc. [99].

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

Regarding economic limitations of **wind generation,** the main issue is the investment cost for certain technologies to be installed; usually, subsidies are required, but also there is the market issue which limits the potential benefit of the wind turbines on the market provision (mainly balancing) [100].

Wind turbines constitute a **wildlife hazard**, endangering birds that fly too close to rotating blades.

4.1.1.2.3 Small scale hydropower

The main technical challenges for small scale hydropower are related to connection to the distribution network. Hydropower resources available for development are often situated in remote areas and **require the construction of additional power lines** in order to feed the production into the grid [15].

Small-scale hydropower is usually connected to a radial distribution network, which was not initially designed for this and has **limited hosting capacity available**. Connection of generation brings several challenges related to changes of power flow and possible voltage violations, causing increased losses and excess of the foreseen operational limits for different components.

Small-scale hydropower generation varies typically **according to the seasonal water inflow** (precipitation and snow smelting). Stations having a reservoir are less dependent on the seasonal variation but often have to limit or stop production in order to maintain the least water flow in the river. This causes seasonal voltage variations, which have to be resolved by, for example, switching On Load Tap Changer (OLTC) transformers, meaning additional costs for the local Distribution System Operator, DSO.

Small-scale hydropower normally is not dispatchable, which brings additional challenges related to potential imbalances both locally (bottlenecks) and at the system level (bottlenecks and frequency deviations).

There are also some economic and environmental limitations regarding **small-scale hydropower**. At present, there are about 11 TWh of electricity generated by small-scale hydropower in Norway, which is about 7% of annual production in general [101]. According to [102], the current small-scale hydropower capacity and the potential in Europe are 19.7 and 37.6 TW . In addition to this, approximately 400 sites (3.2 TWh) for small-scale hydropower are already approved for development [103], [104], but the building cannot be initiated due to prohibitively high construction costs. The construction costs vary a lot according to the local landscape. The potential sites are often situated in remote mountainous areas without roads or an electricity grid in the proximity. This means **very high initial capital expenditures** related to both constructions of the station itself and connection to the electricity grid [105]. It is natural to assume that this limitation is not national and can be equally discovered in other countries.

Environmental concerns often bring several limitations related to the construction and operation of small-scale hydropower as for example, the local fish stocks. This normally requires maintaining minimum water flow in the river and limiting or stopping generation in periods with low water inflow. In addition, the environmental limitations may not allow the construction of the grid connection.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

4.1.1.2.4 Wave and tidal energy generation

Regarding wave and tidal technologies, there are several technical and infrastructure challenges that they need to overcome [106] in other to be competitive.

Lack of maturity. Because these technologies are quite new, they may face non-expected challenges. In order to avoid these challenges appearing on the deployment over the ocean, it is of high importance to identify them at the R&D stages and overcome them by means of task testing.

Limited site availability. As in the case of all renewable energies having a good resource is of vital importance. For this, it is necessary to find a good site. In the case of ocean energies, this is a complex process as it implies having specific information, such as high-resolution maps, which normally are not largely available.

Harsh environment. All the components need to be designed to be stress-resistant so that they can face not only extreme atmospheric conditions but corrosion for long periods. Among others, the main climatic conditions that adversely impact offshore renewables are the high humidity and high salt concentration in the atmosphere and, depending on the location, high wind, currents and waves on a regular basis. The installation of wave/tidal generation systems is technologically challenging due to the underwater location.

Electrical grid infrastructure and capacity. In most cases, there is not an offshore grid connection available. The commissioning of the connection cables implies a high capital cost. Another issue deals with the onshore grid connection capacity since, in many cases, wave and tidal farms are connected to small and very often unstable coastal areas.

As far as wave energy is concerned, energy conversion devices have a **lower Technology Readiness Level** (TRL) than that of tidal energy and their deployments are in most cases restricted to demonstration and pilot projects [107]. This has led to a global installed capacity of only 2.5 MW [106].

Another complementary barrier associated with **wave/tidal generation** are **socio-political limitations**. For example, when analysing political limitations Ocean Governance takes on special significance since more than two-thirds of the ocean, the so-called High Seas, do not belong to a specific Government. In fact, they are part of the global commons and governed by all nations [108]. This may derive in ownership disputes, especially where other activities are already in place, such as conservation, shipping, etc.

Another critical issue is that relevant stakeholders (i.e. policymakers, civil servants and regulators) do not have the **essential technology awareness** of ocean technologies. Nowadays, these actors lack the necessary technology awareness that is needed to advance wave and tidal technologies [106].

Finally, it is of high importance the social acceptance of these technologies. For example, the **visual impacts** of ocean energies may provoke rejection from the surroundings communities [106].

The low maturity of wave and tidal technologies, the uncertainties derived from lack of familiarity and operation experience together with the **high initial capital expenditures** ([21], [109]) and

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

Levelized Cost of Energy (LCOE) have a direct effect on the following economic and financial aspects [106]:

Competitiveness. Given the small number of operational wave and tidal power plants, it is not easy to have an accurate estimation of the LCOE of these technologies. However, and considering the current estimation, these technologies are not competitive, mostly due to their high initial capital expenditure and LCOE.

Funding. The uncertainties derived from the technology maturity and performance can be perceived as high risk and can act as a major blockage in securing funding for such technologies.

Robust supply and value chains. The lack of familiarity and operational experience can make the wave and tidal technologies to be perceived as risky. This makes it difficult to find suitable funding sources. Additionally, due to the fact that there are few standardised components, availability challenges may appear in the supply and value chains in many cases.

There are environmental challenges that wave and tidal technologies need to overcome [106].

Unknown negative impacts. Current environmental impact knowledge is based on a few small individual prototypes with no experience in arrays deployment. Negative impacts could arise in the form of animal-turbine/device interactions, noise, electromagnetic fields (EMF) produced and habitat loss. Some impacts could be assessed from other offshore applications, such as offshore wind (with current emerging floating wind turbines) ; however, these impacts need to be studied in detail since wave and tidal technologies usually have underwater moving parts [21] [107].

Coastal impacts. Coastal areas have a fragile environmental equilibrium. Small changes in ocean and river currents can geomorphologically modify beach areas. Current environmental impact knowledge is based on a few small individual prototypes with local environmental conditions. Also, the biological equilibrium may be affected, as relatively little is known about the effects of these technologies on marine life due to the early stage of technology deployment.

4.1.1.2.5 Concentrated solar generation (CSP)

The main technical limitations of CSP are the following:

Intermittency. Solar thermal energy, unlike energy produced by conventional production units, is not uninterrupted, and its operation depends to a large extent on weather phenomena, such as air temperature, wind density, wind speed, rainfall, solar radiation and seasonal changes [22] [110]. For this reason, CSP suffers from a lack of flexibility, whereas there are difficulties in the grid integration, especially of large plants. In addition, there is a seasonality in the production of energy from these solar thermal systems because the production is lower during the period of highest demand, in the winter when it is cloudy and days are shorter [29]. CSP has a major advantage over other renewable energy generation sources such as wind energy or PV, which is the ability to store the electricity surplus in the form of thermal energy.

Degradation. Some types of solar panels can cause problems in their operation in areas with frost or even show significant damage such as breakage of cover, piping, etc.

Obtaining permits and **grid access** are the main challenges for new CSP plants.

Access to water or gas networks for backup may be difficult in remote locations and will certainly become important if large numbers or large CSP plants are deployed in desert regions.

Heat losses. In conditions where there is a large temperature difference between the solar thermal system and the ambient temperature, high heat losses are observed, thus reducing the overall efficiency of the system. Poor insulation also results in additional heat losses [22] [30].

Large Spaces required. Most of the solar thermal plants require large areas for installation (except parabolic dishes, which have smaller space requirements). They also need to be in an area where there is a very high amount of radiation. This means that it cannot be built near residential and commercial areas.

Cost competitiveness Nowadays CSP is not competitive in electricity markets, except for remote areas such as islands or remote grids. Therefore its development depends on incentives [111] [112].

Wildlife Endangerment. Because some types of solar thermal plants use hundreds of massive mirrors, it can leave a negative impact on the animal wildlife, and it could endanger species.

Additional limitations of **CSP technology** are related to economic barriers :
High upfront/investment costs. The major drawback of CSP is that capital cost and maintenance cost is more expensive than other power stations. It is even more expensive than Solar PV Plants, with an increasing cost difference over the last years, which has recently favoured PV implementation over solar thermal. Several studies mention that the LCOE for Solar Thermal Plant is about 0.12 – 0.25 €/kWh, whereas solar PV systems only cost about 0.05 to 0.08 €/kWh.

4.1.1.2.6 Geothermal electricity generation

Despite the advantages related to the installation and operation of this technology, there are some limitations that should be considered before exploiting this source from a technical point of view.

One limitation is the **dependence on geotechnics**. Certain geotechnical conditions such as high underground temperature, natural hydrothermal fluid reservoirs and access to that fluid should be present to make geothermal power generation possible. Hence, it depends on the availability of the source. Moreover, the **surface instability** related to geothermal power generation during the construction also can be recognized as a disadvantage [78].

With a **discouraging efficiency**, when compared to other renewable energy sources, geothermal is not the preferred system to go for yet. Other disadvantages are:

Land subsidence: as a result of the hot water/steam flowing from the underground geothermal field, and due to the different soil responses to the injected fluid, the ground can be subject to cracking;

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

Induced landslides and seismic activities: the fluid circulation in the geothermal field and variation in the fluid pressure in a stressed ground formation can lead to rock fracture;

High water demand for the operation of the system;

Wastewater and contamination of soil nature: the wastewater from using water as heat transfer fluid is usually loaded by foreign materials which can be hazardous to the environment upon discharge to water bodies;

Noise is caused because of the machinery and equipment used during the construction and operation of the plant.

The main economic limitation of **geothermal electric generation** is the initial investment cost related to drilling costs, as well as the construction costs. Although the initial cost is large, the operating cost of a geothermal plant is low compared to conventional resources such as coal power plants.

Geothermal power plants can have some minor **GHG emissions,** contributing to global warming, acid rain, radiation and toxic smell. But these are negligible effects compared to large scale industrial emissions. However, these emissions can be further decreased using exhaust emission control systems [78].

4.1.1.2.7 Backup generators

The main technical challenges when installing a backup generator are the following:

- It needs **regular maintenance** (i.e., oil and filters replacement).
- It can be very **noisy** ; however, there are also soundproof barriers that owners can use to reduce the sound in the workplace.
- Fuel may not be accessible during a blackout, so it could **require local fuel storage**.
- It is **very bulky** and has large and heavy components [113], [114].
- Installation of diesel-generator **requires space** and infrastructure, including cooling, exhaust, air and fuel supply systems. It is therefore difficult to retrofit diesel-generators systems into existing premises.

The main economic limitation due to **backup generators** is the **price of diesel fuel,** which will continue to rise due to regulations. Additionally, the **cost of installation is expensive** compared to other types of generators. However, the low maintenance cost mitigates the effect [113] [114].

Environmental limitations of backup generators concern **high levels of emissions** of carbon dioxide, nitrogen oxide, particulate matter and exhaust gas. This effect is much higher with respect to the natural gas equivalent technology [113] [114].

4.1.1.2.8 Fuel cells

Stationary fuel cells are **less mature technology**, compared with conventional ones. The large majority of micro-CHP technologies are based on Stirling engine, Organic Rankine Cycle or Internal Combustion Engine (ICE) technologies, characterised by high heat-to-power ratios. Innovative technologies based on fuel cells were launched onto the market by two European funded projects, Ene.field (http://www.enefield.eu) and PACE (https://pace-energy.eu/), where more than 4,000 units have been demonstrated for residential and commercial applications.

Compared to other micro-cogeneration technologies, Fuel Cell micro-CHP has a low 'heat-to-power ratio'(meaning it produces a relatively low amount of heat and a relatively high amount of electricity compared to other micro-CHP technologies), and it is well suited to the evolving trend in buildings towards higher electricity use and low space heating demand. In these installations, Fuel Cell micro-cogeneration systems are fed by natural gas to produce both heat and electricity for an end-user.

A common barrier to all fuel cell technologies is that their **transient behaviour** is considered to be relatively slow, making them ineffective in peak shaving or emergency loads uptake.

Nevertheless, in spite of the positive and great evolvement of fuel cells technologies in stationary applications, there still are some other technical barriers that are analysed below for each type of fuel cell.

- **Polymer Electrolyte Membrane Cells (PEMFC)**: the performance of PEMFC fuel cells can be influenced by many parameters, such as operating temperature, pressure and humidification of the gas streams. Therefore, in order to improve the FC performances, it is essential to know these parametric effects on the FC operations.
- **Phosphoric Acid Fuel Cells (PAFC)**: if compared to other fuel cell types of the same size, the PAFC is less powerful, and as a consequence, it is bulkier. The identification of the best FC size represents a key target resulting in significant economic savings.
- **Alkaline Fuel Cells (AFC)**: this type of FC is easily poisoned by CO_2, which can affect its performance. A purification process needs to be implemented frequently by increasing the operational costs. Moreover, also the durability of this FC is affected by this poisoning. The material durability is another technical barrier to overcome.
- **Molten Carbonate Fuel Cells (MCFC)**: this type of FC presents the key technical barrier of durability, considering the high operating temperatures that can cause corrosion.
- **Solid Oxide Fuel Cells (SOFC)**: also this FC is affected by the technical barrier of durability related to the high operating temperatures. Moreover, they are characterized by a very long start-up time (several hours).

Relevant use cases may integrate the use of FC stationary applications with hydrogen as a primary energy vector. Renewable hydrogen-based configurations imply higher requirements than micro-CHP, being necessary to purchase renewable generators (usually PV panels) and hydrogen chain technologies separately. In these cases, barriers and limitations can be linked to the **presence of hydrogen storage on-site**.

The **high investment cost** associated with FC technologies can be considered the primary challenge to procurement around Europe. These technologies typically cost ten times more than conventional CHP systems. Even FC systems have higher investment costs ; they have lower operational and maintenance costs than ICEs and gas turbines.

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement N° 957779

4.1.1.3 H_2 production technical limitations

4.1.1.3.1 Electrolysers

The main technical limitations of green H_2 production are the following :

Complexity and new infrastructure requirements. Demand for low-carbon hydrogen can come from a variety of sectors, and there are many permutations of hydrogen supply and handling that could meet it. For each possible value chain, investments and policies need to be synchronised in scale and time if hydrogen is to be produced and delivered to end-users that are ready to use it.

Not only the deployment of large-scale electrolysis capacity is necessary but also infrastructure such as pipeline, delivery networks and hydrogen refuelling stations is of particular importance for a new energy carrier such as hydrogen other than the H_2 final users, allowing to sustain a spontaneous supply-demand scheme.

The ability of governments to commit to large (and necessary) infrastructure investments other than fostering H_2 final users is limited in many countries and regions: public-private investment models can help but may add further complexity. In some cases, these investments will also need to be coordinated across borders, requiring international collaboration at a level not yet seen for hydrogen [38] [40].

Safety risks. Hydrogen – as well as any other combustible gas – comes with safety risks (related to the production, storage and utilization phases) which must be properly addressed from a plant design and engineering point of view in synergy with the international/national regulatory framework [115]. Although such aspects can be easily managed at large-scale industrial or commercial plant level (where hydrogen has been used in processes for many years), the installation at small-scale residential level is challenging, and it is still not yet clear how citizens will react to these aspects of hydrogen.

In addition, due to the high energy intensity, electrolysers **can represent a large additional electrical load** when the capacity is upscaled, which could represent an issue in weaker or electricity grids. In fact, electrolyser capacity deployment should always be carried out in synergy with RES capacity deployment or in relation to existing curtailment issues (possibly co-locating the two plants) to strengthen the grid rather than to weaken it with additional transport and distribution requirements (when RES and electrolyser plants are installed in different locations) [116].

High cost. Most applications for low-carbon hydrogen are not cost-competitive without direct government support. Yet the relative costs of producing hydrogen from different sources in different regions and how they will compete in the future are unclear. This makes it difficult to compare potential future hydrogen prices with those of alternatives such as solid-state batteries, pumped-storage hydropower, electric vehicles, biofuels and electrification of high-temperature heat, many of which have head starts and could reap the benefits of path dependency.

In addition, the business cases of hydrogen production plants by electrolysis are mainly **driven by the cost of electricity**, leading to cost-competitive H_2 production in low-cost electricity regions – possibly leading to an asymmetry in the global H_2 production price, which will advantage some countries greatly respect to others [117].

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement N° 957779

In the case of fuel cells and electrolysers systems, the speed of cost reduction is a key factor, yet experts disagree on the relationship between the scale of fuel cell demand, cost and performance improvements [40].

4.1.2 Technical limitations in Energy Storage

4.1.2.1 Thermal energy storage technical limitations

4.1.2.1.1 Sensible heat and Cold Energy Storage

SHTES and SCTES systems are mature technologies. The most relevant technical limitations to be considered are related to the storage material and are the following:

Overall tanks dimension. The low thermal capacity of the typical storage medium used often requires big storage tanks for assuring to accumulate the required thermal energy. For many applications, such as residential ones, this aspect could represent a severe limitation. With the same amount of stored thermal energy, a SHTES/SCTES tank can be even six times larger than a latent heat thermal storage tank.

Thermal losses. The higher the storage medium temperature, the higher the amount of accumulated thermal energy. However, thermal losses strongly depend on the temperature of the storage materials. This aspect is crucial for large heat storage systems or for heat storage systems characterized by large heat exchange surfaces with the external environment, as in the case of seasonal heat storage systems. Therefore, in the designing phase of a seasonal thermal storage system, it is necessary to determine the right compromise between the temperature of the storage material at the end of the charging and the total volume of the storage system for assuring good storing performance and restricted thermal losses.

Similarly, this limitation affects also SCTES systems: the lower the storage medium temperature, the higher the amount of accumulated thermal energy (cold), and the higher thermal losses.

Salt stability. The current two-tank molten salt systems installed within a solar thermal power plant is a proven and reliable technology, but the maximum operating temperature is limited to around 500°C for salt stability.

The main economic barrier of **Sensible heat and cold energy storage** is the storage materials cost. The choice of the storage material is affected by high costs. For that, in most of the thermal storage systems applications, low-cost or zero-cost thermal storage materials are used, such as water, gravel, and soil.

4.1.2.1.2 Latent Heat and Cold Energy Storage

PCM-based LHTES and LCTES systems are a new technology compared with sensible conventional heat thermal energy storage systems. Applications beyond prototypes are very few. The most

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement N° 957779

relevant technical limitation to be considered are related to the storage material and are reported in the following:

Applications. The advantages related to the use of LHTES systems strongly depend on the choice of the specific storage material for the specific application. The choice of the storage material has to take into account some essential technical factors [118], listed below.

• *Thermodynamic properties*:
- the melting point at the desired operating temperature;
- high latent heat of fusion per unit mass, so that fewer material stores a given amount of energy;
- high density, so that less volume is occupied by the materials;
- high specific heat, so that significant sensible TES can also occur;
- high thermal conductivity, so that only small temperature differences are needed for charging and discharging the storage;
- congruent melting, the material should melt completely so that the liquid and solid phases are homogenous;
- small volume changes during phase transition so that a simple container and heat exchanger can be used.

• *Kinetic properties*:
- high nucleation rate to prevent subcooling;
- high crystallization rate.

• *Chemical properties*:
- reversible melting / solidification cycle;
- chemical stability;
- non-perishable after a high number of cycles;
- not corrosive;
- non-toxic, non-flammable and non-explosive.

Subcooling. Subcooling is a phenomenon in which the PCM does not immediately solidify once it reaches its melting temperature, but it begins the phase transition at lower temperatures.

Phase separation. Non-pure PCMs, such as hydrated salts and some eutectics, may undergo phase separation during the melting process due to the different density values present in the mixtures. This alters the PCM, which may not retain its homogeneity characteristics in subsequent cycles.

Low thermal conductivity. PCMs are, in general, characterized by very low thermal conductivity that may involve too low heat exchange rates and too slow solidification/melting cycles, which could cause storage systems failures. Furthermore, low values of the thermal conductivity require larger heat exchange surfaces, determining the decrease of the system's compactness. Therefore, having a good thermal exchange between PCM and a heat transfer fluid or between PCM and the surrounding environment is essential to obtain compactness and thermal efficiency as high as possible.

Corrosive. Many PCM materials are corrosive, affecting the housing material of the storage tank.

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement N° 957779

The high investment cost associated with the storage material used in **Latent heat and cold energy storage** can be considered the primary challenge to the procurement around Europe. These technologies can cost up to ten times more than conventional materials for sensible heat storage applications. Additionally, environmental barriers consist in the toxicity of some storage materials. It is necessary to take this limitation into consideration when designing the storage system, both for possible damage to the user and for the disposal of materials at the end of their life.

4.1.2.1.3 Thermochemical heat and cold energy storage

Although sensible heat storage systems and latent heat storage systems have been heavily researched and are widely used domestically and industrially, thermochemical heat storage (THS) systems are currently undergoing a surge in research and development.

Recent studies suggest that THS has significant advantages when compared with the other heat storage methods, including higher storage density, lower volume requirements, low heat loss (approaching zero), and lower charging temperature. On the other hand, the **complexity** and **higher investment costs** remain the main obstacles to rolling out these systems commercially.

In contrast to other energy storage like sensible or latent energy storage, high energy densities are possible, as well as long storage times and transport, if necessary. Furthermore, the operating conditions can vary in a wide range of temperatures and pressures depending on the TCES system in use.

Maturity. Thermochemical energy storage is a very young field of research where many areas are still unknown. Thus, there is much to gain; however, strong efforts are necessary to develop practical TCES systems and bridge fundamental research with the application. The cost of the chemical material and its energy density, its kinetics, and cycle stability for loading heat and heat release, the storage–reactor systems, and their design are all important characteristics.

The main fields in which strong efforts are necessary to develop practical TCES systems and bridge the gap from fundamental research to application are the discovery of cost-effective, abundant and affordable chemical materials with high energy densities and cycle stability [119].

In order to create thermochemical heat storage, many materials are needed, including toxic, having a bad impact on the environment. Keep this in mind when using and disposing of the device. Many materials are needed to manufacture thermochemical heat storage devices, some of which are **toxic/environmentally harmful**.

Currently, the use of thermochemical energy storage by ordinary users is hampered by its high purchase cost of 8–100 €/kWh. For comparison: explicit heat storage (e.g., water) costs 0.1–10 €/kWh, whereas warehouses based on phase change materials can be purchased for 10–50 €/kWh [120] [121].

4.1.2.2 Local electricity storage technical limitations

4.1.2.2.1 Electrochemical batteries

There are several technical barriers that affect the different types of electrochemical batteries:

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

Low energy densities. Current battery technologies still have energy densities between one and two orders of magnitude lower than traditional chemical energy carriers such as hydrocarbons.

Another technical limitation regarding the installation of batteries in the power system comes from the **discharge time of the system**, which limits the type of service that can be provided by the storage. Batteries are easily scalable in power and energy, but the cost increases in proportion to the size. Normally, 1-2 hours battery systems are installed in Europe (4 hours in the USA), meaning that full power can only be provided for around 2 hours. Normally, batteries are expected to be used for applications limited to a maximum of 10 hours.

Another technical limitation of batteries is **degradation**. In the case of the power system, proper sizing of the battery system should be carried out to be able to provide the requested service both at the first and last year of their lifetime. Operation conditions will be important to maximise the lifetime of the batteries.

Physical space might be a limitation for battery systems, especially in urban environments when it needs to be connected to an already existing infrastructure. Substations, especially if they are Gas Insulated Electrical Substations (GIS), but also if they are located in a populated area, do not normally have much space to build new installations. Therefore, depending on the size, the installation of a new battery system might be difficult.

Reference [122] identifies the gaps between the targets and performance for electrochemical storage to support the EU SET-plan, which focusses on the weaknesses of each technology (additional information has been added to that from [122], see also Table 3 in 3.2.2.1):

- **Lead-acid**: advanced lead batteries have improved cycle lifetime and improved performance at partial state of charge (SoC). However, research is needed to improve further both characteristics. Other aspects to be improved: specific power and energy density, charge efficiency, long charging time, sensibility to temperature, maintenance requirements and low cycle life and reliability.
- **Lithium-ion**: further improvements in performance (energy density, cycle life) and cost are still expected. One of the challenges of lithium-ion is the supply limitations that may occur in the future, especially of materials widely used today as Cobalt. Abundant and sustainable raw materials are required to meet the expected future needs of batteries. Recycling is complex and needs to be improved (high costs and environmental impacts). Modules made up of lithium-ion cells require a control (Battery Management System) to operate safely. A deeper analysis of the technical limitations of this specific battery technology will be done in the technical limitations associated with mobility in subsection 4.1.3.1 of this document.
- **NaS**: These batteries operate at 300°C, and they have insulation and active heating. If the temperature is not maintained inside the correct threshold, the resulting freeze-thaw cycles and thermal expansion can lead to mechanical stresses, damaging seals and other cell components, including the electrolyte. Aspects that need to be improved in this type of cell are the power rate, the cycle life, higher energy density and cost reduction (currently, they have a high CAPEX). The technology is not completely mature.
- **Flow battery**: for vanadium redox flow batteries, there are two main challenges, substantial cost reduction (that could be achieved by reaching a volume level that will allow for

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 957779

economies of scale) and a better lifetime of the membrane. Other characteristics that could be improved is the power and energy density (high land occupation) and round-trip efficiency.

No single technology is able to serve all the high-energy and high-power of grid and microgrids needs. High-energy applications require storage devices to discharge their energy at rated power for longer than one hour and high-power applications often need storage to discharge all their energy within an hour, or often a much shorter time. In addition, storage technologies in the stationary-applications sector will be required to perform multiple or bundled applications, such as a combination of load levelling, frequency regulation and backup power.

4.1.2.2.2 Supercapacitors and flywheels

Power technologies such as supercapacitors and flywheels are only considered as part of hybrid systems due to their limited energy storage capability, which is not well-matched to the demands required by CES applications [123]. Additionally, the main limitations of these electric storage technologies are the same:

Low Energy Density. Much research is being done on this topic to find solutions to this problem. For supercapacitors, along with electrode material, electrolytes with a stable and wide potential window along with good ionic conductivity are needed. Also, the compatibility issues between the pore size of electrode material and ion size of the electrolyte should be taken into account in order to fully explore the utilization of porous surface of electrode material [124]. However, the low energy density is compensated by their high power density, which makes them a suitable technology for hybridization with batteries, for example, which have poorer performances at high power rates (above 1 C-rate). Flywheels are presently able to store energy for only a couple of hours.

High self-discharge rates. Supercapacitors are not well-suited for long-time energy storage. The self-discharge rate of supercapacitors is significantly higher than that of lithium-ion batteries. Supercapacitors can lose as much as 10-20% of their charge per day due to self-discharge [125].

The self-discharge rate of flywheels is also significantly higher than lithium-ion batteries. The flywheels are not good for long-term energy storage due to the frictional forces that occur reducing the efficiency of the flywheel assembly during operation.

Vibrations. The flywheel shaft, the bearings and the housing constitute an elastic structure that could oscillate. Therefore, a crucial aspect when designing this device is to ensure stable dynamical behaviour.

The main economic limitations related to supercapacitors and flywheels are the **high initial cost**. Regarding the European Energy Storage Technology Development Roadmap Towards 2030, the capital cost of supercapacitors was estimated in the range of 1100 to 2000 €/kW.

The cost of a flywheel can be broken down into two almost independent elements: (1) the flywheel rotor with bearings, casings, and ancillaries such as the vacuum pump (FW), and (2) the MG with the power electronics, including grid-tie inverter (MGPE). Flywheel systems are characterised by low power capital costs but **high energy capital costs**.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

Some supercapacitors have aqueous electrolytes that may contain **hazardous materials** such as methyl cyanide or potassium hydroxide. Other electrolytes used in these devices, such as acetonitrile, are flammable and can release hydrogen cyanide when burned. Like batteries, supercapacitors must be **properly recycled** at the end of their operating life.

4.1.2.2.3 Compressed Air Energy Storage (CAES)

The main technical limitations related to CAES systems are:

CAES still presents **low round trip efficiency** (plants in operation achieve between 40 to 54%)

In order to preheat the compressed air before expanding it in the turbine, natural gas is used for this purpose, and therefore the process is **not CO_2 neutral** anymore, causing environmental issues and an increment of the total price of the CAES system due to its dependency of natural gas price.
Site selection is somewhat limited since it needs the presence of mines, caverns, and certain geological formations.

As is the case with any energy conversion, certain losses are inevitable. Less energy eventually makes it to the grid if it passes through the CAES system than in a similar system without storage.

The underground geology is likely perceived as a **risk issue** by utilities [126] [127] [128]

The **initial investment cost** (mainly reservoir construction) and **maintenance cost** of the **CAES systems are high** compared to other technologies. In particular, the capital costs vary between 60-70% of the overall CAES system cost, including the cost of setting up the underground storage intercoolers for dissipating the heat and compressors and expanders for the air [129]. Additionally, there is **not available an "off-the-shelf" solution** and the current steam turbine equipment has to be adapted to the special thermodynamic specification of CAES power plants, increasing the cost of the installation.

4.1.2.2.4 Liquid Air Energy Storage (LAES)

So far, there is a lack of LAES commercial installations, and therefore, practical studies regarding the enhancement of their performance are not so spread in the scientific literature (few pilot plants available). The main limitations associated with this storage technology are:

Low round trip efficiency: numerical studies show round trip efficiency between 50-60%, but some pilot plants struggle to reach 10-15% overall [130]: this is due mainly to the embedding of energy recovery interventions within the plant. For instance, effective heat and cold recycling can be used to close the gap between real and theoretical efficiency.

It is worth noting that the efficiency is anyway much lower than batteries and pumped-hydro, but similar to CAES and chemical storage as well.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

Small-scale plants limit: in comparison with to batteries, the LAES technology is not practical for small-scale energy storage. If it plays a role in the future energy system, it will be for grid balancing and maybe as backup power for neighbourhoods or large buildings [131].

Safety: since nitrogen and oxygen have different boiling points, there is a risk of concentration of oxygen and possible subsequent explosion. In addition, the very low operating temperatures can be hazardous to both people and materials [131].

4.1.2.2.5 Pumped-hydro power plants

When considering technical limitations of a small-scale PHPP, some of them are specific to the type of installation considered, e.g. a PHPP in a residential building, while others do not depend on the type of installation. Different types of small-scale PHPP found so far in the literature are listed below, along with the most important technical limitations relevant to such installations:

Existing buildings. Some technical limitations arise when a PHPP is installed in an existing building.

- **Structural integrity limitations**: the placement and sizing of the upper reservoir (normally water tanks) must take into account the maximum allowable load that was considered when the structure was calculated. As an example, according to the Eurocode, the maximum load allowed on buildings is 1500 kg/m^2. The maximum allowable load limits the size of the upper reservoir and, therefore, the capacity of the PHPP. The impact of this limitation is different depending on the height of the building; in the case of skyscrapers, the placement of different water tanks connected in series on several floors might be possible [132].
- The sizing of the lower reservoir is constrained by the available space in the basement of the buildings, which usually will be small, requiring a compact configuration of the hydraulic machines [133].
- The use of the existing water supply pipe network in the building is not always feasible. Pressure consistency between the water supply pipe network and the one of the PHPP cannot always be guaranteed [59]. On the other hand, open reservoirs in buildings are exposed to debris. Should the PHPP be integrated into the existing water supply pipe network, some water treatment measures would be required (a filtering system, among others).

Existing water infrastructures. Some technical limitations to the installation of PHPPs in existing water infrastructures, such as drinking water supply systems and systems for wastewater treatment, are listed below:

- There is a lack of information on in-conduit hydraulic machines that makes it difficult to select the appropriate machines [134].
- The use of a probabilistic approach to consider the uncertainty in the drinking water demand is crucial to evaluate the viability of the PHPP [135].
- The operating conditions (pressure and flow rate) in water supply systems are highly variable. This makes both the selection and operation of the PHPP difficult [135].

Solar water pumping. The use of photovoltaic energy to pump water from open wells to an above-ground water tank for both drinking and irrigation water supply purposes may be an effective solution in remote rural areas [136]. When considering the installation of a PHPP using an open well

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

as a lower reservoir and a tank above ground as a upper reservoir, some technical limitations may arise, such as:

- The lack of understanding of the hydrogeomechanical properties of the wells can jeopardize their structural integrity [137].
- The potential groundwater contamination by particles may pose an important risk to the integrity of the hydraulic machinery [60].

As mentioned above, there are other technical limitations to the deployment of small-scale PHPPs that are not primarily dependent on the type of installation, but rather are mainly related to the availability and performance of the hydraulic machinery of the PHPP, such as:

- There are not many “off-the-shelf” turbines well suited to the typical operating conditions in the above-mentioned applications. They are usually tailor-made for each particular site [135]. This has an impact on both the investment and maintenance costs as spare parts are hardly available [138].
- Efficiencies of pico and micro-hydro turbines are significantly lower than those of large turbines [132], [139].
- The above-mentioned limitations often lead to opting for the use of pumps operating in reverse mode, usually referred to as pump as turbine (PAT) [140]. Centrifugal pumps, as well as their spare parts, are available in almost every region of the world for a wide range of heads and flow rates [141]. In addition, the use of a single hydraulic machine allows reducing the cost of the PHPP’s hydraulic circuit.
- There is very limited information about the performance of pumps operating in turbine mode [142].
- The efficiencies of pumps operating as turbines reported in the literature are lower than those of large turbines and of the same order of magnitude as those of pico and microturbines [143].

In most of the above-mentioned applications, the operating conditions are highly variable. This might require the use of variable speed drives so as to reduce the hydraulic efficiency loss due to such variable conditions [144].

Regarding larger PHPP plants as those used in island hubs, the environmental impact is significant. The dams required to create the upper and lower reservoirs change the natural water temperatures, water chemistry and river flow characteristics, blocking or diverting the natural course of the river. Damming rivers reduce the water flow, impacting downstream wildlife populations due to a reduction of the water nutrients. Additionally, this block can affect fish migration [145].

Also, dams have an impact on the surrounding landscape around the reservoirs. Pumped hydropower systems cause upstream flooding that destroys wildlife habitats and can even force to human populations to be relocated in other areas far away from their original settlements.

The capital cost of a PHPP is highly dependent upon location, and this cost is primarily related to the cost of the reservoir construction. Despite this, PHPP is still the cheapest energy storage in the world in terms of cost per kWh of capacity, reaching values of 110-200 $/kWh. The most significant cost of a PHPP is the reservoir (76 $/kWh) and powerhouse (742 $/kW) [146].

This project has received funding from the European Union’s Horizon 2020
research and innovation programme under grant agreement N° 957779

4.1.2.3 H_2 storage technical limitations

Hydrogen may be stored at higher density through different technologies, but few of these have reached commercial maturity for large scale applications. The option currently considered most promising, salt cavity storage, is not universally applicable. Therefore, alternative options should be considered. The current technologies for using hydrogen storage differ in approach, and there are still several technical limitations.

For **compressed H_2 gas storage**, there is a low amount of storage in low pressure, **high energy consumption** (about 20%) for compressing hydrogen up to 350 bars, low technology level for very high pressure (over 700 bar), too high volume and weight for compressed H_2 gas.

For **liquid storage**, there is still high consumption of energy for liquefaction, and there are still problems in the process of evaporation.

For **metal hydrides**, there is low storage density, and the technology is very expensive [147].

4.1.3 Main technical limitations in complementary technologies

4.1.3.1 Mobility

The main technical limitations regarding electric mobility are related to batteries and charging points.

One of the most important barriers in EVs is **scarce metals** that are used in batteries and electric motors. Several key elements in the making of Li-ion batters such as cobalt, lithium, nickel and copper are increasing their price exponentially as a consequence of limited supply [148]. Neodymium, terbium and dysprosium are also scarce and rare minerals used to build permanent magnets for EV motors [149].

Some of the reserves of these **raw materials are highly concentrated in a few countries** [150]. Some of them are labelled as conflict areas, and any political problem in these regions can generate a raw material shortage affecting the entire battery value chain.

Even if there were no raw material supply problems, **battery production is also highly concentrated in a few countries** [151], which can significantly affect the global electric vehicle (EV) market in the medium term.

As it was previously described in subsection 4.1.2.2.1, although the efficiency of EVs is much higher than that of ICE vehicles (85-90% in EVs vs 30-35% efficiency in ICE vehicles), the **energy density of Li-ion batteries is much lower than that of fossil fuels** (around 250 Wh/l- 300 Wh/kg vs 9.7 kWh/l-

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

12.2 kWh/kg for gasoline, 10.7 kWh/l-12.7 kWh/kg for diesel, 3.1 kWh/l-12.1 kWh/kg for natural gas), affecting the driving range and vehicle consumption of this type of vehicles significantly [151], [152]. Reducing the vehicle's weight using denser batteries would increase the maximum range and decrease the battery power demands due to the correlation between consumption and acceleration. In heavy road vehicles such as e-buses or e-trucks, these performance limitations are more significant.

Additionally, the variability of battery performance can create unexpected heavy road e-vehicles range limitations and intensify range anxiety among fleet operators. There is a significant variation in operational efficiency between current and lab-test energy efficiency figures due to traffic conditions, passenger load factor, weather (heat, cold, humidity and rain could impact battery performance), air conditioner usage and vehicle age.

For example, batteries lose effectiveness in cold weather since low temperatures decrease the rate at which the chemicals can react, affecting the energy stored. Cold temperatures also require extensive use of heating systems, which further drain the mileage capacity of the batteries. Hot temperatures can also have an impact on the vehicle range since running air conditioning requires a significant amount of battery capacity.

