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CLEAN ENERGY TECHNOLOGY OBSERVATORY: SMART GRIDS IN THE EUROPEAN UNION

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STATUS REPORT ON TECHNOLOGY DEVELOPMENT, TRENDS, VALUE CHAINS AND MARKETS

Joint Research Centre

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Contents

Abstract

Current policies aim at a fundamental decarbonisation of the European economy which is still too dependent on fossil fuels. Electrification based on renewable energy production is considered to be the most effective way to tackle this issue. As a result, electricity demand is projected to increase significantly on a pathway towards climate neutrality. It is well known that increasing the current level of renewable based production is however not enough: such a production needs to be integrated into the energy system by means of a smarter grid infrastructure deeply based on digital and interoperable solutions. In this report, the focus is on the role played by a subset of enabling technologies in the smart grids sector: Transmission innovation (TI), Grid-scale storage services (GSSS), Electric vehicles smart charging (EVSC), Advanced meter infrastructure (AMI) and Home energy management systems (HEMS). For each technology, the current status is reported for R&D, value chain, market and resources, depending on the available data.

Foreword

This report is an output of the Clean Energy Technology Observatory (CETO). CETO's objective is to provide an evidence-based analysis feeding the policy making process and hence increasing the effectiveness of R&I policies for clean energy technologies and solutions. It monitors EU research and innovation activities on clean energy technologies needed for the delivery of the European Green Deal; and assesses the competitiveness of the EU clean energy sector and its positioning in the global energy market.

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Executive Summary

The Energy System Integration strategy (European Commission, 2020) sees at its core a greater direct electrification of end-used sectors. Electricity demand is projected to increase significantly on a pathway towards climate neutrality, with the share of electricity in final energy consumption growing from 23% today to around 50% by 2050 according to certain scenarios. It is of utmost importance that this increasing projected electricity demand shall be entirely supplied by renewable sources. Moreover, by replacing classic fossil-based energy fuels, European residential consumers, SMEs and industry will be less exposed to volatility in global oil and gas pricing and any potential supply shocks. The ability to provide an increasing amount of Europe's energy needs domestically, without the need for imports, adds significant economic, environmental, and security of supply benefits to the rationale of electrification.

In this report, the focus is on the role played by a subset of enabling technologies in the Smart Grids sector. A Smart Grid can be thought as a modernized grid that enables bidirectional flows of energy and uses two-way communication and control capabilities that can lead to new functionalities and applications. Electrification is deeply based on an adequate deployment of smart grid solutions. Failing to accomplish this task would nullify any achievement for instance made on clean energy production. Power systems, namely transmission and distribution networks, are rather complex objects designed some decades ago to work in a centralised manner. Electricity was flowing in one-way from big power plants to transmission bulk, then down to distribution networks, to be finally delivered to final consumers. The decentralisation and the variability of renewable production (often connected at the distribution level) have challenged the power system together with its established method of being operated. But the challenge is not limited only to a supply issue, on the demand side, thanks to the widespread of digital solutions, a number of opportunities have been emerging. Smart metering and home energy management systems can, for instance, make consumers more aware of their energy consumption. Not only that, the deployment of these technologies can give them the opportunity to actively participate to flexibility markets through aggregators or other parties. The focus for this CETO exercise has been put on five enabling technologies: Transmission innovation (TI), Grid-scale storage services (GSSS), Electric vehicles smart charging (EVSC), Advanced meter infrastructure (AMI) and Home energy management systems (HEMS).

Transmission Innovation

The power grid has a key role to play by enabling a cleaner energy integration across the economy and by making electricity supply reliable and secure even under worsened climate conditions. A timely development of grid infrastructure is key to the EU recovery and the integration of renewable energies, including the respective potential for job and value creation.

- To meet the European energy policy goals and the targets of the EU Recovery Plan, the Ten Year Network Development Plan (TYNDP) for year 2020 highlighted a total CAPEX of EUR 135 billion for projects. The construction and commissioning of projects projected for the next 10 years could ensure the creation of 1.7 million jobs across Member States. In terms of Research and Development, a set of thirteen project concepts will be initiated by European TSOs in collaboration with key stakeholders and supported by policy makers and regulatory authorities in the coming years.
- These R&D projects are aimed mainly at optimising cross-sector integration, at preparing the system for deep electrification, at integrating higher levels of large-scale offshore wind integration, at enhancing control centre's operation and interoperability.
- Market players like Prysmian Group, Nexans, NKT are among the leading players in the global high voltage cables market. Several other players are involved in LV, MV and HV Cable Installation, Jointing, Substation and Electrical Equipment.
- In terms of needed resources, a thorough views is offered by the KU Leuven analysis on the clean energy request of materials. A first emerging insight is that an important demand for energy transition metals demand (responsible for 35-45% of the overall) comes from electricity networks and solar photovoltaic production. Electricity networks require significant volumes of copper and aluminium.