Similar limitations are found in the electrification of maritime transport. For example, considering the present limitations on the **capacity of electric batteries**, electrification of maritime transport has been focused on boats having a predictable cyclic operation with a short duration. Therefore, the first area for electrification of maritime transport included local ferries, which often operate at limited distances and have the possibility for frequent recharge of batteries during loading and unloading. Electrification of ferries in Norway started in 2015, when the first fully electric ferry, "Ampere", started regular operation, covering 5 km distance and transporting 120 cars onboard [153]. The operation of the first ferry proved to be successful, and by the end of 2020, there were already 30 ferries in regular service and this figure was expected to be doubled during 2021.

Several trials have been recently made for the electrification of coastal fishing [154] and supply boats [155], which are used for service and support of offshore operations in the petroleum sector. In contrast to ferries, these vessels typically have a less predictable operational pattern with frequent and rapid variations in power output, as well as variable range requirements demanding bunkering flexibility. The specific operational requirements point towards hybrid powertrains using hydrogen fuel cell-generated electricity combined with batteries as a zero-emission energy source alternative.

Apart from the limitation of operational range, the onboard systems on electric boats do not seem to have very strong limitations. Several boats with high requirements related to manoeuvrability and navigation already use electric transmission for their thrust and main propulsion units, for example, Azipods [156], which are powered by gensets.

The lifetime of the battery is also an important technical limitation. During the normal operation of the EV, batteries are deteriorated over time due to irreversible chemical and physical changes produced inside them during their usage. Battery ageing led to a lower battery capacity and to increase their internal resistance, reducing the global performance and range of the EVs [157].

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

Security. One of the biggest concerns related to Li-ion batteries in EVs is the use of organic liquid electrolytes, which are volatile and flammable when operating at high temperatures. A Battery Management System (BMS) which does not properly regulate the charging-recharging process and error during the battery manufacturing process or an external force such as a crash due to a driving accident can cause a chemical leak, which can lead to a fire or even an explosion, with the consequent security problem for users of EVs [158] [159] [160] [161].

Lack of charging points and poor maintenance of these elements. The deployment of electric vehicles and their associated infrastructure is not taking place at the same speed in all European countries. Therefore, travelling with EVs around Europe is more or less difficult depending on the current charging infrastructure already installed in each country [162].

Impact of the charging process on the distribution grid. A large deployment of road EVs can locally affect medium voltage distribution networks increasing power losses, voltage drops, overload lines and transformers (which could require upgrading grid components), degrading the power quality due to the generation of harmonics by the charging point rectifiers, generating phase imbalance for single-phase charging stations, etc. This impact can also affect a higher level of power systems, requiring investment in new generation power plants and reinforcement of the transmission networks [163] [164] [165] [166] [167].

Charging infrastructure for heavy road vehicles have also a higher impact on the electric utilities and the grid. The power demanded from the grid to charge e-buses and e-trucks requires careful consideration of the electric utility's rate structure since certain heavy EVs charging strategies require higher electric power requirements, incurring additional costs depending on the utility's use of energy charges, demand charges, and time-of-use charges. Transmission and distribution upgrades may be needed if the existing infrastructure cannot support the increased load, and these upgrades have their own planning requirements and construction schedules.

For electric ships and ferries is needed a sufficient onshore infrastructure, which will ensure charging of the batteries. In many cases, the charging has to happen in a very limited period of time. In the case of electric ferries, boats have 10-20 minutes for recharging during loading/unloading and several hours during nighttime. This requires fairly high network capacity, which should be available for the supply of the charging points. This is often a problem since ferries are often located in remote areas with a weak network connection. For example, the "Ampere" ferry uses lithium-ion batteries: one is installed onboard (500 kWh) and one battery (350 kWh) at each pier serving as buffers. The buffers were necessary due to fairly limited grid capacity and reduced load for the grid from 1.2 MW to 0.2 MW during 10 min charging [168].

Lack of vehicle-to-grid (V2G) capabilities. According to [169], several car manufacturers do not allow V2G capabilities due to warranty concerns and battery wear. However, this technology is being explored in Japan for resiliency benefits. To accomplish this task, Nissan has developed a V2G kit for homes, taking into account that in Japan, the average home uses 10–12 kWh a day, and a Nissan Leaf has a battery capacity of 24 kWh, it could supply power for two days during a disaster or grid failure.

The necessities, costs, and profits of the V2G technology must be balanced among the three main stakeholders [170]: vehicle manufacturers, vehicle owners, and network operators. The vehicle

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

manufacturer should set a fair price for the V2G capability in order to catch the interest of customers. The vehicle owner should receive a well-balanced incentive for allowing the network operator to use its vehicle to provide some grid service. Besides, the network operator must guarantee that the vehicle will be available for the owner needs. The network operator should obtain enough profit from the readiness of vehicles to make up for the extra cost of monitoring and controlling the power flow between the vehicles and the grid, paying owners, and managing the system.

Lack of information. Policymakers have a small understanding of heavy EV technologies (typical prices, average ranges, basic infrastructure needs, etc.) but also lack additional knowledge on the environmental, health, and economic benefits and disadvantages of adopting this technology. The current e-bus/e-truck market is emerging, and operators have difficulty finding reliable and up-to-date information to produce an accurate cost-benefit analysis of the efficacy of adopting this type of vehicle.

Uncertainties remain regarding the battery lifecycle and the residual value of the vehicles at their point of retirement. Almost no e-buses have been operating long enough to reach their estimated decommission date, so there is currently very little information on how long e-buses will actually last and how these old e-buses perform.

Battery manufacturing requires a very large and complex new supply chain, and it is very difficult to penetrate the global market, requiring a huge capital cost for a new vehicle manufacturer. EVs have a **higher upfront cost** mainly due to the cost of the battery pack. This cost has come down 98% since the 90s, reaching 100 $/kWh, and it is expected to drop further in the coming years [171].

Recycling. Some lithium-ion battery materials currently used in EVs are toxic, carcinogenic, or could undergo chemical reactions that produce hazardous heat or gases [172]. The current global percentage of recycled EV batteries is around 5% [173], but this percentage should be increased to reduce the impact of the decommissioned batteries over the coming years in the environment and also to decrease the need for new mining to get scare materials for new battery packs.

CO_2 emissions for EV charging. Despite the advantages of EVs of not emitting GHG locally in crowded cities, depending on the country's electricity generation mix, the electrification of the transportation sector may increase CO_2 emissions compared to the conventional ICE vehicles [174].

Vehicle servicing. Although EVs require less maintenance, there is a current lack of trained technicians to maintain and repair this type of vehicle.

The high up-front cost associated with e-buses and e-trucks is the primary challenge to deploying these vehicles around the world. These electric vehicles typically cost two-three times more than conventional diesel ones, although these numbers can vary.

These heavy electric vehicles have a **higher initial cost** for several reasons, mostly related to their status as a new technology:

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

- Unknown risks such as uncertainties concerning long-term battery performance, maintenance requirements, and the residual value of these vehicles also impact the financial options.
- Emerging marketplace which has not yet achieved efficient economies of scale in its production

4.1.3.2 Control and data management and technical security limitations

The energy management systems can be grouped in centralised and decentralised. Many existing control system platforms are based on centralized control strategy. This solution is preferable for real-time scheduling and small-scale system [175]. The usage of this type of control for large scale systems is difficult because there is a huge number of data to manage, and the computation time to find the best solution increases with the scale of the system [176].

In order to overcome problems of the computational burden of the centralised solutions for large scale systems, decentralised solutions can be used [176]. These approaches allow concentrating the power generators closer to high demand areas reducing the transmission losses and the energy poverty of the rural areas [177]. One of the most used techniques for decentralised decision making is the Multi-Agent System, but for real-time scheduling, the convergence speed is a critical aspect [175].

Software and hardware are fundamental parts of the energy hubs (communication drivers, databases, control algorithms, sensors, actuation devices, etc). Due to the presence of different energy carriers and systems and the complexity of connections between them, exchanging and processing a large volume of information, especially in an energy hub, requires the use of smart technologies and sufficient hardware capacity with high correlated costs [176]. Also, for the software, some tools can be open source or freeware, but others can be very expensive. For this reason, it is important to consider enough financial support for the management systems in order to have a successful implementation.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

4.2 Regulatory-policy limitations

Regulatory limitations refer to obstacles to the development and exploitation of different local energy resources due to external conditions, regulations and policies. In this section, the main **regulatory limitations** and shortcomings found in the analysis of the different technologies for optimal use of local resources are described. The regulatory constraints presented in this section are defined at the European level. The country-specific limitations are presented in Annex I.

4.2.1 Overview of the main EU regulatory policies

EU ratified the Paris Agreement in 2016 [178] and presented the Winter Package (“Clean Energy for all European” [179]) at the end of this year, with a number of revisions and new legislative proposals to foster the transition to a "clean energy economy" focusing on energy efficiency, renewable energy, new electricity market design, security of supply and new energy governance rules.

In November 2018, the EU presented "A Clean Planet for All", which defined the main pathways to reduce EU emissions by 2050 [180] and, at the end of 2019, the EU took a step forward and presented the European Green Deal with the objective of being the first climate-neutral continent in the world by the middle of the 21st century [181], covering all sectors of the economy, from transportation to energy, industry and agriculture, only to name a few.

On 4th March 2020, the EU Commission presented its proposal for a European Climate Law to ensure the EU meets its objectives [182], and since then, the EU has been legislating to align all EU policies in pursuit of these ambitious goals, presenting among others, the European Industrial Strategy (March 2020) [183], EU Strategies for energy system integration and hydrogen (July 2020) [184], 2030 Climate Target Plan (September 2020) [185], European Climate Pact (December 2020) [186], European Battery Alliance (December 2020) [187], New European Bauhaus (January 2021) [188], New Strategy on the adaptation of climate change (February 2021) [189], Zero Pollution Action Plan (May 2021) [190] and Sustainable blue economy (May 2021) [191].

The main EU Climate Policy Instruments are the following:

The **2030 Climate and Energy Framework** was presented in 2014 (and revised in 2018) has several targets for the period 2021-2030. These objectives include a reduction of at least 40% of GHG emissions compared to 1990 levels by 2030 and a minimum share of 32% for renewables (and at least a 32.5% improvement in energy efficiency) [192].

The **Emissions Trading Scheme (ETS)** determines a price for GHG emissions in the power generation, industry and transport sectors. This trading scheme affects all EU countries (plus Iceland, Liechtenstein and Norway) and is a cap-and-trade system, which sets the price of GHG emissions that electricity generators have to consider when deciding which fossil fuel power plants have to operate (such as coal or natural gas). By 2030, emissions under the ETS must be reduced by 43% from 2005 levels [193].

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 957779

Promotion of **low carbon technologies** by the EU Innovation Fund [194], creating financial incentives for investment in next-generation technologies of carbon capture and storage and utilisation (CCUS), renewable energy generation and energy storage and helping them to reach the market.

Renewable energy promotion through the **Renewable Energy Directive 2018/2001 (RED II)** [195] establishes a legally binding target of 32% renewables by 2030 without prioritising any technology over others. Renewable energy is defined as "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." Hydrogen produced from renewable energy sources is also covered by this Directive.

Internal Electricity Market Directive (IEM) 2019/944 [196] recognizes the increasing role of renewables in electricity generation and self-consumption, moving towards a decentralised generation and providing access to all consumers to all markets on equal terms.

Energy communities are defined in several European legislative acts and documents, but the formal definition was introduced in these two previous Directives. Renewable Energy Communities (RECs) were introduced and defined in RED II [195], and the concept of Citizen Energy Communities, which is a broader term than RECs, were introduced in the IEM Directive [196]. The main terms, definitions, roles and responsibilities of both terms are described in detail in eNeuron deliverable D2.1 [42] and deliverable D3.1 [197].

4.2.2 Regulatory barriers at generation level

4.2.2.1 Regulatory limitations at thermal generation level

Most of the regulatory barriers related to **thermal generation** are related to **environmental issues** such as GHG emissions (in biomass boilers, natural gas boilers, hybrid HP, etc.), the toxicity of fluids (in HP, hybrid HP, geothermal HP, etc.) and **security and installation procedures** such as maximum noise level, vibrations, resilence, etc.

There are other regulatory limitations related to market design. For example, the current EU legislation separately covers the heat and electricity market, thereby reducing the development of co- and tri-generation since these devices suffer barriers in both markets [198].

The European Committee for standardization (CEN) technical committee is influenced by the evolution of **gas boilers** and adapts their standardization works in line with the technologies. There are three main standards concerning gas boilers:

- CEN TC 238: test gases and appliance categories;
- CENTC 109: gas boilers;
- CEN TC 058: safety and control accessories for burners and boilers.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

CEN TC 238 [199]: it specifies the test gases, test pressures and categories of appliances relative to the use of gaseous fuels of the first, second and third families. It serves as a reference document in the specific standards for appliances that fall within the scope of the Council Directive on the approximation of the laws of Member States concerning gas appliances (90/396/EEC). This standard is transposing article 2-2 of the gas appliance directive 90/396//EEC. The standard makes recommendations for the use of the gases and pressures to be applied for the tests. The full procedure is given in the corresponding appliance standards. The test gases and the test pressures specified in CEN TC 238 are in principle intended to be used with all the appliances in order to establish conformity with the corresponding standards;

CEN TC 109 [200]: it is the technical committee that writes standards for gas boilers like the EN 15502-1 (generic standard) covering all boilers operating with gaseous fuels;

CEN TC 058 [201]: it is the technical committee which writes standards for safety equipment and accessories used to control the safety and operation of burners and boilers. If the boiler is equipped with electronic components or systems that perform a safety function, these musts meet the requirements of the following standards: i) NF EN 88-1: pressure regulators and associated safety devices for gas appliances; ii) NF EN 125: flame monitoring devices for appliances using gaseous fuels; iii) NF EN 12 6: multifunctional valves for appliances using gaseous fuels; iv) NF EN 161:2011: automatic shut-off valves for gas burners and gas appliances; NF EN 298: automatic control and safety systems for burners and appliances with or without fans using gaseous fuels; v) NF EN 12067-2: air/gas ratio control devices for gas burners and gas appliances - Part 2: Electronic devices; vi) NF EN 13611: auxiliary equipment for gas burners and gas appliances - General requirements; vii) NF EN 14459: control functions for electronic systems for gas burners and gas appliances - Classification and evaluation method; viii) EN 16340: combustion product sensing devices for gas burners and gas-burning appliances; and ix) EN 1854: pressure sensing devices for gas burners and gas-burning appliances.

The previous three mentioned standards must be strictly followed to have natural gas boilers that are in compliance with the EU regulations. However, the near energy future is going to face an important revolution so that other chemical elements (e.g., hydrogen (H_2)) will be deployed and injected into the natural gas grid to contribute to the decarbonisation of the energy sector. So far, the literature revealed that H_2 could be injected into the natural gas grid up to 5-10% volume in the near future, without the need for major modifications to transmission infrastructure and end-consumer installations. Nevertheless, it is expected an increase to 15-20% volume by the end of 2030, after making the necessary changes to the infrastructure and affected consumer installations [202]. As a consequence, the standards related to the natural gas boilers require a complete revision and update taking into account all the effects coming from the burning of an H_2-CH_4 mixture such as those on fuel and air volumetric flows, on water condensate production, on flashback and reactants ignition, on explosion hazard, on flame detection and controls, and on the material selection and its durability [203].

Even the International Energy Agency (IEA) has proposed to ban the sale of new fossil fuel boilers globally in order to achieve net-zero emissions by 2050 [6] ; the EU aims for a gradual phase-out avoiding banning gas boilers. Some European countries are already getting ahead and are banning the installation of gas boilers in new buildings by 2025 [204] and providing some financial incentives to install renewables-based heating systems such as HP or biomass boilers [205], but others still do

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

not have a defined policy to decarbonise this sector, which means that the withdrawal of this technology will not be made at the same speed throughout Europe.

In some countries or cities, new gas installations are not allowed without a justified cause, such as uneconomic or impossible access to DHW, so in those cases, the implementation of this technology would not be possible [206]. On the other hand, the electricity generation is a key aspect in those places where an electric grid is not present (e.g., rural zones), and renewables coupled with highly efficient energy conversion technology could completely fulfill the energy demand of the end-users located in these zones, thus not being dependent on the national electric grid anymore [207].

The installation of the gas boiler itself is not affected by any other regulatory constraints beyond meeting safety standards.

The only parameter regarding the **electric boilers** regulated by the European Union is the seasonal space heating energy efficiency. Further information regarding its calculation is provided by the Official Journal of the European Union C 207 [208].

Regulatory requirements for **steam boilers** vary from country to country. Depending upon availability, electricity or natural gas were normally used as reserve sources. N-1 requirements are often applied to district heating installations, meaning that the unit should have a configuration allowing to deliver heat in case of breakdown of one of the boilers. In Norway boiler units below 10 MW have exemptions from concession requirements [209].

In Ireland, ELVs (emission limit values) are applied to **biomass installations** if they come within the regulatory regime of the Environmental Protection Agency (EPA), i.e. if the biomass installation is part of a facility operating under an industrial emission (IE), an integrated pollution control (IPC) or a waste licence.

The directives applied are as follows:

- ELVs for large scale plants (i.e. >50 MW thermal input) are applied by the Directive 2010/75/EU and transposed through S.I. 137 and 138 of 2013, and thus have a legislative footing
- ELVs for medium scale plants (i.e. ≥1 MW to <50 MW thermal input) are applied by the transposition of the Directive 2015/2193/EC (‘the MCP Directive’), and have legislative footing when transposed, which was required by December 2017.
- The voluntary standard EN 303-5:2012 sets ELVs for appliances up to 500 kW (rated by heat output) [210].

Regarding **HP**, there are some regulatory limitations about the different types of refrigerants to be used. These refrigerants can be toxic, flammable or even explosive, and they can act as greenhouse gases with a certain global warming potential (GWP). This leads to a high-quality design and manufacturing of units, as well as demands on the skills of installers to dismantle and recover refrigerants . In case the refrigerant is released into the environment, it can have a negative effect no the atmosphere. The majority of residential units deployed today use hydrofluorocarbons, while in large/industrial size heat pumps, the use of natural refrigerants (Ammonia, Propane, CO_2) is more common. The use of hydrofluorocarbons in Europe is regulated under (EU 517/2014) [211]. The implemented phase-down will reduce the availability of f-gases continuously until 2030.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 957779

Depending on the location and particularly in urban environments, local regulations will prevent the installation of external units of the HP due to environmental criteria (noise, vibration, external air heating) and/or aesthetics. Installations must meet the specific noise and vibration regulations existing in each country, city or even neighbourhood or street. For example, if external units are to be placed in common areas of a multifamily building, a common situation in Spain, an agreement with the community of property owners must be reached. Minimum distances apply regarding distance to neighbouring windows. Both national and municipality-specific regulations must be followed. Installation of external units in protected buildings is not allowed.

Regarding **ground source HP**, many European countries have no specific legislation on geothermal energy, or the regulation is so generic to be considered enough to support a widespread and safe diffusion of geothermal energy. The low quality or lack of unified and simple regulation on geothermal energy represents a major obstacle to its dissemination and scaling up of its implementation in a way that ensures sustainability and the absence of natural risks.

The most important regulations in European countries on geothermal energy are related to environmental protection, with a focus on safeguarding groundwater resources and regulating the use of water resources. Countries such as Germany, France, Austria and Switzerland, have specific national regulations with regard to different environmental or risk factors [212].

The general regulatory framework of the EU related to **CHP** is summarised in [213] [214] [215]. The cogeneration is supported by EU legislation, by Europe's Climate Bank and by the European Investment Bank. Its support in European Union Emissions Trading System - EU ETS, Sustainable Finance, European Regional Development Funds and Cohesion Funds or Just Transition Fund, is omitted or demands stricter requirements than the established EU legislation [216]. Moreover, the unpredictable and fragmented policy environments negatively influence the development of cogeneration in the EU [217] [218].

Currently, the EU legislation **separately covers the heat and electricity markets** (e.g. EU ETS, Energy Taxation Directive, EU electricity rules, Energy Efficiency Directive - EED, State Aid rules), and this reduces the growth of cogeneration and its benefits in Europe [216]. There is not a clear EU definition of waste heat at present and its potential applications, including but not limited to district heating.

Even though the requirements in the EED for TSOs/DSOs to promote and facilitate the connection of high efficiency cogeneration, the **actual procedures are lengty and expensive** [216].

There is not an imminent **plan for renewable and decarbonised gases**, and this absence affects the investments and their usage negatively in the most efficient solutions like cogeneration [216].

Besides, the **current evaluation methods** to measure the environmental benefits of cogeneration **are not appropriate** [216].

FC micro-CHP systems must compete with well-established technologies, and therefore, a non-discriminatory and technology open policy and legal frameworks at the EU and national level are needed in order to overcome the market roll-out phase [219] [220].

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement N° 957779

Despite the undeniable advantages of the FC micro-CHP systems with respect to NG-based CHP (high energy efficiency, less or almost zero pollutants, NOx, SOx, particulate, CO), their presence on the market is limited so far. Only a supportive policy and legal framework can accelerate the transition of the micro-CHP sector from emerging technology to full-scale commercialisation.

FC micro-CHP is also promoted as a grid balancing technology. The integration into the grid of its electricity production must be facilitated too and can benefit from feed-in tariffs by selling the surplus of their power generation to the grid (depending on national legislation).

Fuel cell micro-CHP is currently a product at an early market stage where volumes are low and hence product cost is high. The weaknesses of standard market processes in increasing volumes for such an innovative product against an established market product are well known. Only a supportive policy framework can accelerate the transition to mass commercialisation of fuel cell micro-CHP, which will bring important benefits to consumers and the energy system at large. Therefore, fuel cell micro-CHP systems must be recognised as one of the key technologies capable of delivering greenhouse gas and pollutant emission reductions, energy savings, integration of renewable energy sources and smart grid solutions.

One of the key obstacles in this respect is related to the fact that there is no common EU framework for connection of stationary fuel cells to the electricity grids. In general, the connection requirements are more general for all types of power generating units and are not specified for FC micro-CHP systems, causing possible cumbersome administrative procedures to install FC micro-CHP at the **domestic, residential and commercial level**. Another one is related to **the lack of a long-term support approach** including not only direct financial support but also the recognition of fuel cells in the energy efficiency policy mechanisms.

Simplified grid connection procedures and guaranteed access to the grid for electricity produced from high-efficiency micro-CHP systems as well as supportive measures for the produced electricity can further contribute to overcoming the roll-out phase successfully

4.2.2.2 Regulatory limitations at the electricity generation level

The main regulatory principles that affects the electric generation is **Renewable Energy Directive 2018/2001 (RED II)** [195] but there are several regulatory barriers at Member State level policy and incentives which have an impact on the **local distributed electricity generation**. For example, in recent years, several European countries have modified these government’s contracts unilaterally, affecting investor confidence. For this reason, a stable framework is required to develop and deploy these new technologies in the market, avoiding these **legal uncertainties**.

For all generation technologies, the **administrative process** for obtaining authorisation/licences are **complex**, which discourages investors. ENTSO-E has published a regulation for connection of generators [221] and demand connection code [222], but the administrative processes set by different DSOs for the connection of local generation technologies are still a barrier for the smaller domestic users.

Other barriers are related to the **electricity market**, with some difficulties for the participation of distributed and intermittent renewable sources in the balancing markets.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 957779

The provision of balancing energy is still mostly provided by conventional generators, as current balancing market arrangements are still in transition in some countries to accommodate other types of intermittent renewable energy sources such as PV systems and wind generators. Some countries already have the conditions to allow these generators to participate in the provision of energy on the balancing market, while other countries' balancing markets are still not developed to a stage where they can let these power generators participate. Even when these intermittent generators are allowed to provide balancing services, it is mostly for RR [100].

The WindEurope Association (EWEA) has conducted a survey to provide an overview of the balancing responsibility, including cost implications, of wind power generators in the EU countries [223]. The summary of this survey is given in the following table (see Table 6).

Table 6. Summary of the balancing responsibility in different European Countries [223]

Country	Are wind generators balancing responsible?	Are they treated differently from other generators?	Is the provision of balancing services allowed?
Belgium	Yes	No	Yes
Germany	Partly	N/A	Partly (only RR)
France	No	N/A	No
Spain	Yes	No	Yes
Portugal	No	N/A	N/A
Denmark	Yes	No	Yes
Finland	Yes	No	Yes
Norway	N/A	N/A	N/A
Sweden	Yes	No	Yes
Ireland	No	No	Yes

In recent years, the deployment of DERs at the distribution level, which is MV and LV, is quickly increasing. The increasing penetration of renewables at lower levels of national grids has shed light on the **need of revising grid codes at the distribution level** as system stability is at risk.

The revision of grid codes regarding DER penetration at the distribution level is still in process in most European Countries. Eventually, the traditional view on a passive interconnection of renewable generation plants at medium and low voltage is now shifting to a new paradigm, where active interconnection is required for system stability.

Concerning to the distribution network standards in the European Commission, the Directive 2014/35/EU about low voltage support is the only one existing [224]. It is applicable from April 2016, and the target audience is European citizens, which are the end-users of electricity. The objective of such Directive is the harmonisation of laws with regards to electrical equipment designed within certain voltage limits. The manufacturer must take all measures necessary to ensure compliance. This way, protection against hazards of LV equipment is guaranteed. The electrical devices on which this Directive applies are those with a voltage range between 50 V and 1000 V for alternate current or 75 V and 1500 V for direct current. As always, European Directives only specify principles, and therefore, the implementation and guidance are upon the responsibility of national authorities.

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement N° 957779

Related to CECs-RECs, IEM Directive 2019/944 [196] sets the rights and obligations of **CECs** in accordance with the roles they assume (final customers, producers, suppliers or DSOs), but the **national regulations transposing this have not yet been defined**. Furthermore, at this moment there are no common Pan-European rules which define all aspects of ownership and operation of these communities, and each Member State has certain variation in the regulatory market framework.

Regarding **PV systems**, national regulation in this sector has had a very important effect on its growth. For example, some of the support schemes implemented in the early stages of photovoltaic development did not take into account that the cost of solar panels was going to decrease so quickly in a brief period of time and the incentives to install these PV systems grew disproportionately, affecting either the budgets of the countries or charging the electricity bills paid by final consumers. Some countries, such as Spain and Italy, had to retroactively modify the payments that they had committed to with PV producers, reducing investor confidence and impact on the deployment of PV technology.

One of the first measures that were applied to promote the installation of PV panels at the domestic level was the “net metering” policy, which consists of making a balance between the energy consumed and injected from the buildings into the electricity grid. This net metering avoided the need to install expensive electrical storage systems, such as electrochemical batteries, and favoured the rapid deployment of solar panels. This policy was adopted in several European countries such as Belgium, Denmark, Holland, Portugal, etc. [225] [226] [227].

Because the cost of solar panels fell faster than legislators had initially expected, the number of PV installations began to grow; it was required to change the “net metering” policy, being replaced by self-consumption policies, which favour real-time local self-consumption of PV generation. Usually, these measures are well accompanied by a sales rate for the excess PV electricity injected into the grid.

In recent months, the EU has been promoting collective self-consumption in flats and condominiums, and different EU countries have approved new rules (Holland, Austria, Sweden, France, Germany, Spain, etc.). These schemes are based in the the concept of Renewable Energy Communities (REC) and Citizen Energy Communities (CEC) introduced in the Clean Energy for All Europeans package [179].

All above changes in the support schemes to the installation of PV panels have created an uncertain environment which may hinder the investments in such a technology.

RECs should be allowed to sell renewable energy production to their neighbours. For this purpose, it’s necessary to define some crucial issues as e.g. the perimeter within which transactions are permitted and the interaction between individuals within the REC and between them and other neighbouring RECs. These key components are now defined in national implementation in Member States [228].

Another important regulatory constraint is the **diversity of regulations** to be considered when installing local electric generation in LECs-RECs. These regulations are affected at different scales:

This project has received funding from the European Union’s Horizon 2020
research and innovation programme under grant agreement N° 957779

European, national, regional and local levels. Additionally, these regulations may be not directly related to electricity production. For example, the installation of solar pv rooftop or microwind turbines on buildings must also be compliant with several national and local building regulations. Marine renewable energy devices (specifically **wave and tidal**) have specific environmental requirements and must comply with the coastal legislation which are, in many cases, country specific [21]. Also **geothermal electricity generation** must comply with several environmental regulations, focusing mainly on groundwater resources safeguarding, in the framework of the legislation regulating water resources utilisation (as it happens in Germany, Netherlands, Austria and Switzerland). **Small-scale hydropower plants** in e.g. rural LECs-RECs are also affected by water river legislations that vary from country to country.

In the heat and power sector, the **Energy Efficiency Directive (2012/27/EU)** [229] and the increase in energy efficiency targets represent strong development opportunities for hydrogen as renewable gas and for **fuel cell micro-CHP**.. High-efficiency cogeneration is seen as an important technology to increase efficiency in the heating and cooling sector, and its deployment is fostered at various levels. The Directive promotes the use of technologies such as hydrogen FC micro-CHP.

This obligation for the EU Member States to lead a comprehensive assessment of the potential for high-efficiency cogeneration represents an opportunity for the fuel cell CHP and hydrogen industries to increase their visibility and demonstrate their technologies' potential for more energy-efficient and sustainable heating and cooling systems.

The installation of fuel cell-micro CHP units in buildings requires compliance with the regulations for use, storage and distribution of gaseous fuels and the Directive 2014/94/EU on the deployment of alternative fuels infrastructure [230]. The current regulations for the distribution and use of gaseous fuels and the regulation on the storage of chemical products do not meet with the hydrogen needs for residential or tertiary building installations that may arise if FC-micro CHP are used to cover part of the demand for heat and electricity in buildings. An update of these regulations on the production, storage and distribution of gaseous fuels such as hydrogen should be required at national level.

Regulatory limitations for **backup generators** are related to **emission limits**. The regulation (EU) 2016/1628 of the European Parliament and of the Council of 14 September 2016 establishes for all engines referred to in Article 2(1) emission limits for gaseous and particulate pollutants as well as the administrative and technical requirements relating to EU type-approval [231].

For the backup generators, the emission limits (see and from this document, Table II-1 and Table II-2 in Reference [231]) are applied for:

- category NRE: engines having a reference power of less than 560 kW used in place of Stage V engines of categories IWP, IWA, RLL or RLR;
- category NRG: engines having a reference power that is greater than 560 kW, exclusively for use in generating sets; engines for generating sets other than those having those characteristics are included in the categories NRE or NRS, according to their characteristics.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

Table 7. (Table II-1: Stage V emission limits for engine category NRE defined in point (1) of Article 4(1) from [231])

Emission stage	Engine sub-category	Power range	Ignition type	CO	HC	NOx	PM mass	PN	A
		kW		g/kWh	g/kWh	g/kWh	g/kWh	#/kWh	
Stage V	NRE-v-1	0 < P < 8	CI	8	(HC + NOx ≤ 7,50)		0,40 (1)	—	1,1
	NRE-c-1								
Stage V	NRE-v-2	8 ≤ P < 19	CI	6,6	(HC + NOx ≤ 7,50)		0,4	—	1,1
	NRE-c-2								
Stage V	NRE-v-3	19 ≤ P < 37	CI	5	(HC + NOx ≤ 4,70)		0,015	1 × 10 12	1,1
	NRE-c-3								
Stage V	NRE-v-4	37 ≤ P < 56	CI	5	(HC + NOx ≤ 4,70)		0,015	1 × 10 12	1,1
	NRE-c-4								
Stage V	NRE-v-5	56 ≤ P < 130	all	5	0,19	0,4	0,015	1 × 10 12	1,1
	NRE-c-5								
Stage V	NRE-v-6	130 ≤ P ≤ 560	all	3,5	0,19	0,4	0,015	1 × 10 12	1,1
	NRE-c-6								
Stage V	NRE-v-7	P > 560	all	3,5	0,19	3,5	0,045	—	6
	NRE-c-7								
(1) 0,60 for hand-startable, air-cooled direct injection engines.									

Table 8. (Table II-2: Stage V emission limits for engine category NRG defined in point (2) of Article 4(1) from [231])

Emission stage	Engine sub-category	Power range	Ignition type	CO	HC	NOx	PM mass	PN	A
		kW		g/kWh	g/kWh	g/kWh	g/kWh	#/kWh	
Stage V	NRG-v-1	P > 560	all	3,5	0,19	0,67	0,035	—	6
	NRG-c-1								

4.2.2.3 H_2 production

There are several regulatory barriers related to **hydrogen**. The first regulatory limitation is the lack of a **common definition and classification** for hydrogen at the EU level (green, blue, pink and brown hydrogen) and the difficulty to determine the renewable origin of the electricity used for H_2production.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

Another barrier is to develop a **fair policy for H_2 production**. For example, if green hydrogen production is supported by subsiding electrolysers or electricity, it could give an unfair advantage compared to other types of H_2 production (i.e. generating H_2 from biomethane) [232].
Although some documentation is available at the international level (standards by ISO/TC 197 - Hydrogen technologies [233]), the documentation is still at an **international standardisation level** which only provides technical and practical guidelines – which are implemented only on a voluntary basis [219].

There is no common EU framework (in terms of compulsory regulations/prescriptions) for installation of Hydrogen generation - electrolyser and their interconnection to the electricity grids or to the transport sector; therefore, each country relies on specific national regulations which set the prescriptions for the installation and national authorities having jurisdiction on the approval of the permitting procedures.

The **roles and responsibilities of the market and regulated players** in the production of hydrogen are **not currently defined**. Therefore, it is necessary to define regulations regarding ownership, production and storage of H_2 installations. In particular, there are two alternatives related to the ownership and operation of electrolysers, one is the natural regulated monopoly, and the other is a commercial activity.

In addition, challenges can be faced in the **coupling of electrolyser systems with RES assets**, sometimes requiring double permitting from a grid connection point of view since the DSO/TSO consider the plants separately, although there is only one common Point of Connection.

Hydrogen components designed to use compressed (gaseous) hydrogen shall be tested in accordance with the test procedures set out in each country with regard to their type.

In some European countries, green hydrogen production is considered an industrial activity and only can be done overland, which has been classified as "industrial". This fact limits the installations of electrolysers at domestic or district scale in LECs-RECs.

4.2.3 Regulatory limitations in Energy Storage

Energy storage can be integrated at different levels of the electricity system: Generation, transmission, distribution and user level. These different locations in the power system will involve different stakeholders and will have an impact on the types of services to be provided, and different business models will be developed.

Limitations are linked to the consideration of the storage, as a whole, within national regulations more than to the specific technology. Regarding the Directive of common rules for the internal market in electricity [196], DSOs and TSOs shall not be allowed to own, develop, manage or operate energy storage facilities unless:

- Other parties have not expressed their interest to own, develop, manage or operate storage facilities.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

- Such facilities are necessary for the DSOs and TSOs to fulfil their obligations, and they are not used to buy or sell electricity in the electricity markets.

The above limitation is for offering opportunities to other stakeholders to participate in the market and avoid market distortion and conflicts by having DSO and TSO selling or buy electricity coming from energy storage. This should not be a big limitation, but it is to be seen how it is materialised.

On the other hand, the rules for the connection of the generators to the grid [234] needs to be fully transposed to national legislation of all MS. When and how this is carried out in each country may have an impact on the deployment of storage in each region. One of the aspects to be considered is which network services are requested to be mandatory, without any monetary compensation, and which of them fall into the ancillary services market.

Linked to this, the development of markets and market products that permit the participation of storage, considering the intrinsic characteristics of the different technologies, will also play a very important role to monetise the benefits that storage can bring to the owners and, in this way, to make storage investments cost-effective and push their deployment at the regional level. Capacity markets, local flexibility markets, market products that take into consideration the state of charge of the batteries, etc., are examples of this. The main limitation for energy storage is the need to create appropriate market signals to incentivise the construction of storage capacity and provision of storage services, creating a European-level market and common balancing markets.

Energy Storage Systems policies, in general, play a major role in the development of green technologies which are good for low carbon emissions. Most of the ESS policies revolve around battery storage as they can easily be integrated into the grid, renewable energy, used in electric vehicles and used as backup power. However, there is no clear legal framework for the interconnection of the different energy storage technologies with the electricity network.

There is an additional uncertainty related to the difficulties of classifying energy storage assets into a legal regime premised on three traditional categories of assets: (1) generation, (2) transmission, and (3) distribution. The most notable source of contention is whether energy storage constitutes a generation or a transmission asset [235].

EU is promoting a new EU regulatory framework for **electrochemical batteries** envisaging the following main innovations, as expressed in the referenced EU communication [236]:

- the introduction, in the battery classification, of a new category of electric vehicle batteries, alongside the existing portable, automotive and industrial battery classes;
- progressive requirements to minimise the carbon footprint of EV batteries and rechargeable industrial batteries: a carbon footprint declaration requirement, applying as of 1 July 2024, complemented by classification in a carbon footprint performance category and related labelling (as of 1 January 2026); and a requirement to comply with maximum lifecycle carbon footprint thresholds (as of 1 July 2027);
- a recycled content declaration requirement, which would apply from 1 January 2027 to industrial batteries, EV batteries and automotive batteries containing cobalt, lead, lithium or nickel inactive materials. Mandatory minimum levels of recycled content would be set for 2030 and 2035 (i.e., 12 % cobalt; 85 % lead, 4 % lithium and 4 % nickel as of 1 January 2030,

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

increasing to 20 % cobalt, 10 % lithium and 12 % nickel from 1 January 2035, the share for lead being unchanged);

- minimum electrochemical performance and durability requirements for portable batteries of general use (applying from 1 January 2027), as well as for rechargeable industrial batteries (from 1 January 2026). The Commission would assess the feasibility of phasing out non-rechargeable portable batteries of general use by the end of 2030;
- a new obligation of battery replaceability for portable batteries;
- safety requirements for stationary battery energy storage systems;
- supply chain due diligence obligations for economic operators that place rechargeable industrial batteries and EV batteries on the market. For this requirement on responsible raw material sourcing (as well as for those related to the carbon footprint and the recycled content levels), the Commission proposal envisages mandatory third-party verification through notified bodies;
- increased collection rate targets for portable waste batteries, excluding waste batteries from light means of transport (65 % by the end of 2025, rising to 70 % by the end of 2030);
- as regards, recycling efficiencies, increased targets for lead-acid batteries (recycling of 75 % by the average weight of LABs by 2025, rising to 80 % by 2030) and new targets for lithium-based batteries (65 % by 2025, 70 % by 2030). The proposed regulation also envisages specific material recovery targets, namely 90 % for cobalt, copper, lead and nickel, and 35 % for lithium, to be achieved by the end of 2025. By 2030, the recovery levels should reach 95 % for cobalt, copper, lead and nickel, and 70 % for lithium.
- requirements relating to the operations of repurposing and remanufacturing for a second life of industrial and EV batteries;
- labelling and information requirements. From 1 January 2027, batteries should be marked with a label with information necessary for the identification of batteries and of their main characteristics. Various labels on the battery or the battery packaging would also provide information on lifetime, charging capacity, separate collection requirements, the presence of hazardous substances and safety risks. Depending on the type of battery, a quick response (QR) code would give access to the information relevant to the battery in question. Rechargeable industrial batteries and EV batteries should contain a battery management system storing the information and data needed to determine the state of health and expected lifetime of batteries. This system should be accessible to battery owners and independent operators acting on their behalf (e.g. to facilitate the reuse, repurposing or remanufacturing of the battery);
- the setting up, by 1 January 2026, of an electronic exchange system for battery information, with the creation of a battery passport (i.e. electronic record) for each industrial battery and EV battery placed on the market or put into service

Regarding the power system, the network connection and the market participation rules are evolving to allow the integration of storage. However, they are not totally defined yet in many countries, such as Spain. The regulation has a strong impact on the profitability of storage systems, for example, the definition of non-remunerated and remunerated services, the network connection requirements, the availability of capacity markets and of market products allowing the participation of storage, etc. In Spain, this is an ongoing task, and currently, operational procedures for energy storage systems are being defined.

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement N° 957779

Regarding **supercapacitors** and **flywheels**, at the time of the approval in 2003 of the Energy Taxation Directive (ETD), various electricity storage and sector coupling technologies were not significant yet, as acknowledged by the evaluation of the ETD published by the European Commission in 2019.97. This leads to possible changes in the ETD arising from the deployment of “new” energy technologies and the specific role of storage in the transition to a carbon-neutral energy system [237].

Energy storage systems policies and the regulatory framework for their interconnection to the electricity networks differ across EU countries in terms of tax incentives, the type of the connection and the size of the storage system (behind the meter or in front of the meter), and the islanding or anti-islanding regulations.

CAES does not have a need for significant modification of existing or the creation of new standards. However, it could be specified that the IPPC directive does not apply to adiabatic CAES processes. Permitting processes to leach caverns for CAES could be simplified in order to accelerate CAES planning/building time [238].

There is a dirthof standards and regulations due to the low deployment of **LAES**. However, the following aspect could be investigated since they are included in almost all the storage technologies:

Consenting: the required planning consents will depend on the jurisdiction and be influenced by the project technology, structure and capacity. Planning authorities may be unfamiliar with newer storage technologies, and therefore ensuring the existing processes are fit for purpose will be important [235].

Jurisdictional uncertainty: one uncertainty is whether sales of power into and out of an energy storage facility constitute wholesale or retail power. However, it depends where the facility is located and who is managing it; for instance, the answer would differ depending on whether it is a merchant generator or whether the energy storage facility is located with a utility for self-supply or supply directly to consumers. As a result, energy storage might support both retail and wholesale markets, meaning it could be subject to both state and federal regulators. The characterisation of the energy storage as generation or transmission can even impact the ability to realize tax credits [235].

Land rights: appropriate land rights will need to be secured for the project, the nature of which will depend on the type of storage project proposed and its expected lifetime. For leasehold-type land rights, the rental arrangements may influence the usage of the storage project. Some landlords may also require technology-specific protections to be included in the documentation, such as contaminated land issues [235].

Regulations and agreements on water use often dictate the output and storage of a given **hydropower** facility. These include water rights, use of the water, flood control, and power regulations. Negotiations among several parties (i.e., government agencies, private entities, or even countries) specify water releases in terms of total water flow during a certain time period, usually for a given month. These regulations and release terms determine the operation of hydropower facilities from one year to another. The right to store and divert water from rivers and lakes for beneficial use is controlled by a framework of water laws depending on the Countries [239].

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 957779

At the European level, a clearer definition of role with regards to the ownership of **hydrogen storage** facilities is required. The Renewable Energy Directive includes a taxonomy of hydrogen, but it mainly focuses on the transport sector and not on the use of hydrogen in other important sectors, e.g. industry. More clarity is needed on the legal status of energy storage, in particular with regards to power-to-gas (P2G). P2G is likely restricted to the function of storing energy. Nevertheless, in practice, P2G could become an important part of a hybrid energy system. Therefore, its definition should not be limited to its role as energy storage from an electricity market perspective. This also has implications on the applicability of the unbundling. In response to this, a test framework could be applied to allow TSOs to invest in such facilities until the market is mature enough to attract more players. The term of immature market refers to the case that no interest is expressed by market parties/investors and as a result TSOs/DSOs could be allowed to proceed in such investments [240].

At the national level and in Germany, regulations and definitions are lacking or unclear. The amendment to the EnWG (Energy Industry Act) passed in June 2021 introduces a regulatory system for hydrogen networks for the first time. This step by lawmakers is aimed at gradually establishing a hydrogen infrastructure in Germany. In this amendment, no legal framework has been considered for carbon capture and storage, which is a prerequisite for a blue hydrogen market. While the introduction of optional network regulation provides more legal certainty for network operators, companies face a number of practical legal issues that are fundamental to the development and implementation of new hydrogen business models [241].

There is insufficient coordination between TSOs and DSOs or between electricity and gas networks resulting in a sub-optimal future of infrastructure. There is also a lack of interoperability between both markets [232].

4.2.4 Complementary technologies of local multi-vector energy systems

4.2.4.1 Mobility

Regarding regulatory barriers for mobility, there is **no a clear standardization of the EV charging connectors**, voltage levels, etc. in the EV charging stations, making interoperability difficult [242] [243] [244]. Even the payment process is different for different charging infrastructures, requiring specific cards, credit cards, specific mobile apps, etc.

A European standardisation that allows a driver travelling with an EV throughout Europe to charge in any of the fast charging points without having to register in any of the companies that offer this service will simplify the process significantly, promoting the electrification of the transportation sector.

The cost of EV is largely determined by the high cost of its battery packs. In order to lower the entry barrier in transport electrification and reduce the cost of purchasing an EV, some manufacturers are promoting the leasing of batteries. The user buys the vehicle except for the battery, which still

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

belongs to the manufacturer [245]. If EVs are used in the V2G applications, users can obtain economic reward participating in ancillary service markets, but depending on the battery ownership, the increment of the battery degradation by participating in V2G will impact this benefit. If the battery is leased and do not belongs to the final users, manufacturers may not allow participation in V2G schemes because they would be penalised due to a reduction of the battery lifetime, but they would not receive any economic benefit, while if the battery is also bought by the final users, they have the rights to participate in this electricity market if the received benefit overcome the cost of the battery degradation. Additionally, batteries' guarantees, which are mainly based on the available range after a certain mileage, could be affected by atypical use of the batteries in V2G schemes.

Electricity market regulation. EVs can contribute to active demand response through aggregators, avoiding charging during the peak demand or adjusting their consumption (V1G scheme) dynamically. Utilities may reward customers for the participation, offering financial incentives, cheaper energy prices, etc., in a similar way to current loyalty programs used by some homes where consumers received an SMS message to reduce their consumption or other buildings with smart thermostats that adjust their set point remotely. This smart unidirectional charging process is currently available by many utilities.

EVs not only can be used to reduce the stress from the grid by V1G. Using bidirectional chargers in V2G applications can optimize the consumption on building or neighbourhood level [246], provide power backup, contribute to local congestion management of the electric network or maximise the use of renewable energies. However, implementing V2G technologies is more complex: requires bidirectional charging-discharging infrastructure, which is more expensive, and bidirectional and standardized communications between EVs, aggregators and utilities. The current protocols used in the charging points -Open Charge Point Protocol (OCPP) [247] do not allow knowing the desired state of charge of the battery, the location of the EV, or the time that the vehicle will be connected. Additionally, grid information is not uniformly available throughout Europe, but this information should be shared in the coming years between DSOs and TSOs following the Clean Energy Package [248].

Energy regulation is complex and provides an obstacle for emerging technologies like V1G and V2G schemes which are challenged to compete in traditional energy markets that are not fully aligned with their capabilities. The current national and European regulatory framework for V2G is not mature yet [249] and should design and implement new flexibility markets, aggregation services, capacity mechanisms and dynamic tariffing to promote V2G technology. For these V2X services, it can be understood that the charger point owner will be responsible but to provide support to the grid and participate in markets must be part of an aggregator; however, for distribution grids, it is not that clear who must be responsible for this system and become the owner.

Other regulatory limitations. Despite the great number of policies carried out over the last decade to promote electric vehicle deployment at different levels, trying to reduce the gap compared to conventional ICE vehicles, such as fiscal incentives, purchase subsidies, registration tax, etc., no coordination action between local, regional and national authorities have been done, limiting the effect of these policies [250].

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement N° 957779

Implementation of **electric buses** normally means significant increase of electricity and power demand in major European cities, requiring costly upgrading of the distribution network. From the regulatory point of view, it is unclear how these expenditures can be recovered by the local DSOs. There is also an open question about ownership of the charging infrastructure, because for the time being system operators are not allowed to own and operate charging stations. The same limitations apply to ownership and operation of storage [196].

Related to **charging infrastructure**, when it comes to "electric roads", the future regulatory terms for this remain unclear, i.e., it appears to be a natural monopoly, so ownership and access to it could be somehow regulated.

As it was previously mentioned, the installation of charging points often requires booster batteries to keep the voltage at acceptable levels in the network. The present European regulation does not allow DSOs to own and operate storage except for certain circumstances.

Existing EV standards are mainly addressed to road vehicles, international [8] (IEC 61851-1, IEC 60364-7, IEC 62196-1…) or national (e.g. Spanish ITC-BT-52). Those standards frameworks need to be reviewed and adapted to the marine environment in those parts where this environment is especially distinctive (e.g. offshore electricity charging platforms). On the other side, the present crafts regulation framework should be evolved in order to cover the option of electric battery-based propulsion [8].

The revised EU Alternative Fuels Infrastructure Regulation (AFIR) [65] require to install charging and H_2 refuelling points at regular intervals on main European roads (every 60 km for electric charging points and every 150 km for H_2 refuelling). This newly revised regulation also include electric trucks and their associated charging infrastructure in their targets. These targets are binding, not voluntary, covering a broader range of levels (highways, roads, urban nodes, etc.) with specific timeframes.

4.2.4.2 Control and data management and security regulatory limitations

The regulatory limitations related to Control Management tools are related to data (collection, storage, recovery, and disposal). In Europe, there exist the “General Data Protection Regulation” (GDPR), where consumer’s data protection and sharing permissions should be managed appropriately by the different actors involved in Control Management tools. This law is known to be effective but there are some aspects to reshape [251]. Some examples are: the benefits of GDPR regulation may not justify the cost of corporate compliance; moreover, there are companies where deals they worked on fell apart because of concerns about a target company’s compliance with GDPR. Almost 30% of European businesses admit to not being in compliance with GDPR. On the other hand, administrative fines have been relatively low.

Control Management tools should be fulfilling also some important certifications as ISO 50001 an international best practice to help organizations better manage energy [252]. Once externally validated, certification is subject to external surveillance audits, further supported by regular internal audits. An ISO 50001 system will also require upfront costs related to certification fees alongside human resources for the regular maintenance of the documentation processes and overall system.

4.3 Summarize

In order to have a general overview of the main limitations and shortcomings for optimal use of local resources encountered in the development of this task from WP2, the most relevant information has been summarized in the following tables.

Table 9 presents the main technical and regulatory barriers associated with the different types of generation sources (thermal, electricity and H_2 production).

Table 9. Main limitations and shortcomings for energy generation sources (thermal, electricity and H_2 production)

	Energy generation technologies	Technical and economic limitations-shortcomings	Regulatory limitations
THERMAL	**Boilers**		**Common regulatory limitations for thermal generation**: a) GHG & emission limitations b) Lack of fiscal incentives for the user to provide flexibility through thermal loads such as electric boilers, heat pumps and electrolysers
	Electric boilers	Low internal temperature	
		Low heat capacity and low hot water production	
		Possible home repowering requirements	
		Lower upfront costs higher operating costs (depending on the electricity and gas market)	
	Biomass boilers	Delivery and storage of the fuel (wood chips or pellets)	
		Physical size of these boilers	
		Boiler responsiveness	
		Low ability to modulate	
		Waste and cleaning (ash and slag)	
	Natural gas boilers	Security concerns. Danger of gas lekages, fires, explosions	
		Gas quality problems depending on the gas provider	
		Natural gas price dependency (Natural gas is also used in industry, transportation and electricity generation)	
		CO2 and other pollutant emissions	
		Higher upfront costs compared to other thermal generation technologies	
		Higher maintenance costs (require periodical revisions)	
	Steam boilers	Boiler responsiveness. Difficult to regulate heat transfer	
		Noisy	
		Priming, foaming, carry-over, scale and corrosion problems	
		Waste and cleaning (ash and slag)	
	Heat pumps / Hybrid Heat Pumps	Efficiency is reduced with very low outdoor temperatures	
		Difficult to regulate and use as a flexible load	
		Thermal storage is required if HP is also used for DHW	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

		Hybrid heat pumps are more expensive and have higher maintenance costs	
		In some cases, it requires to modify the current installations (replacing conventional radiators with low temperature ones)	
		No common rules for installation of heat pumps (level of noise, vibration, hot air expulsion). Depending on the municipal ordinances	
	Combined Heat and Power (CHP)	Requires a simultaneous demand of head and electricity	
		Most CHP operate at a very narrow range of the cogeneration ratio	
	ICE CHP	Limited to lower temperature cogeneration applications	
		Noisy (particularly low-frequency noise)	
		GHG emissions	
		Require cooling	
		Regular maintenance	
	Gas Turbine CHP	Significant efficiency reduction at partial loads	
		Requires high-pressure gas	
		Limited to lower temperature cogeneration applications	
	Adsorption chillers	Low efficiency	
		Higher purchasing costs	
ELECTRICITY	**PV generation**	Low efficiency	**Common regulatory limitations for electricity generation** a) Complex administrative procedures to obtain authorization for grid connection b) No common MV-LV network requirements (grid codes) c) Legal uncertainty (no appropriate regulation for risk and cost mitigation). d)Lack of funding for the less developed generation technologies e) Market integration. Difficulties for the participation of distributed and intermittent renewable sources in some electricity markets (balancing markets) f) Lack of specific legislation for some renewable sources (CSP, small-scale hydro, wave-tidal, geothermal, etc.) and H_2 production
		Space requirements	
		Solar panel degradation	
		Variability. Requires storage to be a controllable energy source	
		Hazardous materials in PV cell manufacturing process	
		Water use (particularly in the manufacturing phase)	
	Wind generation	Variability. Requires storage to be a controllable energy source	
		Limited locations	
		Wildlife hazard	
		Micro wind turbines: structural vulnerability (vibrations) and lower controllability	
	Small-scale hydropower plants	Limited locations	
		Remote areas. Requires construction of additional power lines	
		In weak grids, possible voltage violations	
		Regulations and agreements on water use	
		Environmental concerns to construct and operate small-scale hydropower plants	
		Very high initial cost (particularly if dams must be constructed to create water reservoirs)	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

	Wave and tidal energy generation	Lack of maturity	
		Limited locations	
		Harsh environment	
		Remote areas. Requires construction of additional power lines	
		Environmental impacts	
		Social acceptance. Disputes with other current sea activities such as fishing, shipping, tourism, etc.	
		High initial capital expenditures	
	Concentrated solar-thermal power (CSP)	Intermittency. Requires storage to be a controllable energy source	
		Degradation. Higher maintenance costs	
		Space requirements	
		Heat losses	
		High upfront costs.	
		Water requirements	
		Require access to gas networks	
		Environmental impact (wildlife enlargement)	
	Geothermal electric generation	Limited locations	
		Induced landslides and seismic activities	
		High water demand	
		Wastewater and contamination of soil nature	
		Noise	
		High initial investment costs (drilling and construction costs)	
		Environmental concerns (GHG emissions, water pollution, etc.)	
	Backup generation	Regular maintenance	
		Noisy	
		Emission limits (for fossil-fuelled backup generators)	
		Requires an additional infrastructure (for fuel and air supply, for cooling and exhaust)	
		Very high operating costs (particularly in ICE backup generators)	
	Fuel cells	Not fully matured technology	
		Slow dynamic behaviour	
		Durability (AFC, MCFC and SOFC)	
		High investment cost	
H_2 production	**Electrolysers**	Complexity	**Common regulatory limitations for H2 production** a) Lack of common definition and classification for hydrogen at EU level
		Construction of new infrastructure	
		Safety concerns	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

		High costs	b) Difficulty to determine the renewable origin of the electricity used for H_2 production c) Lack of fair policy for H_2 production d) Lack of common EU framework for the installation of electrolysers for H_2 production and their connection to gas-H_2 pipelines and electricity grids e) The role and responsibilities of different agents in the H_2 production and market are not defined (some definitions about ownership of the production and storage of H_2 facilities are required) f) H_2 production business models are mainly driven by electricity costs
		High electricity demand. It could be an issue in weaker electricity grids.	

Table 10 presents the main technical and regulatory barriers related to energy storage (thermal, electricity and H_2 storage).

Table 10. Main limitations and shortcomings for energy storage sources (thermal, electricity and H_2 storage)

	Energy storage technologies	Technical and economic limitations-shortcomings	Regulatory limitations
THERMAL	**Sensible heat-cold energy storage**	Overall tank dimension	**Common regulatory limitations of energy storage**: a) Complex administrative procedures for obtaining authorization for grid connection of the different energy storage installations b) Classification of energy storage assets into the current legal regime with three traditional categories of assets: Generation, transmission and distribution c) Lack of appropriate market signals to incentivise the construction of storage capacity and provision of storage services d) Different interests on energy storage-renewable energy deployment for each MS e) Regulation of network connection and market participation rules for energy storage is not totally defined in each MS f) Lack of clear regulation about the ownership of the storage and its control and management g) Main problem: transposition of EU rules to national legislation
		Thermal losses	
		Salt stability	
		Storage materials cost	
	Latent heat-cold energy storage	Low maturity	
		Subcooling	
		Phase separation	
		Corrosion	
		Low thermal conductivity	
		PCM materials are too expensive	
		Environmental impacts of PCMs (toxicity of some storage materials)	
		Very high costs	
	Thermochemical heat-cold energy storage	Very low maturity (still in laboratory stage)	
		Very high investment cost	
		Environmental issues (toxic materials)	
ELECTRICITY	**Electrochemical batteries**	Low energy densities compared with traditional chemical energy carriers (hydrocarbons)	
		Degradation	
		Required larger physical space	
		Long charging time	
		Low cycle life	
		Safety Concerns (fire, explosions)	
		Environmental impact (hazard and toxic materials). Recycling	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

	Supercapacitors	Low energy density	
		High self-discharge rate	
		Environmental impact (some electrolytes contain hazardous materials)	
		High initial costs	
	Flywheels	Low energy density	
		High self-discharge rate	
		Vibrations. Mechanical stress	
		High initial costs	
	CAES	Low round trip efficiency	
		Variable efficiency	
		Environmental hazard	
		Location limitations (caverns location)	
		Air leakage issues	
		Very high initial investment costs	
	LAES	Low round trip efficiency	
		Not practical for small-scale energy storage	
		Safety concerns	
		Very high initial investment costs	
	PHPP	Location limitations	**PHPP specific limitations**: Regulations and agreements on water use
		High initial capital costs (primarily related to the cost of the reservoir's construction)	
		Structural integrity limitations in conduit pico PHPP in buildings (installations in water infrastructures)	
		Not "off-the-self" turbines for pico PHPP in buildings	
		Environmental impacts	
H_2 storage	Compressed H_2 gas storage	High energy consumption	**H_2 regulatory limitations**: a) A clearer definition of role with regards to the ownership of hydrogen storage facilities is required b) Clearer use of H_2 in other sectors such as industry c) Clearer legal status of Power to Gas (P2G) infrastructures d) Insufficient coordination between TSOs and DSOs and between electricity and gas networks e) Lack of interoperability between electricity and gas markets.
	Liquid storage	High consumption of energy for liquefaction	
		Evaporation problems	
	Sold (metal hydrides)	Low storage density	
		Very expensive	

Finally, in Table 11 the main limitations of mobility and control and data management technologies are shown.

Table 11. Main limitations and shortcomings for complementary technologies

Other technologies	Technical and economic limitations-shortcomings	Regulatory limitations
Mobility	Scarce materials for batteries and electric motors Raw materials concentrated in a few countries outside the EU Current battery production high concentrated in few countries outside the EU Low energy density of Li-ion batteries Lifetime of the battery pack Safety concerns Lack of charging points (outside main cities) Poor maintenance of the charging points Impact of the charging process on the distribution grid (grid reinforcement requirements) Lack of V2G capabilities. Some car manufacturers do not allow V2G capabilities Very high upfront cost of EVs due to the cost of the battery packs Environmental issues (recycling of battery packs and PMSM, which contain hazard materials) CO2 emissions for EV charging (depending on the country's electricity generation mix)	EV policies differ across EU countries (different tax incentives, different emission reduction targets, different charging infrastructure deployment) No clear policies to integrate V2B, V2H or V2G schemes No clear standardization of EV charging connectors, voltage levels, etc. Difficulties in charging points interoperability Current Open Charge Point Protocol, OCPP does not support V2X capabilities
Control and data management	Data and control standardization	General Data Protection Regulation (personal data)
	Data cybersecurity	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

5 Impact on eNeuron pilots

In this section, it is evaluated the possible impact of the main limitations found in the previous analysis over the eNeuron pilots. A detailed description of these demo sites are described in Deliverable 2.2 [1]. Table 12 presents the main technologies that have been considered for the implementation in each of the four eNeuron pilot facilities. This information will be updated with the data provided by WP6 of eNeuron project.

Table 12. Technologies used in the eNeuron Pilots

VECTOR GENERATION			PILOTS			
			Polish Pilot	Norwegian Pilot	Portuguese Pilot	Italian Pilot
Number of Technologies	Category	**Technology**	**Bydgoszcz City**	**Skagerak Energy Lab**	**Lisbon's Naval Base campus**	**U. Politecnica delle March**
1	**Thermal Generation**	Heat pump	X	X	X	X
2		Hybrid heat pump				
3		Natural gas boiler			X	
4		Electric boiler	X	x	X	x
5		Micro-chp (including electricity generation)				
6		CHP (including electricity generation)	X			X
7		Steam boilers				
8		Adsorption chiller				
9		Solar collector (hot water)	X		X	
10		Biomass boiler				
11	**Local Electricity Generation**	PV	X	X	x	x
12		Wind				
13		MicroHydro / Hydro				
14		Wave/Tidal				
15		CSP				
16		Geothermal				
17		Backup diesel generator	X	X		

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

18		Fuel Cells (electricity/heat)				X
19	H2 Gen.	Electrolyzer				X
		VECTOR STORAGE	PILOTS			
20	Electricity Storage	Batteries (including EV as V2B-V2G)	X (lead-acid)	X (Li-ion)	X (Li-ion)	
21	Electricity Storage	Supercap				
22	Electricity Storage	Flywheel				
23	Electricity Storage	Compressed Air Energy Storage (CAES)				
24	Electricity Storage	Liquid Air Energy Storage (LAES)				
25	Electricity Storage	Pumped-Hydro power plants				
26	Thermal storage	Sensible heat and cold	X (storage tank)		X (storage tank)	
27	Thermal storage	Latent heat and cold				
28	Thermal storage	Thermochemical heat and cold				
29	Thermal storage	~~Cold storage~~				
30	H2 Storage	H2 storage				X (metal hydrate)
		MOBILITY	PILOTS			
31	Mobility	EVs and their charging infrastructure		X	X	X
32	Mobility	Heavy vehicles (vans, buses, trucks)				
	Mobility	Electric Ferries / Boats				
		Control Management Tools				
33	Control	Research /Commercial plataforms	X	X	X	X

5.1 Impact on Polish Pilot

The pilot covers the major energy nodes of Bydgoszcz, connected to both LV and MV grids.

Most of the buildings are recent and enjoy some degree of energy self-sufficiency. They have been equipped with smart metres. Nearly all MV/LV grids at the pilot area's stations are equipped with balancing meters connected to the central Advanced Metering Infrastructure (AMI) system by means of a cellular network. All P, Q, V, I measurements are directly available from a primary substation or indirectly from a SCADA system. This allows for near real-time energy flow tracking management and mapping.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

Polish pilot involves 7 public buildings, mainly sports facilities but also incineration plant and animal shelter. Within the eNeuron project, the buildings will form an energy hub allowing to exchange energy via the grids between its members, information on their energy production and energy needs with the energy hub.

The high-level management architecture proposed for the local energy system is based on the central master application concept, which controls micro-energy hubs installed at each energy node or asset. The central application will coordinate the micro energy hubs through the eNeuron tool to act complementary and provide the following benefits:

- Local energy management – in terms of loads and generation;
- Grid flexibility management;
- Maximum use of locally produced power – reduced energy in-flow from transmission system operators and the high-voltage (HV) grid;
- Optimised local energy system for ancillary services to the MV grid – to avoid congestion of local active grid and to support voltage stability.

The main technologies that are/will be installed within the energy hub are:

- Heat pumps;
- Electric boiler;
- CHP;
- PV;
- Solar thermal;
- Backup diesel generator;
- Isolated thermal water tank;
- Electrical energy system storages using lead acid batteries.

Limitations of the above technology influence the operation of the buildings via energy consumption, costs of building maintenance and its impact on the environment. In particular, the identified limitations are:

- Lack of regulations and double taxation regarding production of heat and electricity through cogeneration,
- High dependency from the gas supply,
- High consumption of reactive power (capacitive and inductive),
- Lack of energy receivers in the summertime for collectors,
- Real-time energy accounting with the heating company.

5.2 Impact on Norwegian Pilot

The existing limitations related to using diesel-powered gensets and the forthcoming environmental restrictions encouraged the Norwegian Pilot Operator to invest in BESS together with PV panels and power electronics. According to IEM Directive 2019/944, DSOs are not allowed to own and operate energy storage facilities. However, this Directive is still in transposing process in Norway, and the final outcome of the process remains unclear. Thus ownership and operation of energy storage are

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

not limited, especially considering that the energy storage is essentially used for operational purposes, i.e., improved reliability and quality of supply.

The future of the installation, especially the potential extensions, should consider the present and forthcoming limitations:

- **Ownership of charging stations for EVs is not allowed for the DSOs** and thus has to involve an external operator for the station (-s).

Potential development of the installation should consider:

- **Limitations related to ownership of hydrogen infrastructure**, which may allow optimal utilisation of the PV panels, i.e., electrolyser (-s) and storage facilities. It is an open question whether it will be treated as a natural monopoly or commercial activity. If latter, the development and operation should be transferred another company.

The same applies to the use of the generated hydrogen; there are three main alternatives or combinations of these:

- Use of hydrogen for **fuelling of H_2-vehicles**. Potential limitations of ownership and operation should be considered.
- Use of hydrogen **for the operation of CHP generating electricity and heat for local use**. In general, this may be challenging, considering that as DSO, the operator of the Norwegian pilot cannot produce electricity. However, following the forthcoming regulation in Norway, Active Customers can share among them up to 500 kW of self-produced electricity at the same property. This potentially opens possibilities for the development of a local multi-energy hub.

5.3 Impact on Portuguese Pilot

The Portuguese Pilot is located in the Lisbon Naval Base campus, property of the Portuguese Navy. This military facility has its own private electrical distribution grid, which interfaces with the public DSO grid at the MV level.

Being a public entity, through the parent Ministry of Defence, the Navy will naturally abide by the goals of several national plans for carbon emission reduction and RES penetration, like for example the National Plan for Energy and Weather 2021-2030, which aims for a 45% reduction in greenhouse gases, 35% increase in energy efficiency and 47% increase in installed RES capacity by 2030 in Portugal.

The envisioned demonstration energy hub comprises a district within the Base, composed by two micro-energy hubs (prosumer buildings/infrastructures), one main PV plant, and some consumers. Thus, all the assets and grids within the Energy Hub will be privately managed by one single entity: the Portuguese Navy.

This fact simplifies the implementation of this demo pilot because several members of the LEC will be, in fact, part of the same entity. Some aspects like, for example, peer-to-peer trading will then be partly simulated. Also, there will be no DSO involved in the operation of the LEC. This implementation brings many advantages for demonstration purposes but also some regulatory limitations. The whole Lisbon Naval Base campus electrical grid, containing the Portuguese Pilot

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

demo Energy Hub, is considered a single customer with a single point of connection to the DSO and thus will have to follow the national regulations at this point of connection.

The main technologies that are/will be installed within the Portuguese Pilot Energy Hub are:
- PV;
- Solar thermal;
- Heat pumps;
- Natural gas boiler;
- Electric water heaters with storage tank;
- EV chargers;
- Small scale battery storage systems;

All these assets can and will be owned by the Portuguese Navy, as per Portuguese legislation. Other technologies, like H_2 and large scale battery storage systems, were discarded for the moment due to several reasons like technology immaturity and high costs.

Regarding the generating assets: PV, the total installed capacity inside the Lisbon Naval Base will be no larger than 1 MW, which is the maximum value for which a license is not required. The PV generated electricity is expected to be always consumed inside the Naval Base, and thus there will never be an exportation of energy to the public grid. The DSO will not “see” the PV production, but instead, it will be seen as a reduction in consumption.

The installation of solar thermal capacity and the eNeuron optimisation of flexible resources, for example heated water tanks, will also translate in a net reduction of electricity and natural gas consumptions, as “seen” in their respective points of connection to the public grids. Nevertheless, this total optimization will have some technical limitations, mainly due to the degradation and reduced capacity of some equipment.

In regard to EV chargers and battery storages, Portuguese regulations allow for small scale battery storage and V2G inside private consumption facilities on a “self-consumption” basis. The systems of this type installed in the Lisbon Naval Base during the pilot will have a total capacity that will also always be absorbed inside the premises of the Base. V2G functionality will also pose some challenges due to technology immaturity and EV compatibility.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 957779

5.4 Impact on Italian Pilot

The Italian demo is based on four main campuses of Università Politecnica delle Marche (UNIVPM), located in the town of Ancona. Within the project, the university is identified as an energy hub and the four sites as micro-energy hubs.

The main technologies installed in the UNIVPM's campuses are the following, besides than being shown in Figure A:

- Adsorption chillers;
- Circulation pumps:
- Combined Heat and Power unit (CHP);
- Electric boiler;
- Electric vehicle charging stations;
- Electrolyser;
- Fuel cell;
- Heat pump.

The **thermal power plant of the UNIVPM** site is composed of a 575 kWe CHP plant ICE based (natural gas-fuelled) coupled with a district heating/cooling network that satisfies thermal/cooling energy needed by the internal facilities. Since the engine is natural gas-fuelled, NOx emissions must be below 100 mg/m^3 as imposed by the Italian legislation (it is valid for plants that have been built before 2013). The thermal power plant is located in a dedicated and insulated zone to not have noises during its functioning ("Legge n. 447 del 26 ottobre 1995: Legge quadro sull'inquinamento acustico").

The **cooling energy** is provided by an adsorption chiller that is directly integrated into the CHP unit, using the waste heat from the exhausts. Nevertheless, adsorption chillers present a low COP that is strictly dependent on its configuration, thus affecting not only the overall performance of the system but also the O&M costs. The higher the number of cycles, the higher the performance and the cost as well.

The **CHP unit** operates mainly at rated conditions since it has a considerable performance drop when operating at part loads (generally during the mid-seasons); in that case, the use of electric boilers and heat pumps satisfies the energy demand of the campus.

Electric boilers have been installed due to their low costs: furthermore, the Italian government incentives the deployment of these systems by applying a discount of 65% by replacing the old natural gas boilers. However, since Italy is strictly dependent on the power plants natural gas-fuelled that faced a considerable increase in terms of prices, the electricity costs will increase as well, possibly limiting the deployment of this technology until renewables will fulfil most of the energy demand.

Also**, heat pumps** have been installed in the UNIVPM campus. This technology has the same discount of 65% given to the electric boilers, thus further incentivising their deployment.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

In addition, an integrated **hydrogen system** is also installed in the UNIVPM campus, and it is composed of:

i) one **alkaline electrolyzer** of 23 kW,
ii) **metal hydrates storage** of 3,000 l, and
iii) a 1 kWe fuel cell.

The purpose of this system is to study how the hydrogen could be deployed as energy storage in the future European and Italian energy scenarios based on renewables, as well as provide information on the performance of the hydrogen production within a power-to-power context. So far, no international standardizations are present, thus still limiting the deployment of these technologies. Indeed, this system would contribute to giving feedback and indications on the future EU framework related to hydrogen use.

Finally, **electric vehicle charging stations** are installed in the UNIVPM campus, thus further contributing to the deployment of future mobility. Different kinds of electric vehicle supply equipment (EVSE) are present in the market: AC and DC types with different power levels. AC chargers requiring longer times to charge the vehicle completely. They have power ratings ranging from 2.3 kW (single-phase) to 22 kW (three-phase), but this power is mainly limited by the AC-DC onboard charger installed in the EV. DC chargers bypasses these onboard chargers, allowing faster recharging process. Some DC charging stations provide up to 350 kW of power, charging an EV in about 20 minutes.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

6 Potential recomendations

The main objective of this section is to propose potential recommendations to overcome the main technical and regulatory limitations and shortcomings detected during the analysis performed in this particular task of WP2.

The required energy transition requires a rethink of the current energy system. One general recommendation is to provide a common regulatory framework to integrate different types of generation (thermal and electricity) with different types of storage, allowing an increase in the flexibility and efficiency of these multi-energy systems as a whole.

Additionally, it is required to digitalise all the local distributed energy chains in the near future, from the generation, through storage and final consumption, for optimal management of the system. This digitalization will be based on new digital information and communication technologies (ICT) – such as Artificial Intelligence (AI), cloud computing, big data, and 5G. The successful implementation of these technologies should result in significant improvements in the energy distribution, such as more efficient power generation and energy storage, reducing the total energy cost and providing more flexibility. The deployment of these ICT infrastructures should be done at the same time as the upgrading of the other multi-energy infrastructures (such as electricity and gas grids).

6.1 Potential recommendations for generation

6.1.1 Thermal energy generation

According to IEA in their latest report, to reach the CO_2 emission targets, it is required to significantly reduce the consumption of fossil fuels for heating [6]. By 2025, any **gas boilers** that are sold are capable of burning 100% hydrogen and therefore are zero-carbon-ready, while before it is expected to use a fuel composed by natural gas and hydrogen blending to start lowering NOx emission. The share of low-carbon gases (hydrogen, biomethane, synthetic methane) in gas distributed to buildings will rise from almost zero to 10% by 2030 to above 75% by 2050 [6].

Our recommendation is to encourage the transition to fossil-free boilers, promoting the ban **gas boilers** (and other fuelled boilers) in new homes and providing an upgrade scheme for final customers with some financial grants to replace the current gas boilers with low carbon heater technologies such as electric heat pumps, as it is currently being done in several countries such as UK [253].

Biomass boilers can be a good alternative for thermal energy generation. It can offer many economic, social and environmental benefits such as financial incentives, avoiding the use of fossil fuel based resources, job opportunities creation and CO_2 and NO_x emissions reduction.

However, before installing a biomass boiler, care should be taken to additional challenges such as other environmental impacts of biomass (e.g. land and water resources, soil erosion, loss of

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

biodiversity and deforestation) followed by operating limitations (e.g. fouling, low heating value, storage etc.) [254].

Electric boilers and **heat pumps** can contribute actively to balance local electricity generation and demand, providing demand side flexibility. In order to improve the efficiency of the system, these electric heating systems must be coupled with thermal energy storage (i.e. sensible heat storage tanks, thermal mass of the building envelope, etc.), allowing to downsize the heat generation system, resulting in economic benefits.

This active demand management can be indirectly performed, by dynamically adjusting the electricity price, allowing consumers to activate their heaters during periods of time when the electricity cost is very low. If during these periods, the thermal demand is also low, the generated heat can be stored in the heating storage systems. When the electricity cost is higher, consumers must avoid the consumption of these heaters and extract the thermal energy previously stored in the tanks. The electricity price can be provided by the DSO through the smart meters installed in the customers' homes and send this information to the building management systems (BMS) which manage the operation of the HVAC systems. The main problem of this control scheme is the price sensitivity. It may happen that if the building thermal demand is high, customers do not disconnect their heaters, despite the high price of electricity, even if the electric grid is overloaded.

The other solution is to perform this active demand management directly by the DSO. They can remotely control the temperature setpoints of each thermal generation units available in the systems (such as electric boilers, heat pumps, etc.) and even disconnect these loads if is required to ensure the stability of the electric system. This solution is more complex to implement, because it requires a two-way communication between the DSO and each customer, and it is also much more intrusive than the above indirect procedure, as it can leave customers without thermal generation control when the electric grid is overloaded, but providing a better grid controllability. For this reason, it is recommended to promote these type of demand response programs for residential applications as it is currently done in several countries [255], [256]. Another way to improve the total efficiency of heat pumps systems powered by intermittent energy sources such as PV systems or micro wind generators installed in LECs is to combine them with a sensible heat storage tanks, as it was previously mentioned. This combination will allow a greater flexibility in the whole system operation because in the event of excess PV generation, it will be possible to store the energy surplus in form of heat (instead of electricity), allowing to use this thermal energy when it is required in the future.

Additionally, the coupling of heat pumps with thermal energy storage systems leads to a more stable operation with fewer on-off cycles, which ultimately contributes to extend their life.

Apart from those improvements at system level, heat pumps can be upgraded at device/unit level, by the use of natural refrigerants with low GWP (global warming potential) or new synthetic refrigerants with enhanced properties. Improvements in the refrigerant cycle or its components can also lead to better heat pumps. For example, dual-source heat pumps can provide high versatility which maximizes their integration in HVAC systems with multiple heat sources and operating modes, thanks to the use of components such as dual-source heat exchangers. All these improvements apply similarly to hybrid heat pumps.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

Currently, the EU legislation covers the heat and electricity markets separately, reducing the hybridation of both systems. It is recommended to provide European regulations that favour this hybridation.

Regarding **CHP**, a complete recognition of cogeneration in sectoral policy for industry, construction and district heating, is advisable. The regulations should foster CHP more as a good chance to deliver heat at lowest cost and to valorise waste heat. The waste heat, in fact, could be recovered either on site or via District Heating and Cooling (DHC) [218]. Moreover, the policy framework should incentivise the use of heat storage for decoupling heat and electricity supply.

The policy should reward the increase in system efficiency due to the use of **cogeneration**, besides at the local level, and encourage the flexible and efficient integration of cogeneration into heating, energy and gas systems. The energy primary savings, obtained using CHP, guarantee, in fact, significant carbon reductions that can help to reach the decarbonisation goals.

To achieve all these benefits, regulators should provide greater incentives for investments in generation and / or networks, for the purchase of cogeneration systems to be integrated.

In the EU context, greater predictability and reduction of political environments fragmentation would positively influence the development of cogeneration.

Again, it could be useful that EU regulation integrates the heat and electricity markets and not treats them separately [216].

Technical limitation regarding **steam boilers** may be overcome by providing good quality of water, protecting against noise, stone, corrosion problems. In practice, the most common water treatment technologies are softening of water in an ionic bed, acid cation exchange, regeneration with sodium cation, water demineralization in a reverse osmosis (RO - reverse osmosis) membrane installation, decarbonisation, water regenerated with hydrochloric or sulphuric acid, CO_2 desorption, softening of water in sodium form. One should take into account the method of supplying water to the steam boiler and the degree of water demineralization in order to reduce the operating costs of the boiler, especially at a time when water and energy prices are rising. The selection of an appropriate demineralization station can guarantee a low degree of boiler desalination.

Technical limitations regarding **adsorption chillers** are low efficiency and high purchasing costs. Continuous research is being conducted to improve the efficiency of adsorption chillers and make them more attractive to the market. Finding optimal parameters of the adsorption chiller is crucial to improve its performance. The application of the right duration of the adsorption and desorption phases greatly affects the performance coefficients. Adsorption chillers are the solution that can not only become a source of eco-friendly cooling but also contribute to reducing the problem of freshwater scarcity.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

6.1.2 Distributed energy generation

Most of the regulatory limitations are common to all forms of electricity generation. One of the main limitations is the need to reduce the complexity of administrative processes at all levels - local, regional and national – related to the installation of local distributed generation, especially at the household level. These complex administrative obstacles discourage the deployment of these systems.

On the other hand, there is a need for a stable legal framework that favours investment. It has been observed that changing regulations mean that investors are reluctant to invest in these technologies as they cannot correctly assess the assumed risk and the return on their investment.

The IEM Directive 2019/944 [196] provides access to all consumers in all electricity markets on equal terms. Unfortunately, this is not possible at the moment and national transpositions need to be further developed to allow the participation of all actors (generators, storage units, final users, aggregators, etc.) in all electricity markets (including balancing markets).

New peer to peer (P2P) trading schemes should be developed in the coming years. These P2P platforms will allow final consumers to share their excess energy amongst others, controlling their energy consumption (and its prices) and providing more flexibility in the system. This trading should be done through a secure and distributed platform, using new technologies such as blockchain.

PV technology. It is recommended to increase the research and development (R&D) in new PV cells to improve its efficiency and reduce its cost. The solar module efficiency has nearly doubled in the past 20 years and its price have fallen more than 64% since 2010, but there is still room for improvement in both areas [257]. It is also necessary to reduce the toxicity of some raw materials and processes during the PV module manufacturing and improve its recycling process.

Most of the PV installations are ground-mounted systems (in rural areas) or rooftop (in urban ones). It is necessary to expand the available surface for PV generation, particularly in high-densed urban environments, supporting more R&D in building integrated photovoltaics (BIPV), integrating these PV modules in bricks, windows and other structural parts of buildings. Other urban and suburban spaces such as streets, roads or highways can be used to integrate PV modules in pavement structures. There are already some PV road pilot installations [258], but some challenges still need to be addressed before they can be widely accepted in the market.

Another recommendation is to continue R&D in power electronics technologies, to reduce losses and increase the efficiency of inverters. These devices can be also integrated onto the PV modules for a better installation.

The introduction of Silicon carbide and Gallium nitride is currently transforming power electronics used in electric vehicles and renewable energy sources, promising higher efficiency, lower costs and reduced requirements compared to the current Si-based power electronic technology [259].

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

Wind Power is a currently available renewable energy generation technology. However, most of its innovation and development has been focused on large applications which make it a poor fit for certain urban areas and local energy communities. In this regard, cost reduction and further developments for increased efficiency and better energy acquisition for low-medium wind speeds are required.

Another recommendation is to further develop and validate Horizontal Axis Wind Turbines (HAWT) technology and simplify its integration into off-grid systems and buildings. Further R&D into new concepts for simplifying building integrated concepts and multirotor applications for higher density must be explored also. Improved controllability and reduce cost must be achieved by including efficient power converters and active power controllers from the mechanical side. Finally, consideration must also be given to the impact that these new technologies may have on local wildlife.

The main limitation of **small-scale hydropower** is that it can be developed only in areas with available resources and suitable landscapes. According to the Norwegian Association of Small-scale Power Plants in 2018 there were 400 sites in Norway approved for construction with total 3.2 TWh of annual energy production [104].

In many cases potential sites for development of small-scale hydropower are located in remote areas, making construction of the water dams, penstocks/channels and hydropower plants itself very expensive (see cost estimations in [260]). In many cases, construction of power lines to the closest connection point at distribution network can also be very costly. This is one of the main practical obstacles for this technology. In addition, development of the potential sites can be limited due local hydrology and protection of existing fish stocks. Generation from small-scale hydropower normally has seasonal variations (even if it has water dams), which may create corresponding voltage violations in the local distribution networks (this normally requires installation of OLTC transformers by the local DSO).

The recent introduction of legislation related to Energy Communities and Active Customers opens many opportunities for development of small-scale hydropower as a common asset, where the necessary construction funds can be raised via the Energy Community membership. This makes small-scale hydropower a very strong driving factor for establishing Energy Communities, especially in rural agricultural areas.

Geothermal technology is currently commercially available; however, it strongly depends on the availability of the geothermal source. One technical limit is the low efficiency when compared to the other renewable energy sources, therefore the recommendation is to promote further R&D to improve the operational efficiency of these systems.

The installation of a **fossil fuel-based back-up generator** is typically required as a backup system to cover the loss or lack of energy production from renewables. However, consideration should also be given to the potential increase of the fossil fuel prices in the future that may discourage the use of this technology. A potential solution in this case could be to replace these backup generators with cleaner hybrid solutions, combining local generation (such as PV or fuel cells) with electric battery storage.

This project has received funding from the European Union’s Horizon 2020
research and innovation programme under grant agreement N° 957779

Wave energy technology is characterised by several different technologies under development, typically low TRLs, high capital investment and LCOE. Policy incentives and further research and innovation on supporting offshore project could result in higher TRLs for these technologies. In addition, the development of innovative business models that combine generation with other uses, such as aquaculture, that are nowadays addressed through blue growth initiatives [261].

Tidal energy technology is currently close to being commercially viable, but still needs to reduce LCOE. Policy incentives and further research and innovation are recommended to make energy production from tidal generation technology a more viable proposition.

Concentrated solar generation is strongly related to economic incentives and is not competitive in electricity markets, except for remote areas such as islands or remote grids. Regarding this limitation of CSP technologies, it is recommended that a Feed-in Tariff could be introduced for the energy generated from CSP plants. On the other hand, the development of long-term policy frameworks to foster and secure CSP technology developments investments are recommended. In addition, regarding the regulatory and policy limitations of CSP technology, the implementation of long-term frameworks, supported by regulatory schemes is needed.

Fuel Cell micro-CHP systems must be accepted as an eligible technology in the national public procurement rules for purchase of products with high-efficiency performance in the government buildings. The public sector constitutes an important driver to stimulate market transformation towards high-efficiency technologies. Buildings owned by public bodies account for a considerable share of the building stock and have high visibility in public life.

A clear and ambitious legislation will finally promote that the European companies in this sector will increase their sales with the result of further cost reductions and increased market share.

6.1.3 H_2 production

Related to **electrolysers** for hydrogen production, it is recommended to improve the R&D to increase the hydrogen conversion efficiency and improve the dynamic behaviour of electrolysers operating at partial loads. It is also necessary to reduce the noble metals used in the electrodes (such as Platinium, Iridium and Ruthenium), improve the membrane permeability and improve electrolyser manufacturing processes to reduce costs.

The durability and stability of the different materials that constitute the electrolyser need to be analyzed in deeper detail, especially when the electrolysers are connected to the electricity grid and are operating in a high dynamic regime due to the variability of the renewable energies. In these cases, a greater degradation has been observed [238].

Hydrogen generation/storage should be a complementary technology together with the reinforcement of the electricity transmission grid and the development of HVDC networks, requiring a cost-benefit analysis to evaluate when it is more interesting to use H_2 instead of extending the grid.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 957779

6.2 Potential recommendations for energy storage

The regulatory environment for large scale energy storage is currently under development. It is required a common and stable legislative framework to promote energy storage, reforming the current electricity markets to allow the provision of ancillary services by energy storage installations.

6.2.1 Thermal energy storage

Sensible heat storage is currently commercially available. Latent heat storage is expected to be commercially available for selected applications in the following years and, thermochemical heat storage is still in the pre-commercial stage.
The recommendations associated with the improvement of **thermal storage** are as follows:

- Promoting R&D for new materials for increasing thermal energy storage and reducing thermal losses.
    - Developing new salt mixtures with lower freezing points and higher temperature stability for sensible heat storage.
    - Research in advanced materials for PCM.
- Improve relevant thermo-physical properties of different storage materials.
- Identify selected applications for thermochemical storage.
- Integrate PCM storage materials in buildings envelopes such as walls, ceiling, roof, etc.
- Reduce the current cost of the different thermal heat storage technologies.

6.2.2 Electric energy storage

In section 3.2.2.1, a brief description of different **electrochemical batteries technologies** has been presented, but none of these technologies matches ideally with all storage applications, and significant challenges related to current energy density, lifetime and cost must be solved in the near future.

The potential recommendations are to promote the R&D in battery technologies to increase the applicability of these elements into grid and mobility solutions. This research should be focused at different levels:

- Cell level, with fundamental research in novel materials for anodes and electrolytes and new battery chemistries, reducing the dependence (and cost) of scarce and expensive raw materials, looking for a substantial increment of energy-power battery density and improving the safety (avoiding the use of toxic or corrosive materials and reducing the risk of fire or explosion).
- Pack level, as an alternative to the current cylindrical electrolyte design, reduces the volume and weight of the battery.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

- Battery system design, with new manufacturing methods for reducing the final costs
- Development of methods and tools for the improvement of battery safety, performance, reliability, and lifetime assessment: design and manufacturing of modules and packs, thermal management performance, advanced battery management, digital twins, interoperability and multiservice operations, dedicated power electronics, sensors, self-healing functionalities, etc.
- Improve the battery management systems (BMS) for diagnostics and control of the batteries, reducing their degradation and improving their life cycle.
- Increase manufacturability and recyclability of battery materials, cells and systems.

It will also be required to improve battery modelling tools for a better understanding of the complex electrochemical behaviours under different duty cycles (duty cycles for batteries used in EVs, duty cycles for batteries used in grip applications, etc.)

Currently, most of the global battery production is carried out in several Asian countries (mainly in China), making Europe vulnerable to a shortage. It is necessary to create a competitive European battery value chain, promoting research and development in this field and local production and creating new jobs.

The primary targets for **supercapacitors** and **flywheels** are to reduce the device cost and to increase the energy density without reducing power output and life.

In order to address the main limitations of **supercapacitors**, it is required to work in three different key areas: on the one hand, improving the energy storage capacity, which requires some research and development in new materials for electrodes, which allow for a larger surface area and an increment in the capacitance of these devices. It is also important to find new materials for the electrolytes capable of operating at higher working voltage to increase the overall specific energy (remember that the energy stored in these devices is proportional to the square of this working voltage). All new materials must be cost-effective to reduce the total cost of the final device. Also, they must be environmental friendly materials, facilitating the subsequent recycling at the end of the device life.
Additionally, it is necessary to improve the manufacturing process to reduce the final costs and finally, if these devices are going to be used in grid applications, it is necessary to establish new test procedures for electrical, thermal and safety characterisation.

In order to improve **flywheels** shortcomings, further research is needed in the following fields [262]:

It is necessary to develop new materials for the flywheel rotors to reduce mechanical stress and achieve higher rotational speeds. New security cases must be developed.

To develop new high-speed electrical machines. Permanent Magnet Synchronous Machine (PMSM) are currently the best option, but magnets are made of rare earth materials and are very expensive, requiring further research in new cheaper materials. New power electronics with higher commutation frequencies to operate the electrical machines are also required, ensuring higher reliability and reducing the switching losses.

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement N° 957779

New simulation and pilot tests must be done to study the hybridisation of these devices with other types of high energy density storage systems such as electrochemical batteries and PHPPs [263].

CAES has a very low technical maturity, and more research must be done in order to increase the reliability of these systems, increase the roundtrip efficiency a reduce the total costs. In order to increase its efficiency, more research in adiabatic processes will be required. In these processes, the heat-generating during the compression stage is used to preheat the air before expansion, avoiding the burn of natural gas for this preheating phase.

In particular, the main key aspects are listed below:

- Heat storage and cold storage are fundamental to improve the efficiency of the whole CAES system since the thermal losses are minimized, and thus, there is no need to use an external primary source to provide thermal energy to the working fluid
- By using the underground salt caverns and the special geological conditions of the cave, a mature technology of large-capacity storage can be easily reused, and the storage pressure and scale meet the CAES usage in a way better than artificial pressure containers
- For small-scale CAES, advanced electric and electronic technology is used to fulfil the direct connection of the high-speed turbine to the generator, remove the mechanical reducer, simplify the structure of the system, and improve the system reliability.

Further R&D is also required for the CAES system in order to improve the low round trip efficiency (plants in operation achieve between 40 to 54%). One possible solution to improve the efficiency of the system could be the installation of a Thermal Energy Storage (TES) and a gas storage system if they are embedded in the preliminary design phase of the whole CAES system itself.

There are some possible gains of CAES systems to improve the efficiency of each subsystem, especially through the installation of a Thermal Energy Storage (TES) and a gas storage system, if they are embedded in the preliminary design phase of the whole CAES system itself [264].

Related to **LAES**:

o It has a high energy density (385 MJ/m3 or 107 kWh/m3). This is similar to batteries, around 20 times higher than CAES and 400 times higher than pumped hydro at 100 meters height. In practicality, this means that a LAES integrated powerplant can be placed without geographical constraints;

o It does not require any scarce or toxic materials and does not produce toxic waste. This is an advantage when compared to most batteries. LAES is reasonably safe compared to chemical storage methods like hydrogen and methane, which are flammable and explosive;

o It can have economic advantages because the medium is free and the components used are technologically mature, long-lasting, mass-produced, and therefore relatively low cost over time. This is especially true compared to batteries which are costly to produce and have a limited lifespan.

PHPPs is the most mature energy storage technology, but there is always room for improvement:

- Study underground reservoirs in inactive mines suitable for small PHPP, requiring only an upper reservoir. In this case, most of the galleries to allocate the lower reservoir and the required electromechanical equipment are already excavated; it is not required the construction of new power lines because the main has a connection point available, reducing the considerably the investment costs.

- Increase the operation flexibility, allowing regulation in pumping mode by installing variable speed motor-generators and the use of ternary systems, which allow the simultaneous operation of generation and pumping, reducing the time required to switch between both modes.
- By leveraging existing infrastructure by retrofitting current PHPP facilities
- Hybridisation with battery storage to enhance frequency regulation of the plant [265].
- The hybridisation of renewable energies with these PHPPs to provide firm generation. In particular, PV floating systems can be installed in PHPP reservoirs, sharing the existing high-voltage grid infrastructure, increasing the overall efficiency [266].
- Establishing regulatory frameworks that incentivise and remunerate the innovative operation of PHPP.

6.2.3 H_2 storage

In the analysis of hydrogen storage, it was concluded that there are some technical and regulatory limitations in its implementation.

Most of the storage technologies are still being researched and developed, which means that substantial advances are still required.

It is also worth mentioning that optimal layouts of large-scale hydrogen storage systems based on adsorption and chemical or metal hydrides are still missing and need to be determined. Basic aspects, such as reactor designs, methods of heat supply for dehydrogenation, and acceptable load ranges, should also be researched and identified for several technologies.

In general, the shortcomings and existing issues, which are elaborated in subsection 4.1.1.3, needs to be mitigated through further research, and this should be supported by funding provided at the national and European level.

As mentioned in subsection 4.2.3, a clear definition of the ownership of hydrogen storage at European should be defined. More clarity is needed on the legal status of energy storage in particular with regards to power-to-gas (P2G).

6.3 Other potential recommendations

Regarding **electromobility**, most Li-ion batteries currently used in EVs employ liquid electrolytes, which is flammable and corrosive. Solid-state electrolytes can address these aspects, increasing the energy density (reducing the weight and volume of the battery pack, which finally will increase the range), allowing quicker charging time and improving safety. Some car manufacturers, such as Toyota, will install these solid-state batteries in some of their new hybrid models in two or three

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

years' time [267], but it is recommended further research on solid-state Li-ion battery technology at the European level.

With an estimation of around 84 million EVs travelling around Europe in 2030 [268], battery life will be a critical issue. The average battery life is around 150,000-200,000 km (10 years), but it can be less depending on how the batteries have been recharged during this period (the recharging regime), how the customers have been driving (the vehicle usage) and even the outside temperature (if the vehicle has been regularly driving under extreme temperatures, its battery pack may have been damaged, decreasing their energy capacity). There are unsolved environmental issues surrounding these batteries to be tackled in the next few decades [269]. For this reason, the EU must promote the development of a circular economy, looking for new methods for recycling these batteries after finishing their life cycle [270].

A high penetration rate of EVs would significantly increase the demand for electricity, requiring an increase in the European generation capacity and high investments. Depending on the particular generation mix of each EU country, the GHG emission intensity of the electricity generation can differ significantly from one country to another. For example, countries such as Poland, Estonia, Bulgaria, Greece, Malta, Cyprus, etc., will emit more GHG by electrifying the transportation sector than if conventional ICE vehicles are maintained due to the weight of the coal-fired electric generation in their national generation mix. Therefore, it is important to integrate renewable generation and battery storage in the new EV charging infrastructures and evaluate the deployment of other types of CO_2 free electricity generation, such as small modular nuclear reactors, to provide additional firm generation.

The transition from ICE vehicles to electric ones will reduce the environmental impact of the transportation sector, but the current transportation model is unsustainable, regardless of how the vehicles are powered (by fuel or electricity). Having a single one and a half tonne vehicle to move one or two people for an hour per day, remaining stationary the rest of the time, is completely inefficient, and for that reason, it is required to prioritize public (and sustainable) public transportation and invest in autonomous vehicles. Despite the progress made in the field of autonomous driving in recent years, there are still major challenges to overcome before these autonomous vehicles can be brought to market and can be safely driven in densely populated urban environments. These vehicles will improve the traffic (particularly in cities), reducing the number of accidents and increasing the accessibility to transportation for senior citizens and disabled people.

Regarding charging infrastructure, at this moment, there are only 225,000 public charging points available in the EU (just 1/9 of these are fast charging points), and 70% of them are concentrated in three different countries (Germany, France and Netherlands), while there are only 4 EU member states with more than 10 chargers per 100 km [271]. Therefore, the current infrastructure is not sufficient and it will be required to increase the progress on charging points deployment in the near future, speeding up the national implementation and supporting the standardization of this infrastructure to allow an easy roaming of EVs.

Regarding road freight transportation, the new AFIR [65] proposed:
The deployment of a network of high voltage fast chargers for trucks (Article 4):

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement N° 957779

- TEN-T[2] core network will have at least 1.4 MW of charging power every 60 km by 2025 (3.5 MW by 2030) with at least one charger with 0.35 MW power output)
- TEN-T comprehensive network will have at least 1.4 MW of charging power every 100 km by 2025 (3.5 MW by 2035)
- Urban nodes will have 0.6 MW charging power by 2025 and 1.2 MW by 2030.

Additionally, it is also proposed to further deploy hydrogen refuelling stations (Article 6), with a capacity of 2t/day every 150 km of compressed hydrogen and 450 km for liquefied hydrogen for the whole TEN-T network by 2030 and LNG refuelling facilities (Article 8).

This new regulation is ambitious, but there are still some problems to overcome. On the one hand, the Megawatt Charging System (MCS) standard, which is required to recharge this type of vehicle, is still in development, but it should be available and be included in AFIR as soon as possible. On the other hand, the current forecast is that there won't be a significant amount of fuel cell trucks on the roads by 2030. For this reason, it will be better to invest the public money to incentive the deployment of charging infrastructure for the propulsion technology that is currently more mature, which is battery-powered electric trucks. The investment of LNG should be phased out because it is a fossil fuel that produces high levels of pollutants [272].

The IEM Directive 2019/944/EU [196] already enables V2G and V2H application participation in all electricity markets. Type 2 (EN 62196-2) and combined charging system Combo 2 (EN62196-3) socket outlets and vehicle connectors do not yet allow bidirectional charging, but other vehicle connectors used in Japanese vehicles (ChadeMO plug standard) is already capable of bidirectional charging. A new EU standard should be developed to enable bidirectional charging with Type 2 and Combo 2 EU connectors. Additionally, it will also be required to define a standardised communication protocol among all agents (EVs, charging points, aggregators, DSO/TSO and other market agents).

As mentioned above, although the participation of storage systems in the electricity market (particularly, providing ancillary services) has already been approved by the current EU legislation [196], it is necessary for national transpositions to define how such participation should be carried out.

Control and data management. In order to further ensure penetration, coordination and integration of different technologies, energy vectors, etc., it is required to further work on common data definitions and standard protocols to follow. Additionally, to advanced control and management techniques, it is required to ensure the secure and private usage of data that needs further development leading to high efficient data treatment and operation. Finally, in order to enhance the resilience and security of data and technologies, cyber-security and GDPR approaches must be handled as well as the treatment of data, and the decision-making system must be redundant and located at the edge.

[2] The Trans-European Transport Network (TEN-T) policy addresses the implementation and development of a Europe-wide network of railway lines, roads, inland waterways, maritime shipping routes, ports, airports and railroad terminals. TEN-T compromises 2 network layrers: The core network, which includes the most important connections, and the comprehensive network, covering all European regions [263]

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

7 Conclusions

The EU has an ambitious plan to reduce greenhouse gas emissions and become climate neutral by 2050. In order to deliver this plan in less than 30 years, a radical change in the way Europeans generate and consume energy for different applications (i.e. heating, cooling, electricity generation, transportation, etc.) is required.

The main objective of this first technical WP of the eNeuron project is to have a general overview of the Pan-European decarbonisation targets and the resulting policy acts, trends and roadmaps that will set the way forward in the coming years. The study identified and benchmarked the indicative status for the deployment of integrated local multi-vector energy systems. Technical limitations, shortcomings and obstacles to innovation, which may prevent the intended transformation of the European energy landscape towards local multi-vector energy systems, were also idenified. This deliverable provided an in depth analysis of these limitations.

Several technical and regulatory limitations related to different technologies implementable in the context of local multi-vector energy systems were identified and described as part of this research. The analysis was carried out by evaluating various aspects of each of the identified technologies.

There are a large number of different technologies available to contribute to the energy transition, albeit at various technological readiness levels. Some of these technologies are very consolidated, while others are in the very early stages of development.

At a technical level, these less-developed technologies such as hydrogen production and storage, will require greater support from the EU, providing additional funds for R&D in new materials, manufacturing processes, etc., to overcome their main identified technical barriers. These technologies will also require additional support to be competitive in the market as has already been done over the last 20 years in Europe with other technologies such as PV generation. But as the technological development improves, these investments can be progressively reduced, leaving them without the support and allowing the competitiveness of the market to improve these technologies naturally, reducing their costs and improving their efficiency.

Regarding regulatory barriers, there are limitations at different levels, with some being easier to overcome than others.

In general, the administrative procedures to install different types of technologies such as energy storage facilities, electrolysers, distributed electric generation or even EV charging points are large and complex. They can require permissions and agreements at national, regional and local levels, which impede these processes and discourage investors. These types of regulatory barriers can be overcome with some coordination between different administrations and/or the relaxing of certain regulatory restrictions, thereby facilitating the installation of new facilities.

It is important to have clear, precise and internationally accepted definitions. At this moment, there is a lack of common definition and classification of H_2 at the EU level. Additionally, the role and responsibilities of different agents in H_2 production and market are not defined at the same EU level. Finally, it is also difficult to determine the renewable origin of the electricity used for H_2 production.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

As observed, most of the identified regulatory barriers are due to the technology having evolved quicker than the current legislation. For example, the participation of distributed and intermittent renewable energy sources, energy storage facilities, final prosumers, electric vehicles, etc. in all electricity markets are allowed by the European legislation, but most of the Member States have not yet transposed the European Directive. There is a lack of clear regulation about how to integrate these new market agents (i.e. a clearer regulation about ownership of the energy storage and its control and management is required). It is also necessary to define regulations regarding ownership of H2 production and storage facilities and clarify the status of Power-to-Gas (P2G). It is essential to update the current electricity market and determine which network services should be mandatory for new agents (e.g., energy storage, EVs through V2G schemes, etc.) and which should be considered as part of the ancillary services market, allowing developers to more easily evaluate the potential benefits and investment analyses.

The current legislation related to heat, gas, transportation and electricity is isolated from the others and does not consider the multidisciplinary nature of these multi-energy carrier facilities. For example, there is a great decoupling between gas and electricity infrastructures and market legislation, but in order to reach the decarbonisation objectives for 2050, both markets will become increasingly intertwined, impacting on each other.

There is also a lack of common Pan-European and national regulations to promote new forms of intermittent renewable energy generation, which are less technologically developed (i.e. CSP, wave-tidal generation, etc.). This lack of common framework also affects the deployment of other analysed technologies such energy storage or co-generation (CHP). When previous policies were implemented to promote certain technologies (such PV generation), there has sometimes been a lack of regulatory stability, changing the initially agreed rules, which has greatly discouraged further investment in these technologies. Therefore, it is very important to have regulatory stability to ensure continued investment in this area.

Finally, regulation can help accelerating the energy transition to meet the mid-century goals, but it is important that no one is left behind. In many cases, the technologies to achieve these goals are already available on the market but require a high level of investment that not all citizens can afford. It is therefore essential to have commonly aligned incentive policies that allows this transition to be made in a short period of time, encouraging the replacement of current technologies with others (e.g., replacing natural gas boilers by heat pumps or conventional ICE vehicles with EVs) through upgrading schemes for final customers.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

8 References

[1] G. Comodi, M. Rossi, L. Jin, A. Mofroti Ferrario, F. Ferracuti, A. Arteconi, M. Di Somma, A. Buonanno, M. Caliano, V. Palladino, V. Rebillas-Loredo, C. Corchero García, J. Fraile-Ardanuy, A. Gutiérrez, G. Conti, D. Jiménez Bermejo, D. Fernández Muñoz, J. Pérez Díaz, A. Cortés, M. Santos-Mugica, E. García, C. Charalambous, L. Louzou, C. Papadimitriou, M. Pio, R. Oliveira, A. Morch, S. Oland, A. O'Connell, A. Coccia, F. Cunha Gomes and A. Khavari, “Technical solutions for multi carrier integrated systems under the LEC concept: A Review,” eNeuron Project, 2021.

[2] S. Kubba, Handbook of Green Building Design and Construction (Second Edition), 20017.

[3] J. Jowett, “What is a boiler and how does it work?,” 19 8 2019. [Online]. Available: https://realpars.com/boiler/. [Accessed 5 12 2021].

[4] SomchartChantasiriwan, «Optimum Installation of Heat Recovery Devices in Biomass Boiler,» *Computer Aided Chemical Engineering,* vol. 48, pp. 1537-1542, 2020.

[5] FWMDEV, “Biomass boiler example,” Forestworldmagazine, 13 5 2017. [Online]. Available: http://www.forestworldmagazine.com/en/biomass-boilers-the-best-option-for-improving-energy-rating-in-buildings/biomass-boiler-example-2/. [Accessed 4 1 2022].

[6] IEA, International Energy Agency, “Net Zero by 2050. A Roadmap for the Global Energy Sector,” IEA Publications, 2021.

[7] HowStuffWorks, “Steam boilers vs. Hot water boilers,” How stuff works, 14 12 2018. [Online]. Available: https://www.timothyoffheating.com/about/blog/how-stuff-works/steam-boilers-vs-hot-water-boilers/. [Accessed 5 12 2021].

[8] BIMS, “The Applications of Steam Boilers in the 21st Century,” BIMS, [Online]. Available: https://bellomyims.com/the-applications-of-steam-boilers-in-the-21st-century/. [Accessed 12 12 2021].

[9] EHPA, European Heat Pump Association, “White Paper: Heat Pumps-Integrating Technologies to Decarbonise Heating and Cooling,” 7 11 2018. [Online]. Available: https://www.ehpa.org/about/news/article/white-paper-heat-pumps-integrating-technologies-to-decarbonise-heating-and-cooling/. [Accessed 5 12 2021].

[10] Johnson Control, «Heat pump or boiler: What's the business cases?,» 2021. [En línea]. Available: https://www.johnsoncontrols.com/en_gb/-/media/jci/be/united-kingdom/iref/jci_iref_district_energy_white_paper.pdf. [Último acceso: 5 12 2021].

[11] SEAI, Sustainable Energy Authority of Ireland, “A Homeowner's Guide To Heat Pump Systems,” [Online]. Available: https://www.seai.ie/publications/Homeowners-Guide-To-Heat-Pump-Systems.pdf. [Accessed 5 12 2021].

[12] INOPLEX, “What’s the difference between absorption and adsorption chillers?,” INOPLEX, 2018. [Online]. Available: https://www.inoplex.com.au/information/whats-the-difference-between-absorption-and-adsorption-chillers. [Accessed 15 12 2021].

[13] Bry-Air, “ADSORPTION CHILLER WORKING PRINCIPLE,” Bry-Air(r), [Online]. Available: https://www.bryair.com/news-and-events/articles/adsorption-chiller-working-principle/. [Accessed 15 12 2021].

[14] IndustryToday, “Adsorption Chillers vs Absorption Chillers,” IndustryToday, 25 2 2019. [Online]. Available: https://industrytoday.com/adsorption-chillers-vs-absorption-chillers/. [Accessed 15 12 2021].

[15] A. Morch, B. Griden, S. Fleten, K. Maribu, B. Johansen, T. Vanebo, M. Berner, J. Stang and P. Naesje, “Erfaringer med lokal kraftproduksjon hos sluttbruker (casestudier) TR A6064,” SINTEF Energiforskning AS, Tronheim, 2004.

[16] Gugler, «Gugler. Water turbines,» [En línea]. Available: https://www.gugler.com/products/. [Último acceso: 5 12 2021].

[17] J. Dauenhauer, “Energy Cast Podcast: Installing conduit hydropower with NLine Energy,” hydroreview.com, 24 7 2020. [Online]. Available: https://www.hydroreview.com/hydro-industry-news/energy-cast-podcast-installing-conduit-hydropower-with-nline-energy/. [Accessed 5 1 2022].

[18] OES, Ocean Energy Systems, “Waves. Kinetic and potential energy associated with ocean waves can be harnessed using modular technologies,” [Online]. Available: https://www.ocean-energy-systems.org/ocean-energy/what-is-ocean-energy/waves/. [Accessed 5 12 2021].

[19] R. Alley, S. Blumsack, D. Bice and M. Feineman, “Wave and Tidal Energy,” The Pennsylvania State University, [Online]. Available: https://www.e-education.psu.edu/earth104/node/1068. [Accessed 5 12 2021].

[20] S. Lochery, “GENERATOR SELECTION FOR OSCILLATING WATER COLUMN,” The University of Edinburgh, [Online]. Available: http://generatorowc.weebly.com/oscillating-water-column.html. [Accessed 16 12 2021].

[21] T. Husseini, “Riding the renewable wave: tidal energy advantages and disadvantages,” Power Technology, 26 10 2018. [Online]. Available: https://www.power-technology.com/features/tidal-energy-advantages-and-disadvantages. [Accessed 5 12 2021].

[22] L. Kumar, M. Hasanuzzaman y N. Rahim, «Global advancement of solar thermal energy technologies for industrial process heat and its future prospects: A review,» *Energy Conversion and Management,* vol. 195, pp. 885-908, 2019.

[23] M. Thirugnanasambandam, S. Iniyan and R. Goic, “A review of solar thermal technologies,” *Renewable and Sustainable Energy Reviews,* vol. 14, no. 1, pp. 312-322, 2010.

[24] SENER, “Planta Solar Térmica Gemasolar,” Sener, 2021. [Online]. Available: https://www.energy.sener/es/proyecto/gemasolar. [Accessed 15 12 2021].

[25] SBP, «Parabolic Trough Power Plant AndaSol II,» SBP, 2009. [En línea]. Available: https://www.sbp.de/en/project/parabolic-trough-power-plant-andasol-ii/. [Último acceso: 15 12 2021].

[26] “Why Areva wants to hang out with Kepco,” Reuters Events. Renewables, 18 11 2013. [Online]. Available: https://www.reutersevents.com/renewables/csp-today/technology/why-areva-wants-hang-out-kepco. [Accessed 16 12 2021].

[27] M. Fedkin and J. A. Dutton, “7.4. Parabolic Dish CSP Technology,” e-Education Institute, College of Earth and Mineral Sciences, Penn State University, [Online]. Available: https://www.e-education.psu.edu/eme812/node/648. [Accessed 16 12 2021].

[28] M. Gallucci, “Thermal Solar Goes Where PVs Can’t Energy storage sparks a concentrating-solar boom,” *IEEE Spectrum,* vol. 58, no. 11, 2021.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 957779

[29] S. Kalogirou, "Solar thermal collectors and applications," *Progress in Energy and Combustion Science,* vol. 30, no. 3, pp. 231-295, 2004.

[30] Y. Tian y C. Zhao, «A review of solar collectors and thermal energy storage in solar thermal applications,» *Applied Energy,* vol. 104, pp. 538-553, 2013.

[31] Department of the Environment, Climate and Communications. IE, "Geothermal Energy in Ireland - A Roadmap for a Policy and Regulatory Framework," 11 1 2021. [Online]. Available: https://www.gov.ie/en/publication/abe7a-geothermal-energy-in-ireland-a-roadmap-for-a-policy-and-regulatory-framework/. [Accessed 5 12 2021].

[32] Offcie of Energy Efficiency and Renewable Energy, "Electricity Generation. Geothermal Technologies Office," [Online]. Available: https://www.energy.gov/eere/geothermal/electricity-generation. [Accessed 5 12 2021].

[33] E. Kalbci, Hybrid Renewable Energy Systems and Microgrids, Elsevier Science, 2020.

[34] Nafion, "Creamos energía limpia para el transporte del futuro," Nafion, 2021. [Online]. Available: https://www.nafion.com/es/support/white-papers/membranes-for-fuel-cells-white-paper. [Accessed 16 12 2021].

[35] G. Lopez Soop, "Hydrogen, the new hype?," Energy-versus-environment, 29 2 2020. [Online]. Available: https://energy-versus-environment.com/. [Accessed 30 12 2021].

[36] J. Adolf, C. H. Balzer, J. Louis, U. Schabla, M. Fischedick, K. Arnold, A. Pastowski y D. Schüwer, «Shell Hydrogen Study. Energy of the Future? Sustainable Mobility through Fuel Cells and H2,» 2017. [En línea]. Available: https://s06.static-shell.com/content/dam/royaldutchshell/documents/shell-h2-study-new.pdf. [Último acceso: 30 12 2021].

[37] P. Spath and M. K. Mann, "Life Cycle Assessment of Renewable Hydrogen Production via Wind/Electrolysis," 1 2 2001. [Online]. Available: https://www.nrel.gov/docs/fy04osti/35404.pdf. [Accessed 8 2 2022].

[38] IRENA, International Renewable Energy Agency, "Hydrogen from renewable power: Technology outlook for the energy transition," 1 9 2018. [Online]. Available: https://www.irena.org/publications/2018/sep/hydrogen-from-renewable-power. [Accessed 5 12 2021].

[39] Q. Homann, "Using Electrolyzers to Produce Renewable Hydrogen," FCHEA, Fuel Cell & Hydrogen Energy Association, 20 3 2020. [Online]. Available: https://www.fchea.org/in-transition/2020/3/30/using-electrolyzers-to-produce-renewable-hydrogen. [Accessed 16 12 2021].

[40] IEA, International Energy Agency, "The Future of Hydrogen: Seizing today's opportunities," 18 6 2019. [Online]. Available: https://www.oecd.org/fr/publications/the-future-of-hydrogen-1e0514c4-en.htm. [Accessed 5 12 2021].

[41] J. Proost, "State-of-the art CAPEX data for water electrolysers, and their impact on renewable hydrogen price settings," *International Journal of Hydrogen Energy,* vol. 14, no. 9, pp. 4406-4413, 2019.

[42] A. Morch, H. Saele, J. Merino, A. Cortés, M. Santos-Mugica, J. Fraile-Ardanuy, A. Gutiérrez, D. Jiménez Bermejo, J. Pérez Díaz, M. Di Somma, A. Buonanno, M. Caliano, V. Palladino, G. Rossi, G. Comodi, M. Rossi, A. Monforti Ferrario, V. Rebillas-Loredo, C. Corchero-García, A. O'Connell and A. Coccia, "Local multi-vector energy systems within the European political and regulatory landscape: scope and key priorities for the study," eNeuron Project, 2021.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

[43] EU Comission. Directorate-General for Energy, “DG ENER Working Paper. The future role and chanllenges of Energy Storage,” [Online]. Available: https://ec.europa.eu/energy/sites/ener/files/energy_storage.pdf. [Accessed 12 12 2021].

[44] E. Rodríguez Ubiñas, “Almacenamiento de energía térmica por calor latente en los edificios: bases para la optimización de aplicaciones pasivas, opacas y traslúcidas,” UPM, Madrid, 2015.

[45] T. Bauer, “Chapter 1: Fundamentals of high temperature thermal energy storage, transfer and conversion,” in *Ultra-High Temperature Thermal Energy Storage, Transfer and Conversion,*, Woodhead Publishing Series, 2020, p. 35.

[46] EASE, European Association for Storage of Energy, “Energy Storage: Technologies,” 2021. [Online]. Available: https://ease-storage.eu/energy-storage/technologies/. [Accessed 5 12 2021].

[47] Northern Power, “Ultracapacitor EnergyBridge UPS for Palmdale Water District,” 3 11 2006. [Online]. Available: https://www.sandia.gov/ess-ssl/docs/pr_conferences/2006/mckay.pdf. [Accessed 28 12 2021].

[48] J. Pikkarainen, «Ultracapacitors Cut Energy Consumption of Port Cranes by 30%,» Skele+on Technologies, 21 10 2020. [En línea]. Available: https://www.skeletontech.com/skeleton-blog/ultracapacitors-cut-energy-consumption-of-port-cranes-by-30. [Último acceso: 28 12 2021].

[49] M. Aneke and M. Wang, “Energy Storage Technologies and Real Life Applications - A state of the art review,” *Applied Energy,* vol. 179, pp. 350-377, 2016.

[50] J. Corte Revuelta, “Energy Storage Analysis of Compressed Air,” Universidad de Zaragoza, Zaragoza, 2019.

[51] V. Duscha, A. Fougeyrollas, C. Nathani, M. Pfaff, M. Ragwitz, G. Resch, W. Schade, B. Breitschopf and R. Walza, “Renewable energy deployment in Europe up to 2030 and the aim of a triple dividend,” *Energy Policy,* vol. 95, pp. 314-323, 2016.

[52] IRENA, International Renewable Energy Agency, «REmap 2030: A Renewable Energy Roadmap,» 1 6 2014. [En línea]. Available: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2014/IRENA_REmap_summary_findings_2014.pdf. [Último acceso: 5 12 2021].

[53] EERA, European Energy Research Alliance, «SP4- Mechanical Energy Storage,» [En línea]. Available: https://www.eera-energystorage.eu/about/sub-programmes/sp4-mes.html. [Último acceso: 5 12 2021].

[54] M. Mazengard, “New England Pumped Hydro Study gets Boost with ARENA Funding,” World-Energy, 3 4 2020. [Online]. Available: https://www.world-energy.org/article/7961.html. [Accessed 5 12 2021].

[55] Andritz, “Andritz,” Pumped storage, [Online]. Available: https://www.andritz.com/products-en/hydro/products/pumped-storage. [Accessed 16 12 2021].

[56] S. Rehman, L. Al-Hadharami and M. Alam, “Pumped hydro energy storage system: A technological review,” *Renewable and Sustainable Energy Reviews,* vol. 44, pp. 586-598, 2015.

[57] Eurelectric, “Hydro in Europe: Powering renewables. Full report,” 2011.

[58] “Service : Solar Water Pump,” your energy, 2021. [Online]. Available: https://yourenergy.in/solar-water-pump.php. [Accessed 6 1 2022].

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 957779

[59] G. Olveira e Silva and P. Hendrick, “Pumped hydro energy storage in buildings,” *Applied Energy,* vol. 179, pp. 1242-1250, 2016.

[60] B. Pali and S. Vadhera, “A novel pumped hydro-energy storage scheme with wind energy for power generation at constant voltage in rural area,” *Renewable Energy,* vol. 127, pp. 802-810, 2018.

[61] M. Majidi and M. Etezadi-Amoli, “Recapturing wasted energy in water pressure reducing valves via in-conduit hydropower generators,” *Measurement,* vol. 123, pp. 62-68, 2018.

[62] TUVSUD, “TUVSUD,” WHAT ARE THE BIGGEST CHALLENGES FACING HYDROGEN STORAGE, TRANSPORTATION AND DISTRIBUTION?, [Online]. Available: https://www.tuvsud.com/sl-si/panoge/energija/konvencionalna-energija/hydrogen-services/hydrogen-storage-transportation-and-distribution. [Accessed 16 12 2021].

[63] EU Commission, “European Green Deal: Commission proposes transformation of EU economy and society to meet climate ambitions,” European Union, 14 7 2021. [Online]. Available: https://ec.europa.eu/commission/presscorner/detail/en/ip_21_3541. [Accessed 5 12 2021].

[64] D. Gutiérrez, “Tesla expande su red de Superchargers: estos son los que abrirán en los próximos meses,” HibridosyElectricos, 23 7 2019. [Online]. Available: https://www.hibridosyelectricos.com/articulo/actualidad/expansion-red-supercargadores-tesla-espana/20190722160002029186.html. [Accessed 16 12 2021].

[65] EUR-lex, «Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the deployment of alternative fuels infrastructure, and repealing Directive 2014/94/EU of the European Parliament and of the Council,» European Union, 14 7 2021. [En línea]. Available: https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX:52021PC0559. [Último acceso: 5 12 2021].

[66] M. Myrers, A. Turton, E. Marshallcross and L. Glover, “Technical Feasibility of Electric Heating in Rural Off-Gas Grid Dwellings,” 1 12 2018. [Online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/762596/Technical_Feasibility_of_Electric_Heating_in_Rural_Off-Gas_Grid_Dwellings.pdf. [Accessed 6 12 2021].

[67] SEAI, Sustainable Energy Authority of Ireland, “Biomass Boilers-Technology Guide,” 1 3 2019. [Online]. Available: https://www.seai.ie/publications/Biomass-Boilers-Technology-Guide.pdf. [Accessed 6 12 2021].

[68] A. Singh, V. Sharma, S. Mittal, G. Pandey, D. Mudgal and P. Gupta, “An overview of problems and solutions for components subjected to fireside of boilers,” *International Journal of Industrial Chemistry,* vol. 9, pp. 1-15, 2018.

[69] S. Carpentier, P. Milin, N. Mostefaoui, P. Nitschke-Kowsky, J. Schweitzer, N. Sadegh and O. Thibaut, “Self-regulated gas boilers able to cope with gas quality variation. State of the art and performances,” 1 10 2018. [Online]. Available: https://www.gerg.eu/wp-content/uploads/2019/10/CCCB_Report_final.pdf. [Accessed 6 12 2021].

[70] EASEE-GAS, «EASEE-gas Common Business Practices CBPs,» EASEE-Gas, 12 5 2020. [En línea]. Available: https://easee-gas.eu/latest-cbps. [Último acceso: 6 1 2022].

[71] Insider, “Commodities. Natural Gas Prices,” Insider, [Online]. Available: https://markets.businessinsider.com/commodities/natural-gas-price. [Accessed 9 12 2021].

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 957779

[72] IEA, International Energy Agency, “Gas Market Report, Q4 2021,” 1 10 2021. [Online]. Available: https://www.iea.org/reports/gas-market-report-q4-2021. [Accessed 9 12 2021].

[73] ES Engineered Systems, “District Heating Electric Boilers Suddenly in Vogue Again,” ES Engineered Systems, 13 4 2021. [Online]. Available: https://www.esmagazine.com/articles/101381-district-heating-electric-boilers-suddenly-in-vogue-again. [Accessed 9 12 2021].

[74] ISAP, Internetowy System Aktów Prawnych, “Rozporządzenie Ministra Gospodarki, Pracy i Polityki Społecznej z dnia 9 lipca 2003 r. w sprawie warunków technicznych dozoru technicznego w zakresie eksploatacji niektórych urządzeń ciśnieniowych,” 16 9 2003. [Online]. Available: http://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20031351269. [Accessed 9 12 2021].

[75] Lin-ka Energy, “Wood pellet plant: 400 - 15,000 kW,” LINKA Group, [Online]. Available: https://www.linkaenergy.com/en/products/wood-pellets-400---15000-kw/. [Accessed 6 12 2021].

[76] Läs mer om Farmarenergi i Eslöv AB, “Farmarenergi i Eslöv AB, Skåne,” 29 11 2016. [Online]. Available: https://www.lrf.se/foretagande/forskning-och-framtid/innovation-och-inspiration/de-tog-steget/framtidsforetag/farmarenergi-i-eslov-ab-skane. [Accessed 6 12 2021].

[77] D. Keogh, M. Saffari, M. de Rosa and D. Finn, “Energy assessment of hybrid heat pump systems as a retrofit measure in residential housing stock,” in *E3S Web of Conferences*, 2019.

[78] H. Kulasekara and V. Seynulabdeen, “A Review of Geothermal Energy for Future Power Generation,” in *5th International Conference on Advances in Electrical Engineering (ICAEE), 2019*, Dhaka, Bangladesh, 2019.

[79] Hybrid Heating EUROPE, “Unlocking the hybrid heating potential in European Buildings,” [Online]. Available: https://hybridheatingeurope.eu/. [Accessed 6 12 2021].

[80] Energy Efficiency and Renewable Energy, “Industrial Heat Pumps for Steam and Fuel Savings,” 1 6 2003. [Online]. Available: https://www.energy.gov/sites/prod/files/2014/05/f15/heatpump.pdf. [Accessed 9 12 2021].

[81] UK Government, «Hybrid heat pumps study,» 12 4 2018. [En línea]. Available: https://www.gov.uk/government/publications/hybrid-heat-pumps-study. [Último acceso: 9 12 2021].

[82] R. Whitlock, “Italian 'Superbonus' is one of the most ambitious heat pump installation schemes to date,” Renewable Energy Magazine, 18 8 2020. [Online]. Available: https://www.renewableenergymagazine.com/miscellaneous/italian-superbonus-is-one-of-the-most-20200818. [Accessed 8 2 2022].

[83] EPA, US Environmental Protection Agency, “Catalog of CHP Technologies,” 1 9 2017. [Online]. Available: https://www.epa.gov/sites/default/files/2015-07/documents/catalog_of_chp_technologies.pdf. [Accessed 6 12 2021].

[84] EU Commision, «Mapping and analyses of the current and future (2020 - 2030) heating/cooling fuel deployment (fossil/renewables),» 1 3 2017. [En línea]. Available: https://ec.europa.eu/energy/studies_main/final_studiesmapping-and-analyses-current-and-future-2020-2030-heatingcooling-fuel_en. [Último acceso: 9 12 2021].

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 957779

[85] K. Grabowska, “Energetic efficiency of adsorption chiller with modified beds construction,” 2019. [Online]. Available: https://winntbg.bg.agh.edu.pl/rozprawy2/11661/full11661.pdf. [Accessed 6 12 2021].

[86] R. Wang, L. Wang y J. Wu, Adsorption Refrigeration Technology: Theory and Application, Singapore: John Wiley & Sons, 2014.

[87] ISE, Fraunhofer Institute for Solar Energy Systems, «Photovoltaics Report,» 27 7 2021. [En línea]. Available: https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdf. [Último acceso: 6 12 2021].

[88] J. Svarc, “Most Efficient Solar Panels 2021,” Clear Energy Reviews, 18 7 2021. [Online]. Available: https://www.cleanenergyreviews.info/blog/most-efficient-solar-panels. [Accessed 6 12 2021].

[89] P. S. Nduka and B. C. Pal, “Harmonic Domain Modeling of PV System for the Assessment of Grid Integration Impact,” *IEEE Transactions on Sustainable Energy,* vol. 8, no. 3, pp. 1154-1165, 2017.

[90] V. Benda and L. Cerná, “PV cells and modules – State of the art, limits and trends,” *Heliyon,* vol. 6, pp. 1-8, 2020.

[91] IEA, International Energy Agency, «Renewables 2020. Analysis and forecast to 2025,» 1 11 2020. [En línea]. Available: https://www.iea.org/reports/renewables-2020. [Último acceso: 6 12 2021].

[92] L. Dunn, M. Gostein and B. Stueve, “Literature Review of the Effects of UV exposure on PV modules,” 16 2 2013. [Online]. Available: https://www.energy.gov/sites/default/files/2014/01/f7/pvmrw13_ps5_atonometrics_dunn.pdf. [Accessed 6 12 2021].

[93] D. C. Jordan and S. R. Kurtz, “Photovoltaic Degradation Rates - An Analytical Review,” 1 6 2012. [Online]. Available: https://www.nrel.gov/docs/fy12osti/51664.pdf. [Accessed 6 12 2021].

[94] J. Kim, M. RAbelo, S. P. Padi, H. Yousuf, E.-C. Cho and J. Yi, “A Review of the Degradation of Photovoltaic Modules for Life Expectancy,” *Energies,* vol. 14, no. 4278, pp. 2-21, 2021.

[95] D. Quansah, M. Adaramola and G. Takyi, “Degradation and longevity of solar photovoltaic modules—An analysis of recent field studies in Ghana,” *Energy Science & Engineering,* vol. 8, no. 6, pp. 2116-2128, 2020.

[96] D.-J. van de Ven, I. Capellan-Perez, I. Arto, I. Cazcarro, C. de Castro, P. Patel y M. Gonzalez-Eguino, «The potential land requirements and related land use change emissions of solar energy,» *Scientific Reports,* vol. 11, nº 2907, pp. 1-12, 2021.

[97] D. Mulvaney, “Solar's green dilemma,” *IEEE Spectrum,* vol. 51, no. 9, pp. 30-33, 2014.

[98] R. Klaeboe and H. Sundfor, “Windmill Noise Annoyance, Visual Aesthetics, and Attitudes towards Renewable Energy Sources,” *International Journal of Environmental Research and Public Health,* vol. 13, no. 8, pp. 1-19, 2016.

[99] A. Attya, J. Dominguez-Garcia and O. Anaya-Lara, “A review on frequency support provision by wind power plants: Current and future challenges,” *Renewable and Sustainable Energy Reviews,* vol. 81, no. 2, pp. 2071-2087, 2018.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 957779

[100] H. Holttinen, A. Ivanova and J. L. Dominguez, "Wind power in markets for frequency support services," in *2016 13th International Conference on the European Energy Market (EEM)*, Porto, Portugal, 2016.

[101] NVE, "Analyse og Framskrivning AV.Kraftproduksjon I Norden Til 2040," 10 2019. [Online]. Available: http://publikasjoner.nve.no/rapport/2019/rapport2019_43.pdf. [Accessed 9 12 2021].

[102] UNIDO, United Nations Industrial Development Organization, "World Small Hydropower Development Report (WSHPDR) 2019," 2019. [Online]. Available: https://www.unido.org/our-focus-safeguarding-environment-clean-energy-access-productive-use-renewable-energy-focus-areas-small-hydro-power/world-small-hydropower-development-report. [Accessed 9 12 2021].

[103] J. Idso, "Small Scale Hydroelectric Power Plants in Norway. Some Microeconomic and Environmental Considerations," *Sustainability,* vol. 9, no. 7, p. 1117, 2017.

[104] Småkraftforening, "Småkraft Rapporten. 400 muligheter," 24 9 2018. [Online]. Available: https://www.smakraftforeninga.no/wp-content/uploads/2018/09/Sm%c3%a5kraftrapporten-2018.pdf. [Accessed 9 12 2021].

[105] A. Morch and B. Grinden, "Lokal kraftproduksjon hos sluttbruker (sluttrapport)," TR A6063 SINTEF Energi Forskning, Trondheim, 2005.

[106] IRENA, International Renewable Energy Agency, «Offshore Renewables: An Action Agenda for Deployment,» 1 7 2021. [En línea]. Available: https://www.irena.org/publications/2021/Jul/Offshore-Renewables-An-Action-Agenda-for-Deployment. [Último acceso: 6 12 2021].

[107] F. Boshell, R. Roesch, A. Salgado and J. Hecke, "Unlocking the potential of Ocean Energy: from megawatts to gigawatts," Energypost.eu, 3 5 2020. [Online]. Available: https://energypost.eu/unlocking-the-potential-of-ocean-energy-from-megawatts-to-gigawatts/. [Accessed 6 12 2021].

[108] Oceanunite, "The High Seas," Oceanunite, [Online]. Available: https://www.oceanunite.org/issues/the-high-seas/.. [Accessed 9 12 2021].

[109] BCD Group, "Wave and Tidal Power," BCF Group, [Online]. Available: https://www.thebcfgroup.co.uk/health-and-safety-pages/environmental-health-and-safety/wave-and-tidal-power.php. [Accessed 9 12 2021].

[110] K. Engeland, M. Borga, J.-D. Creutin, B. Francois, M.-H. Ramos and J.-P. Vidal, "Space-time variability of climate variables and intermittent renewable electricity production–a review," *Renewable and Sustainable Energy Reviews,* vol. 79, pp. 600-617, 2017.

[111] IEA, International Energy Agency, «Technology Roadmap-Concentrating Solar Power,» 1 5 2010. [En línea]. Available: https://www.iea.org/reports/technology-roadmap-concentrating-solar-power. [Último acceso: 6 12 2021].

[112] IRENA, International Renewable Energy Agency, "Concentrated Solar Power: Technology brief," 1 1 2013. [Online]. Available: https://www.irena.org/publications/2013/Jan/Concentrated-Solar-Power. [Accessed 6 12 2021].

[113] M. Kiis, "Advantages and disadvantages of diesel generators," Power UP, 9 3 2021. [Online]. Available: https://www.powerup-tech.com/blog/advantages-and-disadvantages-of-diesel-generators. [Accessed 6 12 2021].

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

[114] Valley Power Systems, «Pros and Cons of Industrial Diesel Generators,» Valley Powert Systems, [En línea]. Available: https://www.valleypowersystems.com/pros-and-cons-of-industrial-diesel-generators/. [Último acceso: 6 12 2021].

[115] Office of Energy Efficiency and Renewable Energy, "DOE Hydrogen Program's Safety Activities," Energygov, [Online]. Available: https://www.hydrogen.energy.gov/safety.html. [Accessed 6 12 2021].

[116] IRENA, "reen Hydrogen cost reduction scaling up electrolysers to meet the 1.5°C climate goal," 1 12 2020. [Online]. Available: https://www.irena.org/publications/2020/Dec/Green-hydrogen-cost-reduction#:~:text=Scaling%20up%20electrolysers%20to%20meet%20the%201.5oC%20climate%20goal&text=Green%20hydrogen%20can%20help%20to,haul%20transport%2C%20shipping%20and%20aviation.. [Accessed 13 12 2021].

[117] F. I. Gallardo, A. Monforti Ferrario, M. Lamagna, E. Bocci, D. Astiaso Garcia and T. E. Baeza-Jeria, "A Techno-Economic Analysis of solar hydrogen production by electrolysis in the north of Chile and the case of exportation from Atacama Desert to Japan," *International Journal of Hydrogen Energy,* vol. 46, no. 26, pp. 13709-13728, 2021.

[118] Y. Sun, S. Wang, F. Xiao and D. Gao, "Peak load shifting control using different cold thermal energy storage facilities in commercial buildings: A review.," *Energy Conversion and Management,* vol. 71, pp. 101-114, 2013.

[119] Y. Yan, K. Wang, P. Clough and E. Anthony, "Developments in calcium/chemical looping and metal oxide redox cycles for high-temperature thermochemical energy storage: A review," *Fuel Processing Technology,* vol. 199, no. 106280, pp. 1-17, 2020.

[120] D. Aydin, S. P. Casey and S. Riffat, "The latest advancements on thermochemical heat storage systems," *Renewable and Sustainable Energy Reviews,* vol. 41, pp. 356-367, 2015.

[121] IRENA, International Renewable Energy Agency, "Thermal energy storage: Technology brief," 1 1 2013. [Online]. Available: https://www.irena.org/publications/2013/Jan/Thermal-energy-storage. [Accessed 13 12 2021].

[122] EASE, European Association for Storage of Energy, "EASE-EERA Energy Storage Technology Development Roadmap 2017," 1 10 2017. [Online]. Available: https://ease-storage.eu/publication/ease-eera-energy-storage-technology-development-roadmap-2017/. [Accessed 7 12 2021].

[123] D. Parra., M. Swierczynski, D. I. Stroe, S. A. Norman, A. Abdon , J. Worlitschek, T. O'Doherty, L. Rodirgues, M. Gillot, X. Zhang, C. Bauer and M. K. Patel, "An interdisciplinary review of energy storage for communities: Challenges and perspectives," *Renewable and Sustainable Energy Reviews,* vol. 79, pp. 730-749, 217.

[124] Poonam, K. Sharma, A. Arora and S. Tripathi, "Review of supercapacitors: Materials and devices," *Journal of Energy Storage,* vol. 21, pp. 801-825, 2019.

[125] A. González, E. Goikolea, J. A. Barrena and R. Mysyk, "Review on supercapacitors: Technologies and materials," *Renewable and Sustainable Energy Reviews,* vol. 58, pp. 1189-1206, 2016.

[126] S. M. Mousavi, F. Faraji, A. Majazi and K. Al-Haddad, "A comprehensive review of flywheel energy storage system technology," *Renewabel and Sustainable Energy Reviews,* vol. 67, pp. 477-490, 2017.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

[127] K. R. Pullen, “The status and future of flywheel energy storage,” *Joule,* vol. 3, no. 6, pp. 1394-1399, 2019.

[128] F. Goris and E. L. Severson, “A review of flywheel energy storage systems for grid application,” in *44th Annual Conference of the IEEE Industrial Electronics Society*, Washington, DC, USA, 2018.

[129] S. R. Salkuti and C. M. Jung, “omparative analysis of storage techniques for a grid with renewable energy sources,” *International Journal of Engineering & Technology,* vol. 7, no. 3, pp. 970-976, 2018.

[130] X. She, X. Peng, B. Nie, G. Leng, X. Zhang, L. Weng, L. Tong, L. Zheng, L. Wang and Y. Ding, “Enhancement of round trip efficiency of liquid air energy storage through effective utilization of heat of compression,” *Applied Energy,* vol. 206, pp. 1632-1642, 2017.

[131] T. Högberg and M. Tholander, “Evaluation of liquid air as an energy storage alternative,” 2018. [Online]. Available: https://kth.diva-portal.org/smash/get/diva2:1216213/FULLTEXT01.pdf. [Accessed 7 12 2021].

[132] J. A. Fonseca and A. Schlueter, “Novel approach for decentralized energy supply and energy storage of tall buildings in Latin America based on renewable energy sources: Case study - Informal vertical community Torre David, Caracas - Venezuela,” *Energy,* vol. 53, pp. 93-105, 2013.

[133] S. Lin, T. Ma and M. S. Javed, “Prefeasibility study of a distributed photovoltaic system with pumped hydro storage for residential buildings,” *Energy Conversion and Management,* vol. 222, p. 113199, 2020.

[134] T. Kumano, K. Matsunawa and R. Nishiyama, “Experimental Test and Feasibility Study of a Micro In-Pipe Hydro Power Generator at a University Building,” *IFAC-PapersOnLine,* vol. 51, no. 28, pp. 380-385, 2018.

[135] A. McNabola, P. Coughlan, L. Corcoran, C. Power, A. P. Williams, I. Harris, J. Gallagher and D. Styles, “Energy recovery in the water industry using micro-hydropower: An opportunity to improve sustainability,” *Water Policy,* vol. 16, no. 1, pp. 168-183, 2013.

[136] N. Mousavi, G. Kothapalli, D. Habibi, C. K. Das and A. Baniasadi, “A novel photovoltaic-pumped hydro storage microgrid applicable to rural areas,” *Applied Energy,* vol. 262, p. 114284, 2020.

[137] J.-H. Kihm, J.-M. Kim, S.-H. Song and G.-Y. Lee, “Three-dimensional numerical simulation of fully coupled groundwater flow and land deformation due to groundwater pumping in an unsaturated fluvial aquifer system,” *Journal of Hydrology,* vol. 335, no. 1-2, pp. 1-14, 2007.

[138] K. H. Motwani, S. V. Jain and R. N. Patel, “Cost analysis of pump as turbine for pico hydropower plants - a case study,” *Procedia Engineering,* vol. 51, pp. 721-726, 2013.

[139] A. T. Thankappan, S. P. Simon, P. S. R. Nayak, K. Sundareswaran and N. P. Padhy, “Pico-hydel hybrid power generation system with an open well energy storage,” *IET Generation, Transmission and Distribution. Special Issue: Distributed & Autonomous Dispatch and Control for Active Distribution Networks/Microgrids Potential Scheme to Realise Plug & Play of DER,* vol. 11, no. 3, pp. 740-749, 2017.

[140] A. Morabito, J. Steimes, O. Bontems, G. A. Zohbi and P. Hendrick, “Set-up of a pump as turbine use in micro-pumped hydro energy storage: a case of study in Froyennes Belgium,” *Journal of Physics: Conference Series,* vol. 813, p. 012033, 2017.

This project has received funding from the European Union’s Horizon 2020
research and innovation programme under grant agreement N° 957779

[141] «Study of a Pump-as-Turbine (PaT) speed control for a Water Distribution Network (WDN) in South-Tyrol subjected to high variable flow rates,» *Energy Procedia,* vol. 148, pp. 226-233, 2018.

[142] “Techno-economic efficiency analysis of various operating strategies for micro-hydro storage using a pump as a turbine,” *Energies,* vol. 14, no. 2, pp. 1-18, 2021.

[143] “Pump as turbine applied to micro energy storage and smart water grids: a case study,” *Applied Energy,* vol. 241, pp. 567-579, 2019.

[144] B. A. Bhayo, H. H. Al-Kayiem, S. I. U. Gilani and F. B. Ismail, “Power management optimization of hybrid solar photovoltaic-battery integrated with pumped-hydro-storage system for standalone electricity generation,,” *Energy Conversion and Management,* vol. 215, p. 112942, 2020.

[145] EIA, US. Energy Information Administration, “Hydropower explained,” EIA, 9 12 2021. [Online]. Available: https://www.eia.gov/energyexplained/hydropower/hydropower-and-the-environment.php. [Accessed 13 12 2021].

[146] R. Baxter, “2020 Grid Energy Storage Technology Cost and Performance Assessment,” 1 12 2020. [Online]. Available: https://www.pnnl.gov/sites/default/files/media/file/Final%20-%20ESGC%20Cost%20Performance%20Report%2012-11-2020.pdf. [Accessed 13 12 2021].

[147] J. Andersson and S. Grönkvist, “Large-scale storage of hydrogen,” *International Journal of Hydrogen Energy,* vol. 44, no. 23, pp. 11901-11919, 2019.

[148] K. Habib, S. T. Handdóttir and H. Habib, “Critical metals for electromobility: Global demand scenarios for passenger vehicles, 2015–2050,” *Resources, Conservation and Recycling,* vol. 154, p. 104603, 2020.

[149] B. Ballinger, D. Schmeda-Lopez, B. Kefford, B. Parkinson, M. Stringer, C. Greig and S. Smart, “The vulnerability of electric-vehicle and wind-turbine supply chains to the supply of rare-earth elements in a 2-degree scenario,” *Sustainable Production and Consumption,* vol. 22, pp. 68-76, 2020.

[150] UNCTAD, United Nations Conference on Trade and Dev;, “Commodities ata a Glance: Special Issue on Strategic Battery Raw Materials,” 2020. [Online]. Available: https://unctad.org/system/files/official-document/ditccom2019d5_en.pdf. [Accessed 7 12 2021].

[151] J. Deng, C. Bae, A. Denlinger and T. Miller, “Electric Vehicles Batteries: Requirements and Challenges,” *Joule,* vol. 4, no. 3, pp. 511-515, 2020.

[152] Department of Chemistry. Beloit Univeristy, “Energy Density,” Beloit, [Online]. Available: https://chemistry.beloit.edu/edetc/SlideShow/slides/energy/density.html. [Accessed 7 12 2021].

[153] The Explorer, “The world’s first electric car and passenger ferry,” The explorer, [Online]. Available: https://www.theexplorer.no/solutions/ampere--the-worlds-first-electric-car-and-passenger-ferry/. [Accessed 7 12 2021].

[154] M. Porru, M. Pisano, A. Serpi and F. Pilo, “Electrification of Leisure Boats: a commercial State-of-the-Art,” in *2020 IEEE Vehicle Power and Propulsion Conference (VPPC)*, Gijon, Spain, 2020.

[155] Equinor, “This battery-hybrid ship was designed to cut emissions. It exceeded their wildest expectations.,” Equinor, [Online]. Available: https://www.equinor.com/en/magazine/battery-hybrid-supply-ship.html. [Accessed 7 12 2021].

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 957779

[156] ABB, “Azipod® electric propulsion,” ABB, [Online]. Available: https://global.abb/group/en/technology/did-you-know/azipod-electric-propulsion. [Accessed 7 12 2021].

[157] M. Jafari, A. Gauchia, S. Zhao, K. Zhang and L. Gauchia, “Electric Vehicle Battery Cycle Aging Evaluation in Real-World Daily Driving and Vehicle-to-Grid Services,” *EEE Transactions on Transportation Electrification,* vol. 4, no. 1, pp. 122-134, 2018.

[158] R. Bisschop, O. Willstrand, F. Amon and M. Rosengren, “Fire Safety of Lithium-Ion Batteries in Road Vehicles,” 2019. [Online]. Available: https://www.researchgate.net/publication/336640117_Fire_Safety_of_Lithium-Ion_Batteries_in_Road_Vehicles. [Accessed 7 12 2021].

[159] Y.-S. Duh, Y. Sun, X. Lin, J. Zheng, M. Wang, Y. Wang, X. Lin, Z. Zhen, S. Zhen and G. Yu, “Characterization on thermal runaway of commercial 18650 lithium-ion batteries used in electric vehicles: A review,” *Journal of Energy Storage,* vol. 41, p. 102888, 2021.

[160] Y.-S. Duh, J.-H. Theng, C.-C. Chen and C.-S. Kao, “Comparative study on thermal runaway of commercial 14500, 18650 and 26650 LiFePO4 batteries used in electric vehicles,” *Journal of Energy Storage,* vol. 31, p. 101580, 2020.

[161] W. Gao, X. Li, M. Ma, Y. Fu, J. Jiang and C. Mi, “Case Study of an Electric Vehicle Battery Thermal Runaway and Online Internal Short-Circuit Detection,” *IEEE Transactions on Power Electronics,* vol. 36, no. 3, pp. 2452-2455, 2021.

[162] G. Falchetta and M. Noussan, “Electric vehicle charging network in Europe: An accessibility and deployment trends analysis,” *Transportation Resarch Part D: Transport and Environment,* vol. 94, p. 102813, 2021.

[163] K. Clement-Nyns, E. Haesen and J. Driesen, “The Impact of Charging Plug-In Hybrid Electric Vehicles on a Residential Distribution Grid,” *IEEE Transactions on Power Systems,* vol. 25, no. 1, pp. 371-380, 2010.

[164] L. Pieltain, T. Gomez San Roman, R. Cossent, C. Mateo Domingo and P. Frias, “Assessment of the Impact of Plug-in Electric Vehicles on Distribution Networks,” *IEEE Transactions on Power Systems,* vol. 26, no. 1, pp. 206-213, 2011.

[165] S. Shafiee, M. Fotuhi-Firuzabad and M. Rastegar, “Investigating the Impacts of Plug-in Hybrid Electric Vehicles on Power Distribution Systems,” *IEEE Transactions on Smart Grid,* vol. 4, no. 3, pp. 1351-1360, 2013.

[166] L. I. Dulau, Bica and D., “Effects of Electric Vehicles on Power Networks,” *Procedia Manufacturing,* vol. 46, pp. 370-377, 2020.

[167] H. Engel, R. Hensley, S. Knupfer and S. Sahdev, “The potential impact of electric vehicles on global energy systems,” 8 8 2018. [Online]. Available: https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-potential-impact-of-electric-vehicles-on-global-energy-systems. [Accessed 7 12 2021].

[168] H. Saele, M. Istad and S. Garnas, “The benefit of batteries in a flexible distribution grid: Results from FlexNett project,” 2018. [Online]. Available: https://www.sintef.no/en/publications/publication/1621388/. [Accessed 7 12 2021].

[169] K. Baker, “Chapter 10-Power, buildings, and other critical networks: Integrated multisystem operation,” in *New Technologies for Power System Operation and Analysis*, Academic Press, 2021, pp. 319-358.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 957779

[170] D. Steward, “Critical Elements of Vehicle-to-Grid (V2G) Economics,” 1 9 2017. [Online]. Available: https://www.nrel.gov/docs/fy17osti/69017.pdf. [Accessed 7 12 2021].

[171] H. Ritchie, “The price of batteries has declined by 97% in the last three decades,” Our World in Data, 4 6 2021. [Online]. Available: https://ourworldindata.org/battery-price-decline#:~:text=The%20price%20of%20lithium%2Dion%20battery%20cells%20declined%20by%2097,halved%20between%202014%20and%202018. [Accessed 13 12 2021].

[172] L. J. Vimmersted, S. Ring and C. J. Hammel, “Current Status of Environmental, Helath, and Safety Issues of Lithium Ion Electric Vehicle Batteries,” 1 9 1995. [Online]. Available: https://www.nrel.gov/docs/legosti/old/7673.pdf. [Accessed 13 12 2021].

[173] E. Wollacott, “Electric cars: What will happen to all the dead batteries?,” BBC News, 27 4 2021. [Online]. Available: https://www.bbc.com/news/business-56574779. [Accessed 13 12 2021].

[174] L. Sobol and A. Dyjakin, “The Influence of Power Sources for Charging the Batteries of Electric Cars on CO2 Emissions during Daily Driving: A Case Study from Poland,” *Energies,* vol. 13, no. 15, p. 4267, 2020.

[175] S. M. Hashemi and V. Vahidinasab, “Microgrids: Advances in Operation, Control and Protection,” in *Energy Management Systems for Microgrids*, Springer, 2021, pp. 61-95.

[176] M. Mohammadi, Y. Noorollahi, B. Mohammadi-ivatloo, M. Hosseinzadeh, H. Yousefi and S. T. Khorasani, “Optimal management of energy hubs and smart energy hubs – A review,” *Renewable and Sustainable Energy Reviews,* vol. 89, pp. 33-50, 2018.

[177] I. Javid, A. Chauhan, S. Thappa, S. Verma, Y. Anand, A. Sawhney, V. Tyagi and S. Anand, “Futuristic decentralised clean energy networks in view of inclusive-economic growth and sustainable society,” *Journal of Cleaner Production,* vol. 309, p. 127034, 2021.

[178] EU Commission, «Paris Agreement,» EU Commission, [En línea]. Available: https://ec.europa.eu/clima/eu-action/international-action-climate-change/climate-negotiations/paris-agreement_es. [Último acceso: 8 12 2021].

[179] EU Commission, “Clean energy for all Europeans package,” EU Commission, [Online]. Available: https://ec.europa.eu/energy/topics/energy-strategy/clean-energy-all-europeans_en. [Accessed 8 12 2021].

[180] EU Commission, “A Clean Planet for All,” EU Commission, 28 11 2018. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52018DC0773. [Accessed 8 12 2021].

[181] EU Commission, “The European Green Deal sets out how to make Europe the first climate-neutral continent by 2050, boosting the economy, improving people's health and quality of life, caring for nature, and leaving no one behind,” EU Commission, 11 12 2019. [Online]. Available: https://ec.europa.eu/commission/presscorner/detail/en/ip_19_6691. [Accessed 8 12 2021].

[182] EU Commission, “Committing to climate-neutrality by 2050: Commission proposes European Climate Law and consults on the European Climate Pact,” EU Commission, 4 3 2020. [Online]. Available: https://ec.europa.eu/commission/presscorner/detail/en/ip_20_335. [Accessed 8 12 2021].

[183] EU Commission, «Making Europe's businesses future-ready: A new Industrial Strategy for a globally competitive, green and digital Europe,» EU Commission, 10 3 2019. [En línea].

Available: https://ec.europa.eu/commission/presscorner/detail/en/ip_20_416. [Último acceso: 8 12 2021].

[184] EU Commission, «Powering a climate-neutral economy: Commission sets out plans for the energy system of the future and clean hydrogen,» EU Commission, 8 7 2020. [En línea]. Available: https://ec.europa.eu/commission/presscorner/detail/en/ip_20_1259. [Último acceso: 8 12 2021].

[185] EU Commission, «State of the Union: Commission raises climate ambition and proposes 55% cut in emissions by 2030,» EU Commission, 17 9 2020. [En línea]. Available: https://ec.europa.eu/commission/presscorner/detail/en/ip_20_1599. [Último acceso: 8 12 2021].

[186] EU Commission, "The European Climate Pact: empowering citizens to shape a greener Europe," EU Commission, 9 12 2020. [Online]. Available: https://ec.europa.eu/commission/presscorner/detail/en/ip_20_2323. [Accessed 8 12 2021].

[187] EU Commission, "Green Deal: Sustainable batteries for a circular and climate neutral economy," EU Commission, 10 12 2020. [Online]. Available: https://ec.europa.eu/commission/presscorner/detail/en/ip_20_2312. [Accessed 8 12 2021].

[188] EU Commission, "New European Bauhaus: Commission launches design phase," EU Commission, 18 1 2021. [Online]. Available: https://ec.europa.eu/commission/presscorner/detail/en/IP_21_111. [Accessed 8 12 2021].

[189] EU Commission, "Building a Climate-Resilient Future - A new EU Strategy on Adaptation to Climate Change," EU Commission, 24 2 2021. [Online]. Available: https://ec.europa.eu/commission/presscorner/detail/en/ip_21_663. [Accessed 8 12 2021].

[190] EU Commission, "European Green Deal: Commission aims for zero pollution in air, water and soil," EU Commission, 12 5 2021. [Online]. Available: https://ec.europa.eu/commission/presscorner/detail/en/ip_21_2345. [Accessed 8 12 2021].

[191] EU Commission, "European Green Deal: Developing a sustainable blue economy in the European Union," EU Commission, 17 5 2021. [Online]. Available: https://ec.europa.eu/commission/presscorner/detail/en/ip_21_2341. [Accessed 8 12 2021].

[192] EU Commission, "2030 climate & energy framework," EU Commission, [Online]. Available: https://ec.europa.eu/clima/eu-action/climate-strategies-targets/2030-climate-energy-framework_en. [Accessed 8 12 2021].

[193] EU Commission, "EU Emissions Trading System (EU ETS)," EU Commission, [Online]. Available: https://ec.europa.eu/clima/eu-action/eu-emissions-trading-system-eu-ets_en. [Accessed 8 12 2021].

[194] EU Commission, "Innovation fund," EU Commission, [Online]. Available: https://ec.europa.eu/clima/eu-action/funding-climate-action/innovation-fund_es. [Accessed 8 12 2021].

[195] EU Commission, "Renewable Energy – Recast to 2030 (RED II)," EU Commission, [Online]. Available: https://ec.europa.eu/jrc/en/jec/renewable-energy-recast-2030-red-ii. [Accessed 8 12 2021].

[196] EU Commission, "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," 14 6 2019. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32019L0944. [Accessed 9 12 2021].

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

[197] H. Sæle, A. Morch, Y. B. Sheikh-Mohamed, M. Di Somma, A. Buonanno, M. Caliano, V. Palladino, C. Papadimitriou, C. Charalambous, K. Bronk, T. Ogryczak, B. Czarnecki, V. Rebillas, A. Ivanova, A. Khavari, S. Castaño-Solís, G. Conti, D. Fernandez, J. Fraile-Ardanuy, A. Guiterrez, D. Jimenez and J. Perez, "Introduction and development of Local Energy Communities in Europe," eNeuron Project, 2021.

[198] M. M. Sokołowski, European Law on Combined Heat and Power, London (UK): Routedge, 2020.

[199] CEN, European Committiee for standardization, "CEN/TC 238 - TEST GASES, TEST PRESSURES AND CATEGORIES OF APPLIANCES," [Online]. Available: https://standards.iteh.ai/catalog/tc/cen/a93a8a6e-89eb-4d5a-af11-f844d9d80c6f/cen-tc-238. [Accessed 8 12 2021].

[200] CEN, European Committee for Standardization, "CEN/TC 109 - CENTRAL HEATING BOILERS USING GASEOUS FUELS," [Online]. Available: https://standards.iteh.ai/catalog/tc/cen/735229de-f3cd-4e80-8c59-ef76418d749b/cen-tc-109. [Accessed 8 12 2021].

[201] CEN, European Committee for Standardization, "CEN/TC 58 - SAFETY AND CONTROL DEVICES FOR BURNERS AND APPLIANCES BURNING GASEOUS OR LIQUID FUELS," [Online]. Available: https://standards.iteh.ai/catalog/tc/cen/6a4e51df-1b8e-4876-8243-5d6faa333a89/cen-tc-58. [Accessed 8 12 2021].

[202] EU Science Hub, "Blending hydrogen into the EU gas system," EU Science Hub, 19 1 2022. [Online]. Available: https://ec.europa.eu/jrc/en/science-update/blending-hydrogen-eu-gas-system. [Accessed 16 2 2022].

[203] F. Schiro, A. Stoppato and A. Benato, "Modelling and analyzing the impact of hydrogen enriched natural gas on domestic gas boilers in a decarbonization perspective," *Carbon Resources Conversion,* vol. 3, no. 1, pp. 122-129, 2020.

[204] EDF, "UK Gas Boiler Ban – Everything You Need to Know," EDF, [Online]. Available: https://www.edfenergy.com/heating/advice/uk-boiler-ban. [Accessed 8 12 2021].

[205] UK Government, "Domestic Renewable Heat Incentive (RHI)," UK Government, [Online]. Available: https://www.gov.uk/domestic-renewable-heat-incentive. [Accessed 8 12 2021].

[206] S. Kozarcanin, R. Hanna, I. Staffell, R. Gross and G. Andresen, "Impact of climate change on the cost-optimal mix of decentralised heat pump and gas boiler technologies in Europe," *Energy Policy,* vol. 140, no. 111386, pp. 1-13, 2020.

[207] R. Khezri, A. Mahmoudi and M. H. Khooban, "Microgrids planning for residential electrification in rural areas," in *Residential Microgrids and Rural Electrifications*, London, Elsevier, 2022, pp. 1-25.

[208] Official Journal of the European Union, "Official Journal of the European Union C207," 3 7 2014. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:C:2014:207:FULL&from=ES. [Accessed 8 12 2021].

[209] NVE, "Lover og regler," NVE, 8 7 2009. [Online]. Available: https://www.nve.no/konsesjon/konsesjonsbehandling-av-fjernvarme/lover-og-regler/. [Accessed 8 12 2021].

[210] IRBEA, Irish Bioenergy Association, "Study on Biomass Combustion Emissions," 1 10 2016. [Online]. Available:

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

https://www.seai.ie/publications/2016_RDD_108._Biomass_Combustion_Emissions_Study_-_IrBEA.pdf. [Accessed 8 12 2021].

[211] BOE, Boletin Oficial del Estado , “Reglamento (UE) 517/2014 sobre los gases fluorados de efecto invernadero,” DIario Oficial de la Unión Europea, 16 4 2014. [Online]. Available: https://www.boe.es/doue/2014/150/L00195-00230.pdf. [Accessed 8 12 2021].

[212] G. De Giorgio, M. Chieco, P. P. Limoni, L. E. Zuffiano, V. Dragone, A. Romanazzi, R. Pagliarurlo, G. Musicco and M. Polemio, “Improving Regulation and the Role of Natural Risk Knowledge to Promote Sustainable Low Enthalpy Geothermal Energy Utilization,” *Water,* vol. 12, no. 10, pp. 1-14, 2020.

[213] EU Commission, “Cogeneration of heat and power,” EU Commission, [Online]. Available: https://ec.europa.eu/energy/topics/energy-efficiency/cogeneration-heat-and-power_en. [Accessed 8 12 2021].

[214] EU Commission, “Heating and Cooling,” EU Commission, [Online]. Available: https://ec.europa.eu/energy/topics/energy-efficiency/heating-and-cooling_en. [Accessed 8 12 2021].

[215] EU Commission, “Energy Efficiency Directive,” EU Commission, [Online]. Available: https://ec.europa.eu/energy/topics/energy-efficiency/targets-directive-and-rules/energy-efficiency-directive_en. [Accessed 8 12 2021].

[216] COGEN Europe, The European Association for the Promotion of Cogeneration, “Position Paper. An ambitious European Green Deal with cogeneration,” [Online]. Available: http://www.cogeneurope.eu/images/COGEN-europe_Green-Deal-Position_Final.pdf. [Accessed 8 12 2021].

[217] COGEN Europe, the European Association for the Promotion of Cogeneration,, “EU Energy Efficiency Legislation Falls Short of Proper National Implementation New Cogeneration Study Reveals,” [Online]. Available: https://www.cogeneurope.eu/newsroom/press-releases/new-survey-of-european-cogeneration-sector-reveals-gap-in-eu-policy-implementation-and-future-ambition. [Accessed 8 12 2021].

[218] COGEN Europe, rhe European Association for the Promotion of Cogeneration, “Towards an Efficient, Integrated and Cost-Effective Net-Zero Energy System in 2050,” 28 10 2020. [Online]. Available: https://www.cogeneurope.eu/images/COGEN-Europe-2050-CHP-Study-Results-28-October-2020-final.pdf. [Accessed 8 12 2021].

[219] HyLAW Online DataBase, “Connection of the E-grid to the electrolyser,” HyLAW Online DataBase, 2018. [Online]. Available: https://www.hylaw.eu/database/electricity-grid-issues-for-electrolysers/connection-of-the-e-grid-to-the-electrolyser. [Accessed 9 12 2021].

[220] FCHO-Fuel Cells and Hydrogen Observatory, “EU Policies,” FCHO-Fuel Cells and Hydrogen Observatory, 16 2 2022. [Online]. Available: https://www.fchobservatory.eu/observatory/Policy-and-RCS/EU-policies. [Accessed 16 2 2022].

[221] EUR-Lex, “Commission Regulation (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators,” 14 4 2016. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:JOL_2016_112_R_0001#d1e1043-1-1. [Accessed 9 1 2022].

[222] EUR-Lex, “Commission Regulation (EU) 2016/1388 of 17 August 2016 establishing a Network Code on Demand Connection,” 17 8 2016. [Online]. Available: https://eur-

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 957779

lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2016.223.01.0010.01.ENG&toc=OJ:L:2016:223:TOC. [Accessed 9 1 2022].

[223] EWEA, the European Wind Energy Association, "Balancing Responsibility and Costs of Wind Power Plants," 1 2 2016. [Online]. Available: https://windeurope.org/fileadmin/files/library/publications/position-papers/EWEA-position-paper-balancing-responsibility-and-costs.pdf. [Accessed 8 12 2021].

[224] EUR-Lex, "Directive 2014/35/EU of the European Parliament and of the Council of 26 February 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of electrical equipment designed for use within certain voltage lim," 29 3 2014. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32014L0035. [Accessed 8 12 2021].

[225] U. Nguyen, "Photovoltaic panels: near the end of the compensation scheme?," Energyprice.be, 5 11 2021. [Online]. Available: https://www.energyprice.be/blog/photovoltaic-panels-near-the-end-of-the-compensation-scheme/. [Accessed 8 12 2021].

[226] H. Martin, J. de la Hoz, A. Aliana, S. Coronas and J. Matas, "Analysis of the Net Metering Schemes for PV Self-Consumption in Denmark," *Energies,* vol. 14, pp. 1-22, 2021.

[227] Zonnefabriek, "Net metering in the Netherlands. How does it work and what will change from 2023?," Zonnefabriek, [Online]. Available: https://www.zonnefabriek.nl/en/solar-panels/net-metering-in-the-netherlands/. [Accessed 8 12 2021].

[228] IEA, International Energy Agenccy, "Snapshot of Global PV markets," 2021. [Online]. Available: https://iea-pvps.org/snapshot-reports/snapshot-2021/. [Accessed 8 12 2021].

[229] EU Comission, "Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC Text with EEA relevance," 14 11 2012. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32012L0027. [Accessed 9 12 2021].

[230] EUR Lex, "Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure," 22 10 2014. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014L0094. [Accessed 16 2 2022].

[231] EU Commission, «Regulation (EU) 2016/1628 of the European Parliament and of the Council of 14 September 2016 on requirements relating to gaseous and particulate pollutant emission limits and type-approval for internal combustion engines for non-road mobile machinery, ame,» 16 9 2016. [En línea]. Available: https://eur-lex.europa.eu/eli/reg/2016/1628/oj. [Último acceso: 9 12 2021].

[232] A. Barnes, "Can the current EU regulatory framework deliver decarbonisation of gas?," 1 6 2020. [Online]. Available: https://www.oxfordenergy.org/wpcms/wp-content/uploads/2020/06/Can-the-current-EU-regulatory-framework-deliver-decrbonisation-of-gas-Insight-71.pdf. [Accessed 12 12 2021].

[233] SIO, "ISO/TC 197 Hydrogen Technologies," 1990. [Online]. Available: https://www.iso.org/committee/54560.html. [Accessed 9 12 2021].

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

[234] EU Commission, “Commission Regulation (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators,” 14 4 2016. [Online]. Available: https://op.europa.eu/es/publication-detail/-/publication/1267e3d1-0c3f-11e6-ba9a-01aa75ed71a1/language-en. [Accessed 9 12 2021].

[235] A. L. Stein, “Reconsidering Regulatory Uertainty: Making a Case for Energy Storage,” [Online]. Available: https://bear.warrington.ufl.edu/centers/purc/docs/papers/1414_Stein_Reconsidering%20Regulatory%20Uncertainty.pdf. [Accessed 9 12 2021].

[236] European Parliament, “New EU regulatory framework for batteries. Setting Sustainability requirements,” 2021. [Online]. Available: https://www.europarl.europa.eu/RegData/etudes/BRIE/2021/689337/EPRS_BRI(2021)689337_EN.pdf. [Accessed 9 12 2021].

[237] C. Andrey, P. Barberi, L. v. Nuffel, F. Gérard and J. Gorenstein Dedecca, “Study on energy storage. Contribution to the security of the electricity supply in Europe,” 8 5 2020. [Online]. Available: https://op.europa.eu/en/publication-detail/-/publication/a6eba083-932e-11ea-aac4-01aa75ed71a1/language-en. [Accessed 9 12 2021].

[238] EASE, European Association for Storage of Energy, “EASE/EERA Energy Storage Technology Development Roadmap towards 2030. Technical Annex,” [Online]. Available: https://ease-storage.eu/publication/easeeera-energy-storage-technology-development-roadmap-towards-2030/. [Accessed 9 12 2021].

[239] B. Stoll, J. Andrade, S. Cohen, G. Brinkman and C. Brancucci Martinez-Anido, “Hydropower Modeling Challenges,” 1 4 2017. [Online]. Available: https://www.nrel.gov/docs/fy17osti/68231.pdf. [Accessed 9 12 2021].

[240] ACER, European Union Agency for the Cooperation of Energy Regulators, «Possible reegulation of hydrogen networks,» 26 1 2021. [En línea]. Available: http://extranet.acer.europa.eu/en/Gas/Documents/ACER%20H2%20Paper_%20vFinal_clean.pdf. [Último acceso: 9 12 2021].

[241] CMS, “Hydrogen. The Energy Carrier of the Future. Legislation and regulation on hydrogen use,” [Online]. Available: https://cms.law/en/deu/insight/hydrogen. [Accessed 9 12 2021].

[242] EVExpert, “Connector types for EV charging around the world,” EVExpert, [Online]. Available: https://www.evexpert.eu/eshop1/knowledge-center/connector-types-for-ev-charging-around-the-world. [Accessed 9 12 2021].

[243] G. Rajendran, C. A. Vaithilingam, N. Misron, K. Naidu and M. R. Ahmed, “A comprehensive review on system architecture and international standards for electric vehicle charging stations,” *Journal of Energy Storage,* vol. 42, p. 103099, 2021.

[244] EPRI, Electric Power Research Institute, «Interoperability of Public Electric Vehicle Charging Infrastucture,» 1 8 2019. [En línea]. Available: https://www.eei.org/issuesandpolicy/electrictransportation/Documents/Final%20Joint%20Interoperability%20Paper.pdf. [Último acceso: 9 12 2021].

[245] Y. Huang, L. Qian, D. Soopramanien and D. Tyfield, “Buy, lease, or share? Consumer preferences for innovative business models in the market for electric vehicles,” *Technological Forecasting and Social Change,* vol. 166, p. 120639, 2021.

[246] Nissan Motor Corporation. Official Global Newsroom, “Europe’s largest energy storage system now live at the Johan Cruijff Arena,” Nissan Motor Corporation. Official Global

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 957779

Newsroom, 29 06 2018. [Online]. Available: https://global.nissannews.com/en/releases/europes-largest-energy-storage-system-now-live-at-the-johan-cruijff-arena. [Accessed 9 12 2021].

[247] Open Charge Alliance, “OCPP 2.0.1. Open Charge Point Protocol,” Open Charge Alliance, [Online]. Available: https://www.openchargealliance.org/. [Accessed 9 12 2021].

[248] EU Commission, “The EU Clean Energy Package,” 4 6 2021. [Online]. Available: https://op.europa.eu/es/publication-detail/-/publication/7fa59d21-c7ff-11eb-a925-01aa75ed71a1. [Accessed 9 12 2021].

[249] EU Smart Cities Information Systems, “Electric Vehicles and The Grid. Solution Booklet,” 1 10 2020. [Online]. Available: https://smart-cities-marketplace.ec.europa.eu/sites/default/files/2021-02/D32.1D3_Solution%20Booklet_EVs%20and%20the%20Grid.pdf. [Accessed 9 12 2021].

[250] IEA, International Energy Agency, “Global EV Outlook 2021. Accelerating ambitions despite the pandemic,” 1 4 2021. [Online]. Available: https://iea.blob.core.windows.net/assets/ed5f4484-f556-4110-8c5c-4ede8bcba637/GlobalEVOutlook2021.pdf . [Accessed 9 12 2021].

[251] S. T. Mercer, “The Limitations of European Data Protection As a Model for Global Privacy Regulation,” *AJIL Unbound,* vol. 114, pp. 20-25, 2020.

[252] E. G. T. Juang, “Understanding the Requirements of the Energy Management System Certification,” 1 7 2011. [Online]. Available: https://www.sgs.com/~/media/Global/Documents/White%20Papers/sgs-energy-management-whitepaper-en-11.ashx. [Accessed 9 12 2021].

[253] Uk Government. Ministry of Housing, Communities & Local Government, “The Future Homes Standard,” 1 10 2019. [Online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/852605/Future_Homes_Standard_2019_Consultation.pdf. [Accessed 21 12 2021].

[254] R. Saidur, E. Abdelaziz, A. Demirbas, M. Hossain and S. Mekhilef, “A review on biomass as a fuel for boilers,” *Renewable and Sustainable Energy Reviews,* vol. 15, no. 5, pp. 2262-2289, 2011.

[255] ERGON Energy, “PeakSmart air conditioning,” ERGON Energy, 2021. [Online]. Available: https://www.ergon.com.au/network/manage-your-energy/reward-programs/peaksmart-air-conditioning. [Accessed 23 12 2021].

[256] Southern California. Edison, “Saving Incentive Programs for Homes,” Southern California. Edison, 2021. [Online]. Available: https://www.sce.com/residential/demand-response. [Accessed 23 12 2021].

[257] A. Brentley, “Current Trends in Solar Energy: 2021 and Beyond,” GreenLancer, 17 9 2021. [Online]. Available: https://www.greenlancer.com/post/current-trends-in-solar-energy. [Accessed 9 1 2022].

[258] C. McFadden, “6 Examples of Solar Powered Roads That Could Be a Glimpse of the Future,” Interesting Engineering, 13 7 2019. [Online]. Available: https://interestingengineering.com/6-examples-of-solar-powered-roads-that-could-be-a-glimpse-of-the-future. [Accessed 9 1 2022].

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 957779

[259] L. Gear, “Electronics: The Silicon Carbide Inverter,” IDTechEx, 17 2 2021. [Online]. Available: https://www.idtechex.com/en/research-article/teslas-innovative-power-electronics-the-silicon-carbide-inverter/23080. [Accessed 19 1 2022].

[260] NVE, “Cost base for small-scale hydropower plants (<10 MW),” 1 2 2012. [Online]. Available: https://publikasjoner.nve.no/veileder/2012/veileder2012_02.pdf. [Accessed 19 1 2022].

[261] EU Commission, “Aquaculutre,” EU Commision, 1 1 2022. [Online]. Available: https://ec.europa.eu/oceans-and-fisheries/ocean/blue-economy/aquaculture_es. [Accessed 16 2 2022].

[262] S. Choudhury, “Flywheel energy storage systems: A critical review on technologies, applications, and future prospects,” *International Transactions on Electrical Energy Systems,* vol. 31, no. 9, pp. 1-26, 2021.

[263] C. Bendib and M. Kesraoui, “Wind-Solar Power System associated with Flywheel and Pumped-Hydro Energy Storage,” in *2019 10th International Renewable Energy Congress (IREC)*, Sousse,Tunisia, 2019.

[264] CTCN, Climate Technology Centre & Network, “Flywheels,” CTCN, [Online]. Available: https://www.ctc-n.org/technologies/flywheels. [Accessed 7 12 2021].

[265] M. R. H. Asif and T. Iqbal, “"Diesel consumption in a high penetration remote hybrid power system with a pumped hydro and battery storage,” in *2013 IEEE Electrical Power & Energy Conference*, Halifax,Canada, 2013.

[266] Y. Cholteeva, “EDF and Uzbekhydroenergo to develop pumped hydro and floating PV,” Power Technology, 21 4 2021. [Online]. Available: https://www.power-technology.com/news/edf-and-uzbekhydroenergo-to-develop-pumped-hydro-and-floating-pv/. [Accessed 19 1 2022].

[267] A. Nedelea, “Toyota’s First Solid State Battery Will Equip A Hybrid, Not An EV,” InsideEVs, 7 1 2022. [Online]. Available: https://insideevs.com/news/559277/toyota-solidstate-battery-hybrid-2025/. [Accessed 10 1 2022].

[268] D. Mavrokefalidis, “Nearly 84m EVs will be on Europe’s streets by 2030,” Energy Live. News, 21 6 2021. [Online]. Available: https://www.energylivenews.com/2021/06/21/nearly-84m-evs-will-be-on-europes-streets-by-2030/. [Accessed 20 12 2021].

[269] I. Morse, “A dead battery dilemma.,” Science, 20 5 2021. [Online]. Available: https://www.science.org/content/article/millions-electric-cars-are-coming-what-happens-all-dead-batteries. [Accessed 20 12 2021].

[270] EU Commission, “Batteries and Accumulators. Batteries regulation,” EU Coission, 10 12 2020. [Online]. Available: https://ec.europa.eu/environment/topics/waste-and-recycling/batteries-and-accumulators_en. [Accessed 20 12 2021].

[271] ACEA, “ACEA Position Paper. Proposal for the Alternative Fuels Infrastructure Regulation (AFIR),” 1 11 2021. [Online]. Available: https://www.acea.auto/files/ACEA_Position_Paper-Alternative_Fuels_Infrastructure_Regulation.pdf. [Accessed 19 1 2022].

[272] A. Krajinska, “Are compressed natural gas vehicles a clean solution for transport?,” 16 6 2020. [Online]. Available: https://www.transportenvironment.org/wp-content/uploads/2021/07/2020_06_TE_CNG_particle_report.pdf. [Accessed 19 1 2022].

[273] Italian Government, “Schema di decreto legislativo recante attuazione della direttiva (UE) 2019/944 del Parlamento europeo e del Consiglio, del 5 giugno 2019, relativa a norme comuni peril mercato interno dell'energia elettrica e che modifica la direttiva 2012/27/UE, nonché r,” 20 10 2021. [Online]. Available:

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 957779

http://documenti.camera.it/leg18/dossier/pdf/VQAG294.pdf?_1639834182950. [Accessed 16 2 2022].

[274] M. E. Biresselioglu , S. A. Limoncuoglu , M. H. Demir, J. Reichi, K. Burgstaller, A. Sciullo and E. Ferrero, "Legal Provisions and Market Conditions for Energy Communities in Austria, Germany, Greece, Italy, Spain, and Turkey: A Comparative Assessment," *Sustainability,* vol. 13, no. 20, pp. 1-25, 2021.

[275] SNAM, "SNAM: HYDROGEN BLEND DOUBLED TO 10% IN CONTURSI TRIAL," SNAM, 8 1 2020. [Online]. Available: https://www.snam.it/en/Media/news_events/2020/Snam_hydrogen_blend_doubled_in_Contursi_trial.html. [Accessed 16 2 2022].

[276] GEC, «Le Comunitàenergetiche in Italia. Una guida per orientare i cittadini nel nuovo mercato dell'energia,» 1 1 2020. [En línea]. Available: https://www.enea.it/it/seguici/pubblicazioni/pdf-volumi/2020/guida_comunita-energetiche.pdf. [Último acceso: 16 2 2022].

[277] GEC, «La Comunitá Energetica,» 1 1 2021. [En línea]. Available: https://www.pubblicazioni.enea.it/component/jdownloads/?task=download.send&id=427&catid=3&m=0&Itemid=101. [Último acceso: 16 2 2022].

[278] S. Meneghello, "Energy Sharing in renewable energy communities: the Italian case," 1 04 2020. [Online]. Available: http://www.e4g.polimi.it/wp-content/uploads/2020/12/2020_04_Meneghello_Stefano.pdf. [Accessed 16 2 2022].

[279] LOVDATA, "Lov om produksjon, omforming, overføring, omsetning, fordeling og bruk av energi m.m. (energiloven)," LOVDATA, 29 06 1990. [Online]. Available: https://lovdata.no/dokument/NL/lov/1990-06-29-50. [Accessed 16 2 2022].

[280] NVE-RME, "Batteri tilknyttet nettet," NVE-RME, 15 12 2021. [Online]. Available: https://www.nve.no/reguleringsmyndigheten/kunde/nett/tilknytning-av-forbruk-og-produksjon/batteri-tilknyttet-nettet/. [Accessed 16 2 2022].

[281] LOVDATA, "Lov om infrastruktur for alternativt drivstoff," LOVDATA, 19 06 2020. [Online]. Available: https://lovdata.no/dokument/NL/lov/2020-06-19-95. [Accessed 16 2 2022].

[282] LOVDATA, "Lov om eierseksjoner (eierseksjonsloven)," LOVDATA, 16 06 2017. [Online]. Available: https://lovdata.no/dokument/NL/lov/2017-06-16-65. [Accessed 16 2 2022].

[283] LOVDATA, "Lov om burettslag (burettslagslova)," LOVDATA, 06 06 2003. [Online]. Available: https://lovdata.no/dokument/NL/lov/2003-06-06-39?q=ladepunkt. [Accessed 16 2 2022].

[284] RME, "Ordning for deling av fornybar kraftproduksjon," Reguleringsmyndigheten for energi (RME), 1 8 2021. [Online]. Available: https://www.nve.no/media/12625/forslag-til-forskriftsendring-deling-av-produksjon-3666137_1_1.pdf . [Accessed 16 2 2022].

[285] LOVDATA, "Forskrift om økonomisk og teknisk rapportering, inntektsramme for nettvirksomheten og tariffer," LOVDATA, 11 03 1999. [Online]. Available: https://lovdata.no/dokument/SF/forskrift/1999-03-11-302. [Accessed 16 2 2022].

[286] Olje- og energidepartementet , «Regjeringens hydrogenstreategi,» 1 1 2021. [En línea]. Available: https://www.regjeringen.no/contentassets/8ffd54808d7e42e8bce81340b13b6b7d/regjeringens-hydrogenstrategi.pdf. [Último acceso: 16 2 2022].

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

[287] ENOVA, “Solcelleanlegg,” ENOVA, 2 2 2022. [Online]. Available: https://www.enova.no/privat/alle-energitiltak/solenergi/el-produksjon-/. [Accessed 16 2 2022].

[288] NVE, “Elsertifikater - behandlede anlegg,” NVE, 1 1 2022. [Online]. Available: https://www.nve.no/energi/virkemidler/elsertifikater/elsertifikater-behandlede-anlegg/. [Accessed 16 2 2022].

[289] Urzad, “Wchodzi w życie duża nowelizacja Prawa energetycznego,” 07 07 2021. [Online]. Available: https://www.ure.gov.pl/pl/urzad/informacje-ogolne/aktualnosci/9604,Wchodzi-w-zycie-duza-nowelizacja-Prawa-energetycznego.html?search=2078518. [Accessed 16 2 2022].

[290] Urzad, “Elektromobilność: Prezes URE wyznaczył operatorów ogólnodostępnych stacji ładowania oraz dostawców usług ładowania w kolejnych pięciu miastach,” 07 05 2021. [Online]. Available: https://www.ure.gov.pl/pl/urzad/informacje-ogolne/aktualnosci/9439,Elektromobilnosc-Prezes-URE-wyznaczyl-operatorow-ogolnodostepnych-stacji-ladowan.html. [Accessed 16 2 2022].

[291] Ministerstwo Klimatu i Srodowiska, “POLSKA STRATEGIA WODOROWA DO ROKU 2030,” 7 1 2021. [Online]. Available: http://isap.sejm.gov.pl/isap.nsf/download.xsp/WMP20210001138/O/M20211138.pdf. [Accessed 16 2 2022].

[292] Kancelaria Sejmu, “o odnawialnych źródłach energi,” 20 1 2015. [Online]. Available: https://isap.sejm.gov.pl/isap.nsf/download.xsp/WDU20150000478/U/D20150478Lj.pdf. [Accessed 16 2 2022].

[293] Agencia Portuguesa do ambiente, “Legislação e regulação para a Economia do Hidrogénio,” 19 05 2021. [Online]. Available: https://apambiente.pt/sites/default/files/_SNIAMB_A_APA/Publicacoes/Guias_Manuais/Guia%20promotor_Hidroge%CC%81nio_FINAL24052021.pdf. [Accessed 16 2 2022].

[294] R. Dierman, “El gobierno federal quiere acabar con la doble carga de los sistemas de almacenamiento de energía con la enmienda EnWG,” PV magazine, 10 2 2021. [Online]. Available: https://www.pv-magazine.de/2021/02/10/bundesregierung-will-mit-enwg-novelle-doppelbelastung-von-energiespeichern-beenden/]. [Accessed 15 2 2022].

[295] Bundesnetzagentur, “Regelungen zu Stromspeicherni m deutschen Strommarkt,” 1 3 2021. [Online]. Available: https://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Sachgebiete/Energie/Unternehmen_Institutionen/ErneuerbareEnergien/Speicherpapier.pdf?__blob=publicationFile&v=2. [Accessed 16 2 2022].

[296] DENA, Deutsche Energie-Agentur, “columna vertebral de la transición energética,” DENA, Deutsche Energie-Agentur, 29 1 2020. [Online]. Available: https://www.dena.de/newsroom/rueckgrat-der-energiewende/. [Accessed 16 2 2022].

[297] WECF, “Comunidades energéticas: una mirada a la situación legal actual en Europa,” WECF, 13 5 2020. [Online]. Available: https://www.wecf.org/de/energiegemeinschaften-ein-blick-auf-die-aktuelle-rechtslage-in-europa/. [Accessed 16 2 2022].

[298] Bundesministerium für Wirtschaft und Klimaschultz, “Instrumento de financiación para la generación de energía: la EEG,” Bundesministerium für Wirtschaft und Klimaschultz, 1 1 2021. [Online]. Available: https://www.erneuerbare-

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 957779

energien.de/EE/Navigation/DE/Foerderung/Foerderprogramme/foerderprogramme.html. [Accessed 16 2 2022].

[299] Energy co-operatives Ireland et al. , “Community Energy for Ireland (Executive Summary),” 1 1 2020. [Online]. Available: https://www.foe.ie/assets/files/pdf/executive_summary_community_energy_leaflet.pdf. [Accessed 16 2 2022].

[300] UCD Energy Institute, “A National Hydrogen Strategy is needed to develop Ireland¡s Hydrogen potential,” 1 6 2020. [Online]. Available: https://energyinstitute.ucd.ie/wp-content/uploads/2020/06/UCD-Energy-Institute-The-need-for-a-Hydrogen-Strategy-for-Ireland.pdf. [Accessed 16 2 2022].

[301] Bridge Horizon 2020, “Energy Communities in the EU Task Force Energy Communities,” 1 12 2019. [Online]. Available: https://www.h2020-bridge.eu/wp-content/uploads/2020/01/D3.12.d_BRIDGE_Energy-Communities-in-the-EU-2.pdf. [Accessed 16 2 2022].

[302] Community Power Electricity Supplier, “Co-operative Energy Trading System on the way for Ireland,” Community Power Electricity Supplier, 6 5 2019. [Online]. Available: https://communitypower.ie/co-operative-energy-trading-sysyems-on-the-way-for-ireland/. [Accessed 16 2 2022].

[303] SEAI-Sustainable Energy Authority of Ireland, “Renewable Electricity Support Scheme (RESS),” SEAI, 1 1 2022. [Online]. Available: https://www.seai.ie/community-energy/ress/. [Accessed 16 2 2022].

[304] BOE, Boletín Oficial del Estado, “Resolución de 11 de diciembre de 2019, de la Comisión Nacional de los Mercados y la Competencia, por la que se aprueban las condiciones relativas al balance para los proveedores de servicios de balance y los sujetos de liquidación responsables del balance,” BOE, 11 12 2019. [Online]. Available: https://www.boe.es/diario_boe/txt.php?id=BOE-A-2019-18423. [Accessed 20 1 2022].

[305] BOE, Boletín Oficial del Estado, “Resolución de 10 de diciembre de 2020, de la Comisión Nacional de los Mercados y la Competencia, por la que se aprueba la adaptación de los procedimientos de operación del sistema a las condiciones relativas al balance aprobadas por Resolución de 11 de di,” BOE, 10 12 2020. [Online]. Available: https://www.boe.es/diario_boe/txt.php?id=BOE-A-2020-16964. [Accessed 20 1 2022].

[306] BOE, Boletín Oficial del Estado, “Resolución de 14 de enero de 2021, de la Comisión Nacional de los Mercados y la Competencia, por la que se modifica el procedimiento de operación 3.3 Activación de energías de balance procedentes del producto de reserva de sustitución (RR),” BOE, 14 1 2021. [Online]. Available: https://www.boe.es/diario_boe/txt.php?id=BOE-A-2021-701. [Accessed 20 1 2022].

[307] BOE, Boletín Oficial del Estado, “Real Decreto-ley 23/2020, de 23 de junio, por el que se aprueban medidas en materia de energía y en otros ámbitos para la reactivación económica.,” BOE, 23 6 2020. [Online]. Available: https://www.boe.es/buscar/act.php?id=BOE-A-2020-6621. [Accessed 20 1 2022].

[308] BOE, Boletín Oficial del Estado, “ Ley 24/2013, de 26 de diciembre, del Sector Eléctrico,” BOE, 26 12 2013. [Online]. Available: https://www.boe.es/buscar/doc.php?id=BOE-A-2013-13645. [Accessed 20 1 2022].

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 957779

[309] UNE, Normalización española, "Comité CTN 206 - Producción de Energía Eléctrica," UNE, 1 11 2021. [Online]. Available: https://www.une.org/encuentra-tu-norma/comites-tecnicos-de-normalizacion/comite?c=CTN%20206. [Accessed 9 12 2021].

[310] R. Pasquali, T. H. Williams, S. Blake and J. McAteer, "Geothermal Energy Use, Country Update for Ireland," in *European Geothermal Congress 2019*, Den Haag, The Netherlands, 2019.

[311] A. W. Thompson and Y. Perez, "Vehicle-to-Everything (V2X) energy services, value streams, and regulatory policy implications," *Energy Policy,* vol. 137, p. 111136, 2020.

[312] EU 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," 21 12 2018. [Online]. Available: https://eur-lex.europa.eu/eli/dir/2018/2001/oj. [Accessed 9 12 2021].

[313] B. A. Fladen, P. Roll, V. Grigorian, T. Kallevik and U. Tran, "Ordning for deling av fornybar kraftprofuvksjon," 1 8 2021. [Online]. Available: https://www.nve.no/media/12625/forslag-til-forskriftsendring-deling-av-produksjon-3666137_1_1.pdf. [Accessed 30 12 2021].

[314] EU Commission, "Proposal for the Alternative Fuels Infrastructure Regulation (AFIR)," 14 7 2021. [Online]. Available: https://ec.europa.eu/info/sites/default/files/revision_of_the_directive_on_deployment_of_the_alternative_fuels_infrastructure_with_annex_0.pdf. [Accessed 19 1 2022].

[315] EU Commission, "Trans-European Transport Network (TEN-T)," EU Commission, [Online]. Available: https://transport.ec.europa.eu/transport-themes/infrastructure-and-investment/trans-european-transport-network-ten-t_en. [Accessed 19 1 2022].

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

Annex I

In this section, the country-specific existing regulatory limitations found during the identification process are summarised in the following subsections, one for each country. These subsections are divided into six different parts:

- Ownership and operation
- Grid connection
- Hydrogen (H_2)
- Market and business models
- Self-consumption. Energy Communities (ECs)
- Regulatory stability

Regulatory constraints have been assessed in all countries represented in the consortium, with special emphasis on the countries which have eNeuron pilot facilities (Italy, Noray, Poland, and Portugal) because the described constraints may interfere with the implementation of these pilots.

Additionally, the Spanish regulatory barriers related to the participation of LECs in the balancing systems are also detailed.

AI.1 Italy

AI.1.1 Ownership and operation

AI.1.1.1 Grid ownership of energy communities

Internal Electricity Market (IEM) Directive 2019/944: "Citizen Energy Communities (CEC) are entitled to own, estlablish, purchase or lease distribution networks and to autonomously manage them subject to the conditions set out in the directive

Does your country allow this ownership or is there no national regulation yet? is there any ongoing process in this direction?

Italy allows this ownership as reported in the D2.3, Section "7.1.2 Country specific limitations in Italy".
However, the regultion has been modified recently according to the Internal Electricity Market (IEM) Directive 2019/944 that has been published in 20/10/2021 [273].

AI.1.1.2 Energy storage facilities ownership

Internal Electricity Market (IEM) Directive 2019/944: "TSOs/DOs should not allowed to own, develop, manage or operate energy storage facilities" "CEC are allowed to own, develop, manage or operate energy storage facilities"

Does your own legislation allow System Opeators to install and operate energy storage facilities in the grid? What actors are mainly responsible for that (TSO/DSO/CEC/Third parties)?

The Italian Government adopted legislative measures so that the Transmission System Operator (TSO), Terna, and Distribution System Operators (DSOs) may develop and manage storage facilities by means of batteries on their own grids. Batteries have become an attractive technology for electricity storage; however, in Italy energy storage applications are traditionally represented by thermal storage at domestic or commercial levels, and by pumped hydro storage.

AI.1.1.3 EV charging infrastructure facilities ownership

Internal Electricity Market (IEM) Directive 2019/944: Distribution system operators shall not own, develop, manage or operate recharging points for electric vehicles, except where distribution system operators own private recharging points solely for their own use. "CEC are allow to own, develop, manage or operate EV charging points"

What actors are mainly responsible for EV Charging infrastucture facilities?

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

Local authorities – they play a key role in developing charging infrastructures. They set out plans to provide buildings with charging stations, by simplifying the authorisation procedures. **ARERA** – Regulatory Authority for Energy, Networks and Environment is an independent administrative authority that regulates and encourages the development of charging infrastructure for EVs. ARERA sets a grid tariff for the private charging of EVs, removing any regulatory constraints that could hinder the deployment of possible charging points in private places and, recently, also a grid tariff for EV public charging. **Electricity market participants** – electricity generators, suppliers, and distributors. **Charging station developers** – existing developers of new charging infrastructure, in particular Enel which manages just under half of the national public charging points. **Ministry of Environment** – it promotes, jointly with the Ministry of Transport and Infrastructure, sustainable urban mobility policies through co-financing programmes for local authorities.

AI.1.1.4 H2 production facilities ownership

Does your national legislation allow System Operators to own and operate H2 electrolysers?
Are H2 electrolysers treated as regulated natural monopolies? Commercial activities?

H2 electrolyzers are not treated as regulated natural monopolies, but as commercial activities. Indeed, there is a lack of legislation regulating the authorisation process for plants producing green hydrogen through electrolysis, and incentive mechanisms to support P2G plants as well.

AI.1.1.5 Battery ownership of EV

Who is the battery owner in V1G-V2G applications?
-car's owner
-car's manufacturer
-third party (aggregators)

Is it possible to provide flexibility services using V1G-V2G in your country?

Batteries owners can be car owners and aggregators as well. Yes, it can be possible to provide flexibility services to Terna, the national electricity TSO.

AI.1.2 Grid connection

AI.1.2.1 Administrative barriers for obtaining authorization/licences for electricity generation or energy storage. Lengthy and expensive grid connection procedures

Does your country have simplified administrative procedures for domestic prosumers or Energy Communities?

The renewable energy topic is regulated by the Legislative Decree n. 28/2011 that establishes both goals and aims of the energy policy. This decree also provides administrative guidelined of permits to produce renewable energy, as well as defining economic incentives. The collective self-consumption was not possible until related legislation was updated, legislative Decree 162/19 (Decreto Milleproroghe), which has been the converted into law on February 28, 2020 (Law no 8/2020). However, this type of collective self-consumption only applies to residential buildings, tertiary sector buildings, industrial properties, or public administration buildings [274].

AI.1.2.2 Lack of common grid codes procedures for connection of DER generators to the distribution grid (MV-LV)

Is it applicable in your country?

N. A.

AI.1.3.3 Energy storage grid connection

Is it allowed to install an energy storage facility connected to the grid? At what level (HV, MV, LV)?

Yes, both Terna (TSO) and Enel have developed some projects, and installed storage as well, thoughout Italy, especially in the Center and in the South. Power range: 16-35 MW, Energy range: 16-175 MWh (MV level).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

AI.1.3 Energy Storage

AI.1.3.1 Definition of the energy storage as a market actor

No commonly definition for Energy Storage at EU level.
Is ENERGY STORAGE currently recognised as an activity or an asset class in your national electricity market?

The legislative framework is fragmented and does not fully cover all the main features of the elctric market. Legislative Decree no. 28/2011 stated that the TSO may develop storage systems to increase the despatch of intermittent generation. Moreover, the TSO may develop and manage distributed storage facilities by means of batteries, and the same may be done by DSOs on their own grids.

AI.1.3.2 Double taxes-fees for energy storage

They are considered consumers and producers at the same time.
Does your national legislation impose double taxes for ENERGY STORAGE or H2 production facilites?

N.A.

AI.1.4 Hydrogen

AI.1.4.1 Definition and classification for H2

No commonly agreed definition and classification for H2 at EU level.
Does your country have a clear definition for H2?

Currently, there is a lack of: 1. legislation regulating the authorisation process for plants producing green hydrogen through electrolysis, and 2. incentive mechanisms to support P2G plants.

AI.1.4.2 Dificulty to determine the renewable origin of the electricity required to operate the electrolysers (green H2)

No, generally wind, solar and hydropower.

AI.1.4.3 Blending H2 and methane in Natural Gas pipeline

The use of natural gas infrastructure by different gas types can generate inadequate gas quaility creating uncertain access for new gases.
Does your country have any regulatory limit to blend H2 into the current natural gas?

Not yet, but the national natural gas TSO, SNAM, is working to achieve a maximum blending of 10% within the national gas network [275].

AI.1.4.4 Interoperability between different markets. Sector coupling

Is there any coordination betwen electricity and gas networks in terms of planning/operation in your country?
Is there any interoperability in the natural gas infrastructure between your cross-border neighbor countries?

N.A.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

AI.1.5 Market and business models

AI.1.5.1 Legal barriers to the full participation of all agents (renewable generators, energy storage facilities, EV aggregators, demand side management, final consumers) in all local electricity markets (particularly in flexibility services)

Does your current national legislation ensure a fair and equal access to all electricity markets. (Define what is fair e.g. to participate in frequency market requires 10 MW, is this fair?

Yes, it is fair. For instance, members of the community will be able to access the incentives only if their rated capacity will be lower than 1 MW. It is important that this threshold value has to be considered as a whole, where members of the community must have a rated power lower than 1 MW.
Moreover, the limit according to which only production plants w***ith a rated power less than 200*** kW can join the renewable energy community does no longer exist [276].

AI.1.5.2 Lack of business models (only few energy storage applications can justify market-based business cases)

Does your current legislation prevent the creation of new business models (i.e. offering flexibilty services using energy storage or EVs)?

N.A.

AI.1.5.3 Technology neutrality in generation, storage and H2 production

Does your current national legislation ensure fair competition between different technical solutions?
For example, if green hydrogen production is supported via subsidies for electrolysers or subsidised electricity, this could give an unfair advantage compared to either biomethane or blue hydrogen.

So far, legislations that regulate the H2 production through renewables does not exists. Up to now, only incentives for producing electricity with renewables is used, and the competition among the different renewable surces is anyway fair. All these renewable sources are competitive where they are available (e.g., some places present more wind, others more sun availability, etc.).

AI.1.6 Self consumption. Energy Communities (ECs)

AI.1.6.1 Geographic scope of Energy Communities (ECs)

ECs are limited to not involve the use of public grid
Consumers of Ecs are located behind the same MV/LV transformer
Consumers of Ecs are located in the same geographic area (<500m)
No geographic limitations for consumers in an EC

Energy communities share the produced energy among the members that constitute the energy community itself. A connection with the grid is present when a surplus of energy production occurs, so that the electricity can be sent to the national grid. Up to now, the energy communities in Italy can only be established downstream of the same MV/LV transformer substation, for single plants with a power lower than 100 kW and overall not exceeding 200 kW (related to PV). No information is provided either in terms of geographical constraints or to lenght boundaries within which the members can be part of the same energy community. It is worth noting that members of the community will be able to access the incentives only if their capacity will be lower than 1 MW [277].

AI.1.6.2 Technologies

Are Generation Technologies for Energy Communities restricted to renewable energies only?

No, technologies that limit anyhow pollutants' emissions are also considered (e.g., cogeneration units where both electricity end thermal energy are produced and used simultaneously).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

AI.1.6.3 Consumer's rights

Do participants in Ecs maintain the same rights than the rest of consumers (right to choose their energy supplier, ensuring quality of supply and quality of service and also ensuring to choose a flexibility management service provider outside the EC)?

Yes [278].

AI.1.6.4 Peer to peer trading (P2P)

Is p2p energy trading allow within a EC in your country?

Yes [278].

AI.1.6.5 Generation capacity limits

Do your national regulations have a limit of maximum generation capacities for ECs?

Yes, below 1 MW for having/participating to the incentives [277].

AI.1.6.6 Local grid tariffs

Does your national legislation have local tariffs to support ECs?

N.A.

AI.1.7 Regulatory stability

AI.1.7.1 Regulatory stability to ensure medium-term predictability in the investment and financial conditions

In the past, some of the support schemes implemented to promote PV instalations were very high, and some countries (Spain, Italy, etc.) had to modify retroactively the payments to the PV producers, producing a lost of the investors' confidence

Does your country have a stable regulation for renewable energies, energy storage and H2 support?

Concerning energy storage and H2 support, no regulation has been provided so far. On the other hand, regarding the renewables, there is a solid regulation; indeed, from an incentive perspective, Italy has provided for different kinds of support schemes (e.g. Green Certificates, feed-in tariffs, off-take regimes, net metering services). The current incentive policy for newly built plants is based on competitive tender for awarding incentives, adopting a neutral approach among groups of technologies with similar structure and levels of cost. The incentives are paid based on contracts for difference executed with the GSE, the entity in charge of managing the renewable energy support schemes and paying the related incentives (i.e., the incentive amount is equal to the difference between the awarded tariff and the market price). This mechanism is considered to be ideal because it enables pre-defined power levels to be programmed, providing certainty to operators and, at the same time, controlling the costs of the support scheme and avoiding overcompensation with benefits for consumers (that bear the costs of a support scheme passed on the electricity bill), where the market price of electricity goes above the recognised tariffs. The main current support regimes in place for renewables are the following.

All-inclusive feed-in tariffs: this is a support scheme under Ministerial Decree 18 December 2008 for small renewable energy source plants (excluding PV plants). The tariff includes both the incentive and the value of electricity fed into the power grid. The tariff is granted on request to plants entering into operation after 31 December 2007 with a capacity not exceeding 1 MW (200 kW for wind farms). The support period is 15 years.

Off-take regime: regulated under Annex A to ARERA Resolution No. 280/2007, it is managed by GSE and applies to plants below 10MVA. Under agreements with the GSE, producers sell the electricity generated and to be injected into the grid to GSE, instead of selling it through bilateral contracts or directly on the power exchange market. GSE purchases and resells the electricity to be fed into the grid at the zonal price or at a minimum guaranteed price (for plants below 100 kW only).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

Net metering service: under this service, regulated by the TISP (Consolidated Text on the Net Metering Service – ARERA Resolution ARG/elt 74/08), the electricity generated by a consumer or producer in an eligible on-site plant and injected into the grid can be used to offset the electricity withdrawn from the grid. The GSE pays a contribution to the customer based on injections and withdrawals of electricity in a given calendar year and on their respective market values. Net metering is not compatible with the off-take regime and the all-inclusive feed-in tariff. The service applies to: owners of renewable energy source electricity generation plants with a capacity of up to 20 kW; renewable energy source electricity generation plants with a capacity up to 200 kW (commissioned after 31 December 2007); and high-efficiency combined heat and power (CHP) plants with a capacity of up to 200 kW. [0079b572].

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

AI.2 Norway

AI.2.1 Ownership and operation

AI.2.1.1 Grid ownership of energy communities

Does your country allow this ownership or is there no national regulation yet? is there any ongoing process in this direction?

As a member of the European Economic Area, Norway follows development of the Pan-European legislation and implements the mandatory regulations and transposes the European Directives into the national legislation. For the time being transposing of the two EU Directives related to the Energy Communities is still in process, defining the most feasible scenarios and models for the ECs in Norway, meaning that there is not a specific legislation for Energy Communities. There is no legal definition of Energy Communities yet, thus establishing of the energy communities happens today according to the present regulation and on case-by-case basis. Grid Ownership belongs to DSOs, which are often owned by the local municipalities.

AI.2.1.2 Energy storage facilities ownership

Does your own legislation allow System Operators to install and operate energy storage facilities in the grid? What actors are mainly responsible for that (TSO/DSO/CEC/Third parties)?

The present version of the Norwegian Energy Law [279] and related regulations, do not limit ownership of energy storage for the System Operators, which are allowed to own and use electric storage, provided that it is used only for operation of the grid. The energy storage in the Skagerak Energilabb is owned by the DSO. There is an ongoing discussion related to the future status of energy storage, and it is likely to follow the EU's requirements [280].

AI.2.1.3 EV charging infrastructure facilities ownership

Internal Electricity Market (IEM) Directive 2019/944: Distribution system operators shall not own, develop, manage or operate recharging points for electric vehicles, except where distribution system operators own private recharging points solely for their own use."CEC are allow to own, develop, manage or operate EV charging points"

What actors are mainly responsible for EV Charging infrastucture facilities?

Infrastructure for alternative fuels is regulated by a specific law in Norway [281]. There is no specific regulation defining legal status of Energy Communities yet in Norway. However, the law regulating ownership of common assets allows owners of parking areas to install and own EV charging points (§ 25 in [282]) the same terms are repeated in the law related to the housing cooperatives (§ 5-11 in [283]). This means that Energy Communities are likely to have the same regulation as housing cooperatives. Charging stations are owned mostly by Electricity Suppliers, Municipalities, Opertors of Gasoline stations, Car Parking facilities.

AI.2.1.4 H2 production facilities ownership

Does your national legislation allow System Operators to own and operate H2 electrolysers?
Are H2 electrolysers treated as regulated natural monopolies? Commercial activities?

There is no special regulation of ownership of hydrogen electrolysers. The few examples of H2 electrolysers for production of green hydrogen are owned by Electricity Generators.

AI.2.1.5 Battery ownership of EV

Who is the battery owner in V1G-V2G applications?
-car's owner
-car's manufacturer
-third party (aggregators)

Is it possible to provide flexibility services using V1G-V2G in your country?

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

EV batteries are owned by car owners, aggregators treat EV batteries as any other flexible load, no examples of V2G applications.

AI.2.2 Grid connection

AI.2.2.1 Administrative barriers for obtaining authorization/licences for electricity generation or energy storage. Lengthy and expensive grid connection procedures

Does your country have simplified administrative procedures for domestic prosumers or Energy Communities?

Formal regulation for Energy Communities in Norway is under development. Active Customers are defined as consumption/generation unit behind single metering point, where electricity feeding is below 100 kW. The qualified Active Customers have exemption from grid charge for feeding of electricity. There is a proposal from the Norwegian Regulator [284] about new terms for RES generation: end-users with common investment into RES generation can share its production (up to 500 kW at the same premises) among them. This proposal does not explicitly relate to Energy Communities, but rather to Active Customers.

AI.2.2.2 Lack of common grid codes procedures for connection of DER generators to the distribution grid (MV-LV)

Is it applicable in your country?

In 2017 the national Regulation for grid operations [285] has been updated with new term Active Customers (plusskunder). There are standard agreements and technical requirements for connection of the Active Customers.

AI.2.3.3 Energy storage grid connection

Is it allowed to install an energy storage facility connected to the grid?
-At what level (HV, MV, LV)?

Yes, it is allowed to install batteries and connect these to network. If the voltage level is above 1 kW it is necessary to obtain a license, as any high voltage installation.

AI.2.3 Energy Storage

AI.2.3.1 Definition of the energy storage as a market actor

Is ENERGY STORAGE currently recognised as an activity or an asset class in your national electricity market?

Energy storage does not have a specific status, and is considered as both production and load. It can participate in the market activities.

AI.2.3.2 Double taxes-fees for energy storage

Does your national legislation impose double taxes for ENERGY STORAGE or H2 production facilites?

Energy storage does not have a specific status, and is considered as both production and load. Units with feeding below 100 kW are considered as active customers and partially exempted from the grid feeding tariff.

AI.2.4 Hydrogen

AI.2.4.1 Definition and classification for H2

Does your country have a clear definition for H2?
Rules and regulations are under development [286]

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

AI.2.4.2 Dificulty to determine the renewable origin of the electricity required to operate the electrolysers (green H2)

No official rules.

AI.2.4.3 Blending H2 and methane in Natural Gas pipeline

Does your country have any regulatory limit to blend H2 into the current natural gas?

Not applicable since Norway does not have onshore distribution netwrok for natural gas.

AI.2.4.4 Interoperability between different markets. Sector coupling

Is there any coordination betwen electricity and gas networks in terms of planning/operation in your country? Is there any interoperability in the natural gas infrastructure between your cross-border neighbor countries?

N.A.

AI.2.5 Market and business models

AI.2.5.1 Legal barriers to the full participation of all agents (renewable generators, energy storage facilities, EV aggregators, demand side management, final consumers) in all local electricity markets (particularly in flexibility services)

Does your current national legislation ensure a fair and equal access to all electricity markets. (Define what is fair e.g. to participate in frequency market requires 10 MW, is this fair?

There are no limitations for joinng the spot- and intraday markets. Local markets do not exist.

AI.2.5.2 Lack of business models (only few energy storage applications can justify market-based business cases)

Does your current legislation prevent the creation of new business models (i.e. offering flexibilty services using energy storage or EVs)?

It does not directly prevent creation of new business models, but it may require obtaining of the necessary licenses.

AI.2.5.3 Technology neutrality in generation, storage and H2 production

Does your current national legislation ensure fair competition between different technical solutions?

Under development

AI.2.6 Self consumption. Energy Communities (ECs)

AI.2.6.1 Geographic scope of Energy Communities (ECs)

ECs are limited to not involve the use of public grid
Consumers of Ecs are located behind the same MV/LV transformer
Consumers of Ecs are located in the same geographic area (<500m)
No geographic limitations for consumers in an EC

N.A.

AI.2.6.2 Technologies

Are Generation Technologies for Energy Communities restricted to renewable energies only?

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

Regulation of Energy Communities is under development. The existing proposal for sharing of electricity at Active Customer level presumes generation from RES only [284].

AI.2.6.3 Consumer's rights

Do participants in Ecs maintain the same rights than the rest of consumers (right to choose their energy supplier, ensuring quality of supply and quality of service and also ensuring to choose a flexibility management service provider outside the EC)?

Regulation of Energy Communities is under development.

AI.2.6.4 Peer to peer trading (P2P)

Is p2p energy trading allow within a EC in your country?

Regulation of Energy Communities is under development, some pilot projects run p2p trading.

AI.2.6.5 Generation capacity limits

Do your national regulations have a limit of maximum generation capacities for ECs?

Regulation of Energy Communities is under development. The existing proposal for sharing of electricity at Active Customer level is limited to 500 kW of shareable electricity [284]

AI.2.6.6 Local grid tariffs

Does your national legislation have local tariffs to support ECs?

Regulation of Energy Communities is under development.

AI.2.7 Regulatory stability

AI.2.7.1 Regulatory stability to ensure medium-term predictability in the investment and financial conditions

Does your country have a stable regulation for renewable energies, energy storage and H2 support?

Customers installing PV panels get one-time support [287], there are support schemes for "green certificates" for small-scale hydro, wind and PV [288]

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

AI.3 Poland

AI.3.1 Ownership and operation

AI.3.1.1 Grid ownership of energy communities

Does your country allow this ownership or is there no national regulation yet? is there any ongoing process in this direction?

The President of the Energy Regulatory Office (URE), at the request of an owner of a transmission network, distribution network, storage facility or liquefied natural gas facility appoints, by way of a decision, for a definite period of time, a transmission system operator, distribution system operator, storage system operator, natural gas liquefaction facility operator or combined system operator and specifies the area, networks or facilities on which the business activity will be conducted (Dz.U.2021.716 t.j.). In Poland, there are over 190 entities with valid licenses for distribution of electricity issued by the Energy Regulatory Office (URE).

AI.3.1.2 Energy storage facilities ownership

Does your own legislation allow System Opeators to install and operate energy storage facilities in the grid? What actors are mainly responsible for that (TSO/DSO/CEC/Third parties)?

The amendment to the Energy Law introduces the requirement to obtain a license for storage facilities with a capacity exceeding 10 MW. Storage facilities with a capacity between 50 kW and 10 MW will only require an entry in the relevant register, which will be maintained by electricity system operators (OSE). On the other hand, energy storage will be settled in accordance with the so-called balance rule. This means that network fees will be charged only for the difference between energy consumed and injected into the grid. In this way, double charging of distribution and transmission fees will be eliminated - for energy taken from the grid to the storage facility and returned from the storage facility to the grid [289].

AI.3.1.3 EV charging infrastructure facilities ownership

Internal Electricity Market (IEM) Directive 2019/944: Distribution system operators shall not own, develop, manage or operate recharging points for electric vehicles, except where distribution system operators own private recharging points solely for their own use. "CEC are allow to own, develop, manage or operate EV charging points"

What actors are mainly responsible for EV Charging infrastucture facilities?

The President of Office of Energy Regulation (URE) appoints, by the decision, to serve as the public charging station operator and charging service provider, the energy company trading in electricity, which sells electricity to the largest number of end customers connected to the distribution network in the municipality, where it is to serve as the public charging station operator.

Operator of a public charging station - is an entity responsible for the construction, management, operational safety, operation, maintenance and repairs of a public charging station. The operator of the public charging station shall ensure that at least one charging service provider operates at the public charging station.

The charging service provider shall provide a charging service including charging and the provision of the use of the charging station infrastructure, shall conclude an energy sales contract with the electricity seller, shall make available - on its website - information on the price of the charging service and the conditions of its provision.

The operator of a public charging station may perform the tasks of the charging service provider [290].

AI.3.1.4 H2 production facilities ownership

Does your national legislation allow System Operators to own and operate H2 electrolysers?
Are H2 electrolysers treated as regulated natural monopolies? Commercial activities?

Based on the current wording of the legislation, it can be presumed that the business activity of transporting hydrogen through a gas network requires a license. There is no clear statement as to whether hydrogen is subject to the rules under the Act, including the principle of separation of economic activity from generation and sale of energy to end users [291]

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

AI.3.1.5 Battery ownership of EV

Who is the battery owner in V1G-V2G applications?
-car's owner
-car's manufacturer
-third party (aggregators)

Is it possible to provide flexibility services using V1G-V2G in your country?

EV batteries are owned by car owner. Lack of legal regulations.

AI.3.2 Grid connection

AI.3.2.1 Administrative barriers for obtaining authorization/licences for electricity generation or energy storage. Lengthy and expensive grid connection procedures

Does your country have simplified administrative procedures for domestic prosumers or Energy Communities?

Recently, some administrative barriers are removed to improve and simplify, among others, the authorization procedures for the construction, expansion, modification and exploitation of production, transport and distribution facilities. Moreover, a more simplified administrative procedure is established to R&I projects

AI.3.2.2 Lack of common grid codes procedures for connection of DER generators to the distribution grid (MV-LV)

Is it applicable in your country?
N.A.

AI.3.3.3 Energy storage grid connection

Is it allowed to install an energy storage facility connected to the grid?
-At what level (HV, MV, LV)?

Yes, it's allowed. Prosumers with energy storage grid connection have to register energy storages more powerful than 50 kW. The registration is mandatory and its purpose is to provide necessary data to improve energy management process.

AI.3.3 Energy Storage

AI.3.3.1 Definition of the energy storage as a market actor

Is ENERGY STORAGE currently recognised as an activity or an asset class in your national electricity market?

Recent amendment to Energy Act removes barriers to development and introduces comprehensive solutions for the operation and development of energy storage in Poland. It regulates the issue of concessions very rationally, completely excludes energy storage from the obligation to prepare tariffs, eliminates double charging of distribution fees, enables investments in energy storage to be included in development plans by Distribution System Operators and the Transmission System Operator.In 2021, for the first time, the auction system will cover RES installations stabilized with an energy storage. These will be the first auctions for this type of RES installations. The market of energy storage in Poland is at an early stage of development. In the field of storage technologies, not only battery technologies, research is still ongoing and new technologies are being developed.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

AI.3.3.2 Double taxes-fees for energy storage

Does your national legislation impose double taxes for ENERGY STORAGE or H2 production facilites?

If it is RES energy storage there is no double taxes, the recent amendment eliminated double tariffs.

AI.3.4 Hydrogen

AI.3.4.1 Definition and classification for H2

Does your country have a clear definition for H2?

Lack of specific regulations in this aspect. Development process in progress- its described in Polish Hydrogen Strategy that aims for development of hydrogen technologies and legislature implementation to 2030 with a perspective to 2040. It will be accomplished by amendment of 14 acts.

AI.3.4.2 Dificulty to determine the renewable origin of the electricity required to operate the electrolysers (green H2)

No, only general renewable energy rules

AI.3.4.3 Blending H2 and methane in Natural Gas pipeline

Does your country have any regulatory limit to blend H2 into the current natural gas?

No regulations

AI.3.4.4 Interoperability between different markets. Sector coupling

Is there any coordination betwen electricity and gas networks in terms of planning/operation in your country? Is there any interoperability in the natural gas infrastructure between your cross-border neighbor countries?

N.A.

AI.3.5 Market and business models

AI.3.5.1 Legal barriers to the full participation of all agents (renewable generators, energy storage facilities, EV aggregators, demand side management, final consumers) in all local electricity markets (particularly in flexibility services)

Does your current national legislation ensure a fair and equal access to all electricity markets. (Define what is fair e.g. to participate in frequency market requires 10 MW, is this fair?

Office of Energy Regulation (URE) is the central administrative body for the management in the energy sector. It regulates: the provision of energy-saving and development of energy efficiency. It is therefore a non-profit organization that regulates in the sector the power zone can be implemented by the Energy Regulations (URE). Market participants on equal rights have broad access to purchase and selling of energy and access information and services, by means of contracting and power supply.

AI.3.5.2 Lack of business models (only few energy storage applications can justify market-based business cases)

Does your current legislation prevent the creation of new business models (i.e. offering flexibilty services using energy storage or EVs)?

2021 is is crucial for energy storage in Poland due to change in Energy Act and other regulations, which will influence the creation of business models for energy storage in Poland.It solved some problems as double taxes, not clear

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

definintion of energy storage (generator, reciver). Energy storage is a sepratate area i nthe law, and there is no need for concession up to 10 MW.

AI.3.5.3 Technology neutrality in generation, storage and H2 production

Does your current national legislation ensure fair competition between different technical solutions?

Polish hydrogen strategy until 2030 defines the goals and activities in the field of modern hydrogen technologies and the creation of the Polish branch of the hydrogen economy. It determines the current state of the hydrogen market, presents the basic technological and business obstacles and sets out the directions in which the market should develop allowing it to compete with conventional fuels in the next decade. It is in line with EU policy for H2, and consider the development. There is no research or evidence that consider this technology development unfair to others.

AI.3.6 Self consumption. Energy Communities (ECs)

AI.3.6.1 Geographic scope of Energy Communities (ECs)

ECs are limited to not involve the use of public grid
Consumers of Ecs are located behind the same MV/LV transformer
Consumers of Ecs are located in the same geographic area (<500m)
No geographic limitations for consumers in an EC

The area of activity of energy communities is not defined, assuming that the only limitation may be the area of operation of the distribution system operator, because the civic energy community may operate in the area of the distribution system operator.

AI.3.6.2 Technologies

Are Generation Technologies for Energy Communities restricted to renewable energies only?

No, technologies that limit anyhow pollutants' emissions are also considered.

AI.3.6.3 Consumer's rights

Do participants in Ecs maintain the same rights than the rest of consumers (right to choose their energy supplier, ensuring quality of supply and quality of service and also ensuring to choose a flexibility management service provider outside the EC)?

Regulation of Energy Communities is under development.

AI.3.6.4 Peer to peer trading (P2P)

Is p2p energy trading allow within a EC in your country?

Yes [292]

AI.3.6.5 Generation capacity limits

Do your national regulations have a limit of maximum generation capacities for ECs?

N.A.

AI.3.6.6 Local grid tariffs

Does your national legislation have local tariffs to support ECs?

Regulation of Energy Communities is under development.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

AI.3.7 Regulatory stability

AI.3.7.1 Regulatory stability to ensure medium-term predictability in the investment and financial conditions

Does your country have a stable regulation for renewable energies, energy storage and H2 support?

N.A.

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement N° 957779

AI.4 Portugal

AI.4.1 Ownership and operation

AI.4.1.1 Grid ownership of energy communities

Does your country allow this ownership or is there no national regulation yet? is there any ongoing process in this direction?

The concept of Local Energy Community was introduced by the Law Decree no. 162/2019. Nevertheless, the concept has still no pratical implementation and is pending a new law to be published in 2021-2.
Grid ownership is public (municipalities, state) and periodically licenced to a DSO. There is currently a single DSO in Portugal.
Private grid portions can exhist and do exist, as long as they are built according to the legislation and follow the DST/TSO rules at the point of connection to the public grid.

AI.4.1.2 Energy storage facilities ownership

Does your own legislation allow System Opeators to install and operate energy storage facilities in the grid? What actors are mainly responsible for that (TSO/DSO/CEC/Third parties)?

The legislation for large grid-scale energy storage is still scarse in Portugal. A new law regulating this subject will probably be published in 2022. Nevertheless, Law Decree no. 162/2019 prescribes and regulates the installation and usage of small-scale battery energy storage for "self-consumption" purposes by private owners. There is currently one grid battery storage installed for demonstration purposes, which is privately owned but managed by the DSO.
On the Portuguese islands of Azores, which have their own laws and government, there are some grid battery storage facilities owned and managed by the Azores DSO.

AI.4.1.3 EV charging infrastructure facilities ownership

Internal Electricity Market (IEM) Directive 2019/944: Distribution system operators shall not own, develop, manage or operate recharging points for electric vehicles, except where distribution system operators own private recharging points solely for their own use. "CEC are allow to own, develop, manage or operate EV charging points"
What actors are mainly responsible for EV Charging infrastucture facilities?

EV chargers located in private property, can be installed and owned by private citizens, or companies. It can be managed by end users, Local Communities or by dedicated companies (not DSOs). EV chargers located in public areas are usually owned by public entities (e.g. municipalities) and managed by dedicated companies. [Based on Law Decree number 39/2010 and Portaria n.º 949-A/2006, de 11 de setembro, alterada pela Portaria n.º 252/2015, de 19 de agosto]

AI.4.1.4 H2 production facilities ownership

Does your national legislation allow System Operators to own and operate H2 electrolysers?
Are H2 electrolysers treated as regulated natural monopolies? Commercial activities?

Regulated by Law-Decree 62/2020. Any entity that wants to own H2 producing equipment should apply for a licence according to the requirements of that decree. Although there is not a specific mention, DSO companies should not own H2 producing equipment because it is not in the spectrum of their allowed regulated activities. But another company from the same Group/Holding of the DSO can own H2 equipment.

AI.4.1.5 Battery ownership of EV

Who is the battery owner in V1G-V2G applications?
-car's owner
-car's manufacturer
-third party (aggregators)

Is it possible to provide flexibility services using V1G-V2G in your country?

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

EV batteries are owned by car owners. Private owners can use V2G for "self-consumption". There are some projects of V2G demonstration that allow EV owners to be paid. It can be managed by the DSO.

AI.4.2 Grid connection

AI.4.2.1 Administrative barriers for obtaining authorization/licences for electricity generation or energy storage. Lengthy and expensive grid connection procedures

Does your country have simplified administrative procedures for domestic prosumers or Energy Communities?

The requirements increase with generation capacity. For the smaller capacities, owners just have to register the generation equipment (no aproval needed). For mid capacities, insurance and inspection required. Above 1 MW, a license approval is required. (Decreto-Lei n.º 153/2014, Decreto-Lei n.º 76/2019, and others)

AI.4.2.2 Lack of common grid codes procedures for connection of DER generators to the distribution grid (MV-LV)

Is it applicable in your country?

There is a Grid Code for connection to the DSO and TSO grids.

AI.4.3.3 Energy *storage* grid connection

Is it allowed to install an energy storage facility connected to the grid?
-At what level (HV, MV, LV)?

See "Energy Storage Ownership" section. The grid energy storage demonstrator is divided between LV and MV levels.

AI.4.3 Energy Storage

AI.4.3.1 Definition of the energy storage as a market actor

Is ENERGY STORAGE currently recognised as an activity or an asset class in your national electricity market?

See "Energy Storage Ownership" section.

AI.4.3.2 Double taxes-fees for energy storage

Does your national legislation impose double taxes for ENERGY STORAGE or H2 production facilites?

N.A.

AI.4.4 Hydrogen

AI.4.4.1 Definition and classification for H2

Does your country have a clear definition for H2?

Yes. A good guide is located in [293], only in Portuguese. There is also a National Plan for Hidrogen. (Resolução do Conselho de Ministros n.º 63/2020)

AI.4.4.2 Dificulty to determine the renewable origin of the electricity required to operate the electrolysers (green H2)

No. The documents above establish rules and also establish an "Origin Guarantee" to guarantee that hydrogen is produced using renewbale sources.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

AI.4.4.3 Blending H2 and methane in Natural Gas pipeline

Does your country have any regulatory limit to blend H2 into the current natural gas?

There are some guidelines for blending goals in the above documents: 15% hydrogen by 2030

AI.4.4.4 Interoperability between different markets. Sector coupling

Is there any coordination betwen electricity and gas networks in terms of planning/operation in your country?
Is there any interoperability in the natural gas infrastructure between your cross-border neighbor countries?

Sector integration appears as a general idea in the above mentioned documents. The electricity DSO and Natural Gas TSO is the same company in Portugal.

AI.4.5 Market and business models

AI.4.5.1 Legal barriers to the full participation of all agents (renewable generators, energy storage facilities, EV aggregators, demand side management, final consumers) in all local electricity markets (particularly in flexibility services)

Does your current national legislation ensure a fair and equal access to all electricity markets. (Define what is fair e.g. to participate in frequency market requires 10 MW, is this fair?

Somewhat fair. Every private entity can sell electrical energy to the grid but, for smaller capacities (unlicenced generation assets), the entities have to make a contract with a regulated "last resource retailer", which will buy the electricity for a price indexed to the market price, according to Law Decree no. 162/2019

AI.4.5.2 Lack of business models (only few energy storage applications can justify market-based business cases)

Does your current legislation prevent the creation of new business models (i.e. offering flexibilty services using energy storage or EVs)?

N.A. Pending new law.

AI.4.5.3 Technology neutrality in generation, storage and H2 production

Does your current national legislation ensure fair competition between different technical solutions?

Legislation under development. It is usual for less mature and innovative technologies to receive incentives and subsidies. According to the National Plan for Hidrogen, and other communications from the Government, there will be some subsidies for Green Hydrogen production.

AI.4.6 Self consumption. Energy Communities (ECs)

AI.4.6.1 Geographic scope of Energy Communities (ECs)

ECs are limited to not involve the use of public grid
Consumers of Ecs are located behind the same MV/LV transformer
Consumers of Ecs are located in the same geographic area (<500m)
No geographic limitations for consumers in an EC

The concept of Local Energy Community was introduced by the Law Decree no. 162/2019. Nevertheless, the concept has still no practical implementation and is pending a new law to be published in 2022. The geographic scope has been defined as "in proximity of RES generation and in electrical proximity, e.g. connected to the same secondary substation, to be evaluated by the DGEG" (energy services national authority).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

AI.4.6.2 Technologies

Are Generation Technologies for Energy Communities restricted to renewable energies only?

Yes, according to Law Decree no. 162/2019

AI.4.6.3 Consumer's rights

Do participants in Ecs maintain the same rights than the rest of consumers (right to choose their energy supplier, ensuring quality of supply and quality of service and also ensuring to choose a flexibility management service provider outside the EC)?

Yes, according to Law Decree no. 162/2019

AI.4.6.4 Peer to peer trading (P2P)

Is p2p energy trading allow within a EC in your country?

There is still no specific regulation. P2P energy trading only mentioned in demonstration projects.

AI.4.6.5 Generation capacity limits

Do your national regulations have a limit of maximum generation capacities for ECs?

Not specifically for Energy communities. But generally RES generation above 1 MW has to be aproved.

AI.4.6.6 Local grid tariffs

Does your national legislation have local tariffs to support ECs?

No. Grid tariffs are inclued in the eletctricity and power prices.

AI.4.7 Regulatory stability

AI.4.7.1 Regulatory stability to ensure medium-term predictability in the investment and financial conditions

Does your country have a stable regulation for renewable energies, energy storage and H2 support?

Currently the legislation has stabilized for new PV and Wind projects, including for lower generation capacities and distributed generation.
No specific regulation for H2 yet, but as mentioned before, there will probably be some subsidies for the first H2 producers.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

AI.5 Cyprus

AI.5.1 Ownership and operation

AI.5.1.1 Grid ownership of energy communities

Does your country allow this ownership or is there no national regulation yet? is there any ongoing process in this direction?

At the current stage ther is no legal framework for energy communities in Cyprus. In Cyprus, the creation of energy communities is on the basis of the Directive(EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market in electricity and amendments
of Directive 2012/27 / EU. The harmonization of the National Legislation with the European Directive 2019/944 is in progress. However, energy communities do not have the right to own a distribution system. The owner of the distribution system is the Electricity Authority of Cyprus.

AI.5.1.2 Energy storage facilities ownership

Does your own legislation allow System Opeators to install and operate energy storage facilities in the grid? What actors are mainly responsible for that (TSO/DSO/CEC/Third parties)?

At this stage there is no legal framework for licensing the installation of a storage system.
An amendment to the Electricity Market Regulation Law is in progress, which contains provisions for the licensing of electricity storage facilities.
The harmonization of the National Legislation with the European Directive 2019/944 is in progress. Based on the European Directive 2019/944, the DSO can not own, develops, manages or operates energy storage facilities. The regulatory framework, however, ensures that DSO can source services from sources such as distributed generation, demand response or energy storage.
It is allowed to the DSD to own, develop, manage or to operate energy storage facilities, which are fully integrated network components, and if the CERA has given its approval or if all the following conditions are met:
(a) The other parties involved in an open and transparent and non - discriminatory bidding process in which is carried out by the DSO and which is subject to review and approval by CERA in accordance with guidelines, have not acquired the right for ownership, development, management or operation similar facilities or could not provide such services at a reasonable cost and in time·
(b) such facilities are necessary in order the DSO to comply with its obligations under provisions of this Law for the effective, reliable and safe operation of the system distribution and facilities are not used for the purchase or sale of electricity in the markets electricity; and
(c) CERA has assessed its necessity derogation and has carried out an assessment of the procedure submission of tenders, including conditions of that procedure, and has provided its approval.

AI.5.1.3 EV charging infrastructure facilities ownership

Internal Electricity Market (IEM) Directive 2019/944: Distribution system operators shall not own, develop, manage or operate recharging points for electric vehicles, except where distribution system operators own private recharging points solely for their own use. "CEC are allow to own, develop, manage or operate EV charging points"
What actors are mainly responsible for EV Charging infrastucture facilities?

Subject to its provisions on Promotion and Development of Alternative Fuels Infrastructure Law, CERA with its regulatory decision determines the regulatory framework in order to facilitates the connection of publicly accessible or private EV charging points with the distribution network and with that slider framework ensures that the DSO cooperates in a way that does not discriminates against any business it owns, develops, operates or manages EV charging stations, as regards, inter alia, the connection to network. The DSD is not allowed to own it, to develop, manage or operate EV charging stations, except in special cases or cases where the DSO owns private EV charging stations exclusively for its own use.

AI.5.1.4 H2 production facilities ownership

Does your national legislation allow System Operators to own and operate H2 electrolysers?
Are H2 electrolysers treated as regulated natural monopolies? Commercial activities?

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

N.A.

AI.5.1.5 Battery ownership of EV

Who is the battery owner in V1G-V2G applications?
-car's owner
-car's manufacturer
-third party (aggregators)

Is it possible to provide flexibility services using V1G-V2G in your country?

Car's owners

AI.5.2 Grid connection

AI.5.2.1 Administrative barriers for obtaining authorization/licences for electricity generation or energy storage. Lengthy and expensive grid connection procedures

Does your country have simplified administrative procedures for domestic prosumers or Energy Communities?

The harmonization of the National Legislation with the European Directive 2019/944 is in progress.

AI.5.2.2 Lack of common grid codes procedures for connection of DER generators to the distribution grid (MV-LV)

Is it applicable in your country?

N.A.

AI.5.3.3 Energy storage grid connection

Is it allowed to install an energy storage facility connected to the grid?
-At what level (HV, MV, LV)?

At this stage there is no legal framework for licensing the installation of a storage system.
An amendment to the Electricity Market Regulation Law is in progress, which contains provisions for the licensing of electricity storage facilities.
The harmonization of the National Legislation with the European Directive 2019/944 is in progress.

AI.5.3 Energy Storage

AI.5.3.1 Definition of the energy storage as a market actor

Is ENERGY STORAGE currently recognised as an activity or an asset class in your national electricity market?

They can contribute to maintain grid voltage levels within the accepted boundaries, increase network capacity, and reduce losses. Therefore, their deployment might defer investments in traditional grid assets, regardless of other regulatory or economic considerations.

AI.5.3.2 Double taxes-fees for energy storage

Does your national legislation impose double taxes for ENERGY STORAGE or H2 production facilites?
N.A.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

AI.5.4 Hydrogen

AI.5.4.1 Definition and classification for H2

Does your country have a clear definition for H2?

N.A.

AI.5.4.2 Dificulty to determine the renewable origin of the electricity required to operate the electrolysers (green H2)

N.A.

AI.5.4.3 Blending H2 and methane in Natural Gas pipeline

Does your country have any regulatory limit to blend H2 into the current natural gas?

N.A.

AI.5.4.4 Interoperability between different markets. Sector coupling

Is there any coordination betwen electricity and gas networks in terms of planning/operation in your country?
Is there any interoperability in the natural gas infrastructure between your cross-border neighbor countries?

N.A.

AI.5.5 Market and business models

AI.5.5.1 Legal barriers to the full participation of all agents (renewable generators, energy storage facilities, EV aggregators, demand side management, final consumers) in all local electricity markets (particularly in flexibility services)

Does your current national legislation ensure a fair and equal access to all electricity markets. (Define what is fair e.g. to participate in frequency market requires 10 MW, is this fair?

Every person has the right to join the Contractual Framework of the Electricity Market Rules as long as it is subject to and agrees with the terms

AI.5.5.2 Lack of business models (only few energy storage applications can justify market-based business cases)

Does your current legislation prevent the creation of new business models (i.e. offering flexibilty services using energy storage or EVs)?

N.A.

AI.5.5.3 Technology neutrality in generation, storage and H2 production

Does your current national legislation ensure fair competition between different technical solutions?

N.A.

AI.5.6 Self consumption. Energy Communities (ECs)

AI.5.6.1 Geographic scope of Energy Communities (ECs)

ECs are limited to not involve the use of public grid
Consumers of Ecs are located behind the same MV/LV transformer

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 957779

Consumers of Ecs are located in the same geographic area (<500m)
No geographic limitations for consumers in an EC

At the current stage ther is no legal framework for energy communities in Cyprus, however, the harmonization of the National Legislation with the European Directive 2019/944 is in progress.

AI.5.6.2 Technologies

Are Generation Technologies for Energy Communities restricted to renewable energies only?

At the current stage ther is no legal framework for energy communities in Cyprus, however, the harmonization of the National Legislation with the European Directive 2019/944 is in progress.

AI.5.6.3 Consumer's rights

Do participants in Ecs maintain the same rights than the rest of consumers (right to choose their energy supplier, ensuring quality of supply and quality of service and also ensuring to choose a flexibility management service provider outside the EC)?

At the current stage ther is no legal framework for energy communities in Cyprus, however, the harmonization of the National Legislation with the European Directive 2019/944 is in progress.

AI.5.6.4 Peer to peer trading (P2P)

Is p2p energy trading allow within a EC in your country?

At the current stage ther is no legal framework for energy communities in Cyprus, however, the harmonization of the National Legislation with the European Directive 2019/944 is in progress.

AI.5.6.5 Generation capacity limits

Do your national regulations have a limit of maximum generation capacities for ECs?

At the current stage ther is no legal framework for energy communities in Cyprus, however, the harmonization of the National Legislation with the European Directive 2019/944 is in progress.

AI.5.6.6 Local grid tariffs

Does your national legislation have local tariffs to support ECs?

At the current stage ther is no legal framework for energy communities in Cyprus, however, the harmonization of the National Legislation with the European Directive 2019/944 is in progress.

AI.5.7 Regulatory stability

AI.5.7.1 Regulatory stability to ensure medium-term predictability in the investment and financial conditions

Does your country have a stable regulation for renewable energies, energy storage and H2 support?

Currently there are 3 schemes for PV installation in Cyprus. The Net metering scheme, the Net billing scheme, and the self production scheme. The Net metering and Net billing schemes are applicable for both residential and industrial customers, while the self production scheme only for industrial.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

AI.6 Germany

AI.6.1 Ownership and operation

AI.6.1.1 Grid ownership of energy communities

Does your country allow this ownership or is there no national regulation yet? is there any ongoing process in this direction?

It is allowed. There are already over 900 distribution system operators in Germany.

AI.6.1.2 Energy storage facilities ownership

Does your own legislation allow System Opeators to install and operate energy storage facilities in the grid? What actors are mainly responsible for that (TSO/DSO/CEC/Third parties)?

For regulatory reasons (unbundling / business unbundling), network operators are generally not allowed to operate storage facilities. Exception: thestorage is a special network-related resource. § 8 Abs. 4 Reservekraftwerksverordnung (ResKV) allows a storage facility to be set up and operated by a transmission system operator as a so-called network reserve. In that case, however, it may only be used outside of the energy market (§ 7 Abs. 1 ResKV).

AI.6.1.3 EV charging infrastructure facilities ownership

Internal Electricity Market (IEM) Directive 2019/944: Distribution system operators shall not own, develop, manage or operate recharging points for electric vehicles, except where distribution system operators own private recharging points solely for their own use. "CEC are allow to own, develop, manage or operate EV charging points"

What actors are mainly responsible for EV Charging infrastucture facilities?

Distribution system operators are not permitted to own charging points for electric vehicles or to develop, manage or operate these charging points, with the exception of those cases where Distribution system operators own certain private charging points for their own use only.

AI.6.1.4 H2 production facilities ownership

Does your national legislation allow System Operators to own and operate H2 electrolysers?
Are H2 electrolysers treated as regulated natural monopolies? Commercial activities?

According to Electricity and gas supply law (Energy Industry Act - EnWG) § 28m unbundling: Operators of hydrogen networks are obliged to guarantee transparency and non-discriminatory design and processing of network operations. In order to achieve this goal, they have to ensure the independence of network operation from hydrogen generation, hydrogen storage and hydrogen distribution. Operators of hydrogen networks are not permitted to hold ownership of systems for hydrogen production, hydrogen storage or hydrogen distribution, or to build or operate them.

AI.6.1.5 Battery ownership of EV

Who is the battery owner in V1G-V2G applications?
-car's owner
-car's manufacturer
-third party (aggregators)

Is it possible to provide flexibility services using V1G-V2G in your country?

Batteries owners are the car's owners. However, a third party (aggregator) and car owner could sign a private agreement in which the aggregator can manage the energy stored in the EV for flexibility services.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

AI.6.2 Grid connection

AI.6.2.1 Administrative barriers for obtaining authorization/licences for electricity generation or energy storage. Lengthy and expensive grid connection procedures

Does your country have simplified administrative procedures for domestic prosumers or Energy Communities?

No information found

AI.6.2.2 Lack of common grid codes procedures for connection of DER generators to the distribution grid (MV-LV)

Is it applicable in your country?

N. A.

AI.6.3.3 Energy storage grid connection

Is it allowed to install an energy storage facility connected to the grid?
-At what level (HV, MV, LV)?

Technical requirements for the connection and operation of storage systems are specified in Germany in the VDE application rules. With these so-called Technical Connection Rules (TAR), VDE FNN defines the specific requirements for the German power system according to European specifications for each voltage level.
So far, storage facilities have not been explicitly considered as grid resources in the German legal and regulatory framework. For system security reasons, the transmission system operator is permitted to intervene in electricity storage according to Section 13 (1) EnWG. However, there are no relevant approaches for congestion management in distribution grids and they must be further developed according to the EU law.

AI.6.3 Energy Storage

AI.6.3.1 Definition of the energy storage as a market actor

Is ENERGY STORAGE currently recognised as an activity or an asset class in your national electricity market?

No wording proposal for German law has so far become known. A clear, legally and economically viable definition, which is based on a technical device clearly recognizable as a power storage device is missing.

AI.6.3.2 Double taxes-fees for energy storage

Does your national legislation impose double taxes for ENERGY STORAGE or H2 production facilites?

It seems that it was the case but it is going to be chaned in an EnWG law amendment [294].

AI.6.4 Hydrogen

AI.6.4.1 Definition and classification for H2

Does your country have a clear definition for H2?

In § 3 No. § 19a EnWG, the term gas, as used in the EnWG, is defined as: "Natural gas, biogas, liquid gas within the scope of §§ 4 and 49 and, if they are fed into a gas supply network, hydrogen, which has been produced by water electrolysis, and synthetically produced methane, which has been produced by water-electrolytically produced hydrogen and subsequent methanation”.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 957779

AI.6.4.2 Dificulty to determine the renewable origin of the electricity required to operate the electrolysers (green H2)

N.A.

AI.6.4.3 Blending H2 and methane in Natural Gas pipeline

Does your country have any regulatory limit to blend H2 into the current natural gas?

The transport of hydrogen as an admixture to natural gas in the existing gas network has so far not been subject to any separate regulatory considerations [295].

AI.6.4.4 Interoperability between different markets. Sector coupling

Is there any coordination betwen electricity and gas networks in terms of planning/operation in your country?
Is there any interoperability in the natural gas infrastructure between your cross-border neighbor countries?

Energiewende (energy transition planning) is based on a central foundation: an integrated infrastructure. The existing systems for electricity, gas, heat and liquid energy sources must be better interlinked and their further development must be coordinated with one another [296].

AI.6.5 Market and business models

AI.6.5.1 Legal barriers to the full participation of all agents (renewable generators, energy storage facilities, EV aggregators, demand side management, final consumers) in all local electricity markets (particularly in flexibility services)

Does your current national legislation ensure a fair and equal access to all electricity markets. (Define what is fair e.g. to participate in frequency market requires 10 MW, is this fair?

AI.6.5.2 Lack of business models (only few energy storage applications can justify market-based business cases)

Does your current legislation prevent the creation of new business models (i.e. offering flexibilty services using energy storage or EVs)?

AI.6.5.3 Technology neutrality in generation, storage and H2 production

Does your current national legislation ensure fair competition between different technical solutions?

AI.6.6 Self consumption. Energy Communities (ECs)

AI.6.6.1 Geographic scope of Energy Communities (ECs)

ECs are limited to not involve the use of public grid
Consumers of Ecs are located behind the same MV/LV transformer
Consumers of Ecs are located in the same geographic area (<500m)
No geographic limitations for consumers in an EC

Regulation of Energy Communities is under development [297]

AI.6.6.2 Technologies

Are Generation Technologies for Energy Communities restricted to renewable energies only?

Regulation of Energy Communities is under development [297]

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

AI.6.6.3 Consumer's rights

Do participants in Ecs maintain the same rights than the rest of consumers (right to choose their energy supplier, ensuring quality of supply and quality of service and also ensuring to choose a flexibility management service provider outside the EC)?

Regulation of Energy Communities is under development [297]

AI.6.6.4 Peer to peer trading (P2P)

Is p2p energy trading allow within a EC in your country?

Regulation of Energy Communities is under development [297]

AI.6.6.5 Generation capacity limits

Do your national regulations have a limit of maximum generation capacities for ECs?

Regulation of Energy Communities is under development [297]

AI.6.6.6 Local grid tariffs

Does your national legislation have local tariffs to support ECs?

Regulation of Energy Communities is under development [297]

AI.6.7 Regulatory stability

AI.6.7.1 Regulatory stability to ensure medium-term predictability in the investment and financial conditions

Does your country have a stable regulation for renewable energies, energy storage and H2 support?

The law for the expansion of renewable energies - in short: Renewable Energy Sources Act (EEG) - is the central funding instrument for renewables in the field of power generation. It regulates the priority purchase, transmission and distribution as well as the remuneration for electricity from wind, sun and Co. [298]

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

AI.7 Ireland

AI.7.1 Ownership and operation

AI.7.1.1 Grid ownership of energy communities

Does your country allow this ownership or is there no national regulation yet? is there any ongoing process in this direction?

Actually there is a barrier related to the connection into the National Electricity Grid ensuring community energy groups to have equitable grid access opportunities in their local areas [299].

AI.7.1.2 Energy storage facilities ownership

Does your own legislation allow System Opeators to install and operate energy storage facilities in the grid? What actors are mainly responsible for that (TSO/DSO/CEC/Third parties)?

N.A.

AI.7.1.3 EV charging infrastructure facilities ownership

Internal Electricity Market (IEM) Directive 2019/944: Distribution system operators shall not own, develop, manage or operate recharging points for electric vehicles, except where distribution system operators own private recharging points solely for their own use. "CEC are allow to own, develop, manage or operate EV charging points"

What actors are mainly responsible for EV Charging infrastucture facilities?

N.A.

AI.7.1.4 H2 production facilities ownership

Does your national legislation allow System Operators to own and operate H2 electrolysers?
Are H2 electrolysers treated as regulated natural monopolies? Commercial activities?

N.A.

AI.7.1.5 Battery ownership of EV

Who is the battery owner in V1G-V2G applications?
-car's owner
-car's manufacturer
-third party (aggregators)

Is it possible to provide flexibility services using V1G-V2G in your country?

Yes, it is possible to provide flexibility services

AI.7.2 Grid connection

AI.7.2.1 Administrative barriers for obtaining authorization/licences for electricity generation or energy storage. Lengthy and expensive grid connection procedures

Does your country have simplified administrative procedures for domestic prosumers or Energy Communities?

See grid ownership section

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

AI.7.2.2 Lack of common grid codes procedures for connection of DER generators to the distribution grid (MV-LV)

Is it applicable in your country?

N.A.

AI.7.3.3 Energy storage grid connection

Is it allowed to install an energy storage facility connected to the grid?
-At what level (HV, MV, LV)?

N.A.

AI.7.3 Energy Storage

AI.7.3.1 Definition of the energy storage as a market actor

Is ENERGY STORAGE currently recognised as an activity or an asset class in your national electricity market?

Energy storages can provide flexibility services to the grid.

AI.7.3.2 Double taxes-fees for energy storage

Does your national legislation impose double taxes for ENERGY STORAGE or H2 production facilites?

N.A.

AI.7.4 Hydrogen

AI.7.4.1 Definition and classification for H2

Does your country have a clear definition for H2?

According to the NECP (National Energy & Climate Plan) Ireland, hydrogen is defined as “a low carbon technology that could have the potential to fully decarbonise the Irish gas network”.

AI.7.4.2 Dificulty to determine the renewable origin of the electricity required to operate the electrolysers (green H2)

No, generally renewable energy sources.

AI.7.4.3 Blending H2 and methane in Natural Gas pipeline

Does your country have any regulatory limit to blend H2 into the current natural gas?

AI.7.4.4 Interoperability between different markets. Sector coupling

Is there any coordination betwen electricity and gas networks in terms of planning/operation in your country?
Is there any interoperability in the natural gas infrastructure between your cross-border neighbor countries?

Not yet, but actually it is cited that hydrogen can also be blended into natural gas networks at low concentrations <20% without the need to change any of the infrastructure or end use devices [300].

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 957779

AI.7.5 Market and business models

AI.7.5.1 Legal barriers to the full participation of all agents (renewable generators, energy storage facilities, EV aggregators, demand side management, final consumers) in all local electricity markets (particularly in flexibility services)

Does your current national legislation ensure a fair and equal access to all electricity markets. (Define what is fair e.g. to participate in frequency market requires 10 MW, is this fair?

AI.7.5.2 Lack of business models (only few energy storage applications can justify market-based business cases)

Does your current legislation prevent the creation of new business models (i.e. offering flexibilty services using energy storage or EVs)?

AI.7.5.3 Technology neutrality in generation, storage and H2 production

Does your current national legislation ensure fair competition between different technical solutions?

AI.7.6 Self consumption. Energy Communities (ECs)

AI.7.6.1 Geographic scope of Energy Communities (ECs)

ECs are limited to not involve the use of public grid
Consumers of Ecs are located behind the same MV/LV transformer
Consumers of Ecs are located in the same geographic area (<500m)
No geographic limitations for consumers in an EC

In Ireland, a Sustainable Energy Community is defined in the SEC Programme as a partnership between public, private and community sectors which aim to be energy-efficient first and use renewable energy and smart energy solutions second. Any actor can participate in a sustainable energy community, irrespective of their geographical location within the country, which makes the concept considerably broader than both REC and CEC in RED II and EMD [301].

AI.7.6.2 Technologies

Are Generation Technologies for Energy Communities restricted to renewable energies only?

AI.7.6.3 Consumer's rights

Do participants in Ecs maintain the same rights than the rest of consumers (right to choose their energy supplier, ensuring quality of supply and quality of service and also ensuring to choose a flexibility management service provider outside the EC)?

AI.7.6.4 Peer to peer trading (P2P)

Is p2p energy trading allow within a EC in your country?

Yes [302].

AI.7.6.5 Generation capacity limits

Do your national regulations have a limit of maximum generation capacities for ECs?

AI.7.6.6 Local grid tariffs

Does your national legislation have local tariffs to support ECs?

The Renewable Electricity Support Scheme has been designed to promote investments in renewable energy generation in Ireland and SEAI will support the communities. [303]

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement N° 957779

AI.7.7 Regulatory stability

AI.7.7.1 Regulatory stability to ensure medium-term predictability in the investment and financial conditions

Does your country have a stable regulation for renewable energies, energy storage and H2 support?

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement N° 957779

AI.8 Spain

AI.8.1 Ownership and operation

AI.8.1.1 Grid ownership of energy communities

Does your country allow this ownership or is there no national regulation yet? is there any ongoing process in this direction?

Renewable Energy Communities (REC), or simply "energy communities", are defined as a legal entity based on open and voluntary participation, owned by persons, SMEs or local authorities [Real Decree 23/2020 updates Law 24/2014 of the electric sector - Art 6]

In contrast to Renewable Energy Communities (REC), Citizen Energy Communities (CEC) have not yet transposed from Directive 2019/944 to national law.

The grid ownership belongs to historically Distribution System Operators (DSO) which are private companies who own and manage the distribution grids. Around 98% of the business is controlled by five large companies. In order to democratise the distribution grid and allow a grid ownership of energy communities, a SMEs or the local authority should purchase the grid to the current DSO grid owner. https://elperiodicodelaenergia.com/democratizar-la-red-de-distribucion-electrica/

However, the local DSO must be complying with the Real Decree 1955/2000, which includes the requirements to be constituted, functions, obligations and rights of a DSO. Some economic and technical requirements could be barriers for small DSOs.

AI.8.1.2 Energy storage facilities ownership

Does your own legislation allow System Opeators to install and operate energy storage facilities in the grid? What actors are mainly responsible for that (TSO/DSO/CEC/Third parties)?

The owners of energy storage facilities can be consumers, energy retailers, energy aggregator and generation facilities and use it in the electricity markets and, when applicable, ancillary services or demand-side services [Real Decree 23/2020 updates Law 24/2014 of the electric sector - Art 6].

The energy storage should not be installed by TSO/DSOs [Distribution System Operator Observatory 2020 - JRC]. However, SOs could get a storage investment approved when it is required for system security, it provides technical capabilities that no other solution can provide, it provides a better cost-benefit result compared to another grid reinforcement solution, or there is no attractive market option to get the service required for the operation of the network. However, demonstrating this by the TSO/DSOs may require a long procedure. [Operating Procedure 3.1. Proceso de programación]

AI.8.1.3 EV charging infrastructure facilities ownership

Internal Electricity Market (IEM) Directive 2019/944: Distribution system operators shall not own, develop, manage or operate recharging points for electric vehicles, except where distribution system operators own private recharging points solely for their own use. "CEC are allow to own, develop, manage or operate EV charging points"

What actors are mainly responsible for EV Charging infrastucture facilities?

The EV charging infrastructure could be owned by final consumers, EV charging services' providers, aggregators, private companies, or energy communities, for their own EV recharge consumption or to offer EV recharge services [Real Decree 23/2020 updates Law 24/2014 of the electric sector - Art 6].

The DSO companies may be holders of last resort of infrastructures for the EV recharging, in case of no private interest, after a concurrent procedure established by the Government [Real Decree 23/2020 updates Law 24/2014 of the electric sector - Art 38].

AI.8.1.4 H2 production facilities ownership

Does your national legislation allow System Operators to own and operate H2 electrolysers?
Are H2 electrolysers treated as regulated natural monopolies? Commercial activities?

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

There is no specific legislation regarding the H2 production facilities or H2 electrolizers. The Spanish H2 roadmap, published in 2020, is not focused on the SO ownership, but rather as a commercial business. Medium and long-term objectives of H2 production, electrolizers and infrastructure are established. The value chain is identified (production, manufacturers, transport, electrolizers, final consumers, etc.) to be supported by the government. The consecution of H2 objectives will be drived by national and European financing mechanisms. [H2 roadmap - Hoja de ruta del hidrógeno: una apuesta por el hidrógeno renovable 2020]

AI.8.1.5 Battery ownership of EV

Who is the battery owner in V1G-V2G applications?
-car's owner
-car's manufacturer
-third party (aggregators)

Is it possible to provide flexibility services using V1G-V2G in your country?

Batteries owners are the car's owners. However, a third party (aggregator) and car owner could sign a private agreement in which the aggregator can manage the energy stored in the EV for flexibility services.

AI.8.2 Grid connection

AI.8.2.1 Administrative barriers for obtaining authorization/licences for electricity generation or energy storage. Lengthy and expensive grid connection procedures

Does your country have simplified administrative procedures for domestic prosumers or Energy Communities?

Recently, some administrative barriers are removed to improve and simplify, among others, the authorization procedures for the construction, expansion, modification and exploitation of production, transport and distribution facilities. Moreover, a more simplified administrative procedure is established to R&I projects. [Real Decree 23/2020]. Prosumers without solar surplusses to the grid or prosumers with an installed solar power less than 15 kW are exempt from the procedures for grid access and connection [Real Decree 244/2019], described in Real Decree 1183/2020 [Energy storage strategy - Estrategia de almacenamiento energético 2021].

AI.8.2.2 Lack of common grid codes procedures for connection of DER generators to the distribution grid (MV-LV)

Is it applicable in your country?

Prosumers without solar surplusses to the grid or prosumers with an installed solar power less than 15 kW are exempt from the procedures for grid access and connection [Real Decree 244/2019]. Otherwise, the procedure for distribution grid access and connection is described in Real Decree 1183/2020.

AI.8.3.3 Energy storage grid connection

Is it allowed to install an energy storage facility connected to the grid?
-At what level (HV, MV, LV)?

It is allowed to install an energy storage facility connected to HV, MV and LV. The procedure for grid access and connection is described in Real Decree 1183/2020, including the energy storage (pumped-hydro and other energy storage technologies). The owners of generation facilities can hybridize storage with their main generation technology. Also, an energy storage facility can request access to the grid, stand-alone or hybridized [Real Decree 23/2020 updates Law 24/2014 of the electric sector - Art 33]. Different modalities of self-consumption with energy storage in MV or LW grid have been defined [Real Decree 244/2019]

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

AI.8.3 Energy Storage

AI.8.3.1 Definition of the energy storage as a market actor

Is ENERGY STORAGE currently recognised as an activity or an asset class in your national electricity market?

The energy storage facilities can participate in the electricty markets, ancillary (grid) services and demand-side services in equality [Real Decree 23/2020 updates Law 24/2014 of the electric sector - Art 6]. The energy storage facility can be considerd as stand-alone facility or hybridized with a generation/consumption facility. Stand-alone ESS is required to be broken into two programming units for buying and selling energy transactions [Operating Procedure 3.1. Proceso de programación]. Other operating procedures have been modified to incorporate the ESS in balancing markets in equality. However, the regulatory framework has not yet finalised because only pumped-hydro can submit both purchase and sale bids, but nor sland-alone ESS [Resolución de 6 de mayo de 2021 de la CNMC]

AI.8.3.2 Double taxes-fees for energy storage

Does your national legislation impose double taxes for ENERGY STORAGE or H2 production facilites?

There are no double taxes/fees for energy storage. There is not grid taxes for energy storage connected in transmission and distribution grids [Circular 3/2020 de la CNMC] in line with the article 2 of Reglament 2019/943 and it is ratified in the current metodology for grid taxes [Real Decreto 148/2021]. Hydrogen is not addressed in the national legulation.

AI.8.4 Hydrogen

AI.8.4.1 Definition and classification for H2

Does your country have a clear definition for H2?

A first classification of H2 based on their energy source and CO2 emissions is defined: grey (from natural gas or other hydrocarbons), blue (grey with CCUS techniques) and green (from renewable sources). Other types are not addressed in the roadmap [H2 roadmap - Hoja de ruta del hidrógeno: una apuesta por el hidrógeno renovable 2020].

AI.8.4.2 Dificulty to determine the renewable origin of the electricity required to operate the electrolysers (green H2)

Renewable hydrogen considers the hydrogen produces via electrolisis from renewable electricity, biogas reforming and biochemical conversion of biomass when sustainability requirement are satisfied [H2 roadmap - Hoja de ruta del hidrógeno: una apuesta por el hidrógeno renovable 2020]

AI.8.4.3 Blending H2 and methane in Natural Gas pipeline

Does your country have any regulatory limit to blend H2 into the current natural gas?

There is not a regulatory limit to blend H2 into the current natural gas infrastructure, because its current generation is rather limited. The blending is considered as an option to transport hydrogen gas, but it implies a loss of value and quality of green hydrogen and it is difficult to separate in the consumption if needed [H2 roadmap - Hoja de ruta del hidrógeno: una apuesta por el hidrógeno renovable 2020]

AI.8.4.4 Interoperability between different markets. Sector coupling

Is there any coordination betwen electricity and gas networks in terms of planning/operation in your country?
Is there any interoperability in the natural gas infrastructure between your cross-border neighbor countries?

The H2 could be generated, when the renewable generation is curtailed to meet electricity demand. Also, H2 could provide large-scale flexibility to the electric network. The current gas infrastructure could be used to incorporate gradually the H2 and allow their use in other energy sectors. Sector integration appears in the long-term roadmap, but

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement N° 957779

not specific legislation is establised [H2 roadmap - Hoja de ruta del hidrógeno: una apuesta por el hidrógeno renovable 2020].

AI.8.5 Market and business models

AI.8.5.1 Legal barriers to the full participation of all agents (renewable generators, energy storage facilities, EV aggregators, demand side management, final consumers) in all local electricity markets (particularly in flexibility services)

Does your current national legislation ensure a fair and equal access to all electricity markets. (Define what is fair e.g. to participate in frequency market requires 10 MW, is this fair?

The energy storage facilities can participate in the electricity markets, ancillary (grid) services and demand-side services in equality [Real Decree 23/2020 updates Law 24/2014 of the electric sector - Art 6]. The market rules have been recently broadening to allow the participation of energy storage and demand in these market and grid services [Operating Procedures 3.1, 3.3, 7.2, 7.3.]. However, the regulatory framework has not yet finalised because only pumped-hydro can submit both purchase and sale bids [Resolución de 6 de mayo de 2021 de la CNMC]. Other services (such as black start, voltage control, and DSO flexibility services) may be adressed in the future [Energy storage strategy - Estrategia de almacenamiento energético 2021].

AI.8.5.2 Lack of business models (only few energy storage applications can justify market-based business cases)

Does your current legislation prevent the creation of new business models (i.e. offering flexibilty services using energy storage or EVs)?

Knowning that a purely market-based business cases could be risky and limited profitable, the energy storage strategy aims to foster new business models related to ESS around energy communities and energy aggregators. PV+ESS grant programs for residential and industrial sectors are considered [Energy storage strategy - Estrategia de almacenamiento energético 2021]. Moreover, auction mechanisms of renewable resources hybridized by energy storage are proposed to incentive their integration until their market maturity [Real Decreto 960/2020].

AI.8.5.3 Technology neutrality in generation, storage and H2 production

Does your current national legislation ensure fair competition between different technical solutions?
The development of the regulatory framework must be based on principles such as technological neutrality, although currently less maturity technologies are supported vis subsidies or grants.

AI.8.6 Self consumption. Energy Communities (ECs)

AI.8.6.1 Geographic scope of Energy Communities (ECs)

ECs are limited to not involve the use of public grid
Consumers of Ecs are located behind the same MV/LV transformer
Consumers of Ecs are located in the same geographic area (<500m)
No geographic limitations for consumers in an EC

Currently, Renewable Energy Communities (REC), or simply "energy communities", are defined as a legal entity based on open and voluntary participation, owned by persons, SMEs or local authorities [Real Decree 23/2020]. Until specific regulation, they should follow the collective self-consumption [Real Decree 244/2019]. Consumers are located in the same geographic area, the maximum distance between the photovoltaic generation and each prosumers must be 500 meters.

AI.8.6.2 Technologies

Are Generation Technologies for Energy Communities restricted to renewable energies only?

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957779

Local energy communities follow the collective self-consumption regulation, which allows non-renewable resources, cogeneration or waste-to-energy technologies [Real Decree 244/2019].

AI.8.6.3 Consumer's rights

Do participants in Ecs maintain the same rights than the rest of consumers (right to choose their energy supplier, ensuring quality of supply and quality of service and also ensuring to choose a flexibility management service provider outside the EC)?

Energy communities are defined as a legal entity based on open and voluntary participation. Above all, consumers must have the right to participate in an energy community as well as maintain their rights and duties as final consumer, ensuring an equitable and non-discriminatory treatment [Guía para el Desarrollo de Instrumentos de Fomento de Comunidades Energéticas Locales 2019]

AI.8.6.4 Peer to peer trading (P2P)

Is p2p energy trading allow within a EC in your country?

There is not a specific regulation which address the P2P energy trading schemes. In the framework of collective self-consumption, (annual or hourly) consumption ratio of the local energy generated is considered per each prosumer indexed to their contracted power and the investment contribution, among others parameters. However, these ratios are fixed beforehand and they are not dynamic according to their real self-consumption [Real Decree 244/2019]. No peer-to-peer markets are implemented.

AI.8.6.5 Generation capacity limits

Do your national regulations have a limit of maximum generation capacities for ECs?

There is any limitation of maximum generation capacities. Previously, the maximum installed power should be the contrated power by the prosumer [Real Decree 244/2019]. However, there are limitation from the distribution grid access. The installed power connected to a substation will not exceed 50% of the installed transformation capacity. For non-manageable generation, the generation capacity in the grid connection point will not exceed 1/20 of the short-circuit power of the grid at said point [Real Decree 413/2019].

AI.8.6.6 Local grid tariffs

Does your national legislation have local tariffs to support ECs?

No. Grid tariffs are related to the contracted power and the energy time periods [Real Decreto 148/2021]

AI.8.7 Regulatory stability

AI.8.7.1 Regulatory stability to ensure medium-term predictability in the investment and financial conditions

Does your country have a stable regulation for renewable energies, energy storage and H2 support?

In the past, the promotion of PV instalations were very high, and the goverment had to modify retroactively the payments to the PV producers, producing a lost of the investors' confidence. Currently, regulatory stability is higher with continuous changes in market rules and procedures implemented in line with the European directives and roadmaps to promote RES and ESS. Medium and long-term objectives related to renewable energies have been defined (Plan Nacional Integrado de Energía y Clima (PNIEC) 2021-2030 & Estrategia de descarbonización a largo plazo 2050). No regulation for H2 has been provided so far, but there is a national strategy to support their deployment [H2 roadmap - Hoja de ruta del hidrógeno 2020].

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement N° 957779

AI.8.8 Regulatory barriers in the Spanish legislation related to the participation of LECs in the balancing services

Reference [304] opened the door to the participation of loads, energy storage and aggregators in the system's balancing services. However, some requirements established in such a Resolution, as well as in the system's operational procedures in which the changes introduced by the Resolution have been transposed, pose some difficulties to the participation of LECs in the system's balancing services. Furthermore, there exist some loopholes in the Spanish legislation, which make it even harder for the participation of LECs in the system's balancing services.

In the Spanish power system, Automatic Frequency Restoration Reserves (aFRRs) are provided by regulation zones [305]. Regulation zones are defined in [304] as groups of programming units that, jointly, are able to regulate (i.e., vary their active power) in response to the orders of an Automatic Generation Control (AGC) system. Regulation zones must be composed of one or more programming units that actively participate in the aFRR service, all of which must be owned or represented by a single market agent.

Different types of programming units are defined in [305]. The most relevant types of programming units pertaining to LECs are:

1) Programming units of renewable generation facilities of groups of facilities. In general, a programming unit of this type is established for electricity delivery for each balancing responsible party (BRP), market participant and type of production (onshore wind, offshore wind, solar PV, solar thermoelectric, etc.). The excess electricity of self-consumption facilities which have not opted for the so-called simplified compensation mechanism is integrated into the grid through this type of programming unit. These types of programming units will be allowed to incorporate energy storage facilities associated with the generation facilities once the relevant regulations have been developed and come into force.

2) Load programming units. There are two types of load programming units depending on whether the electricity is withdrawn or purchased by an electricity retailer or a direct consumer. These types of programming units will be allowed to incorporate energy storage facilities associated with the consumption facilities once the relevant regulations have been developed and come into force.

3) Storage programming units. There are two types of storage programming units: those associated with pumped-storage units and those associated with other storage technologies; two separate programming units are related to pumped-storage units, one for electricity delivery and another for electricity consumption. Other storage facilities not related to any generation or consumption facilities have two separate programming units, one for electricity delivery and the other one for electricity consumption.

In the Spanish power system, manual Frequency Restoration Reserves (mFRR) [305] and Replacement Reserves [306] are provided by programming units.

According to [304], the owners of generation, consumption and storage facilities, as well as their representatives, can qualify to be Balancing Service Providers (BSP). In order for a programming unit to qualify as BSP, it must pass the corresponding qualification test [305].

Regulation zones must have a minimum qualifying amount of 200 MW so as to provide aFRR [304]. This amount refers to the installed power capacity/contracted power in the case of generation/consumption facilities [305]. It's possible to incorporate in a regulation zone programming units owned by companies different from the titleholder of the regulation zone as long as all companies are part of the same group of companies, the regulation zone's titleholder agrees with such incorporation, and all programming units in the regulation zone are connected to and governed from a single control centre [305].

BSPs must have a minimum offer capacity of 1 MW [304], regardless of the balancing service they qualify to provide.

Programming units connected to the distribution network which apply to qualify as BSPs must get the approval of their application by the DSO [305].

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement N° 957779

LECs do not exist as such in the Spanish legislation. It was not until the entry into force of [307] that the figure of "renewable energy community" (REC) was introduced in [308] as a subject that can develop the activity of supplying electricity. RECs are defined as legal entities based on the open and voluntary participation of their associates or members which are situated in the vicinity of renewable energy projects owned and developed by such legal entities and aimed to bring environmental, economic and social benefits to their associates or members or the areas where they are operating.

RECs are not mentioned in [304] or the operational procedures by which the provision of aFRR, mFRR and RR and the corresponding qualification tests are regulated.

To conclude, just as an example, at present, a REC willing to provide, e.g., aFRR in the Spanish power system must apply for the qualification of its renewable generation, load and storage programming units, provided that these have an offered capacity of at least 1 MW, get the approval of the application by the DSO, pass the qualification tests, and associate with other agents (generation companies, consumers, other RECs, etc.) so as to form a group of companies totalizing a qualified amount of 200 MW or higher for the provision of aFRR, or with an existing regulation zone title holder so that the REC's qualified units are incorporated in the regulation zone. In both cases, all programming units of the regulation zone must be connected to and governed from a single control centre.

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement N° 957779