Grid-scale storage services (GSSS)

In order to deliver an efficient and cost-effective energy transition, the development of the network infrastructure must be accompanied and supported by the deployment of novel alternative technologies. This report analyses the role that bulk storage and in particular lithium-ion batteries can provide to support the planning and operation of the electricity grid. Battery storage assets represent an important source of flexibility that can be used for system regulation purposes and to defer costly grid investments. At an operation level, the analysis has shown that storage is already providing relevant contributions to grid services, particularly for frequency regulation on shorter time scales. Regulatory interventions and an ad hoc reformulation of grid services that accounts for the intrinsic battery storage technical limitations could facilitate its larger use in different contexts, such as the provision of capacity resources. From a system planning perspective, the capability of storage to defer grid investments, both for transmission and distribution infrastructure, has been evaluated. While several pilot projects are being developed and tested for such purpose, the regulatory framework that can ensure efficiency and cost-effectiveness of such applications remains to be clarified. The report has also investigated the potential whole-system value of storage assets, which remains difficult to quantify precisely. Most recent studies on the topic show that, in future energy scenarios with high penetration of renewable, a 5% increase of installed battery storage could lead to an approximate -1.7% reduction in generation costs and a -3% reduction of congestion hours on critical transmission lines. In terms of investment trends, an exponential growth of storage installation is expected worldwide. In Europe, recent estimates forecast a 20-fold expansion of storage capacity in the next ten years, reaching an aggregate 45 GW/89 GWh of grid storage assets in 2031. A fundamental drive of these is the significant cost reduction of the battery storage technology expected in the next 8-10 years, with the cost of batteries and of complete storage plants that is expected to be reduced by 40% and 30%, respectively.

Electric Vehicles Smart Charging

Although newly installed EV charging infrastructure (including fast EV chargers, public EV chargers, etc.) does not presuppose smart EV charging operation, the growing number of EVs sales along with the increasing installation of new EV charging stations, are expected to boost smart EV charging. Smart charging optimises the dispersion of power and leads to considerable savings for grid operators, charge point operators, charge point owners and EV drivers. Smart charging also requires new revenue models in monetizing the flexibility of charging EVs. Smart EV charging can offer great opportunities to power systems. EVs and their batteries, through the smart charging techniques (bidirectional managed or vehicle-to-grid, unidirectional managed charging, off-peal charging, etc.), could provide a huge reservoir of flexibility to facilitate the energy transition. New sources of flexibility can help to ensure that power systems are in balance at all times. The number of projects, pilots, and demonstrations have grown alongside development of the larger EV market. Vehicle-to-Grid projects have largely been highly sophisticated, meant to test implementation challenges, battery impacts, and economic potential under a variety of grid service applications. Standardization efforts to support electro mobility have historically focused on traditional electro-technical issues, such as plugs, outlets and electrical safety. However, in order to ensure compatibility and communication between charging points, electricity distribution networks and electric vehicles, appropriate communication interfaces and data models also need to be standardized. Key players operating in the smart EV charging market include ABB (Sweden-Switzerland), Bosch Automotive Service Solutions Inc.(Germany), Schneider Electric (France), GreenFlux and Alfen N.V. (Netherlands), Virta (Finland), Driivz and Tesla (USA), etc. Key players operating in the global smart EV charger market are expanding their presence by engaging in merger & acquisition activities or by establishing new facilities. In terms of materials, the increasing demand for EV charging stations will directly impact the requirements of raw materials, such as stainless steel, copper, aluminium, polycarbonates, elastomers, and thermoplastics polyurethanes used for critical manufacturing components of EV charging stations, such as enclosures, cables, connectors, cable insulation and jacketing, and flexible conduits. For the electronic circuits and boards, which are present in almost every component of a smart EV charging station, silicon and germanium are two crucial raw materials. Furthermore, as the main actors to implement smart EV charging are the electric vehicles, the availability of raw materials to keep up with a smooth EVs production is critical.

Advanced Metering Infrastructure

The analysis of the Advanced Metering Infrastructure has focused mainly on smart meters, evaluating in particular the status of their roll-out and the main adopted technologies. Worldwide, there are currently 1.2 billion of installed smart meters: whereas USA, Canada, EU and Australia have been early adopters of this technology, Asian countries like China, Japan,and South Korea are seeing at the moment a huge increase in installations. The current sizeable investments in smart meters are predicted to further increase in the near future, with the Southern Asia region leading in forecast additional funding. At the European level, the status of the smart meter roll-out is quite heterogeneous: while some countries (Italy, Sweden, Finland, Estonia and Spain) have already completed 90% of the new installations, such percentage remains lower than 50% in other cases (Austria, Greece, UK) and in some other countries (Croatia, Hungary, Ireland, Poland, Romania, Belgium, Czech Republic, Germany, Lithuania, Slovakia) the smart meter roll-out had hardly been initiated. In terms of technologies, Narrow-Band Power Line Communications (NB-PLC) and RF-Mesh have been widely used, especially at early stages of smart meter deployment. More recently, other technologies such as Broadband PLC and Low-Power-Wide-Area Networks (LPWAN) are seeing a wider utilization, thanks to their longer range and lower power requirements.

Home Energy Management Systems

The Home Energy Management (HEM) market has been undergoing significant change. Smart meters, as energy managers, home area networks (HANs), and smart appliances never materialized at scale. Instead, other technologies behind the meter have grown in importance. Utilities have had to change their thinking about how they play in the HEM space in order to engage consumers. Utilities now emphasize advanced analytics, personalization, and targeted engagement with energy users. These features have become mainstream elements of HEM solutions. Europe is a region with a variety of aspects and the potential to drive up the demand for the home energy management systems in the region due to the significant production of smart meters in respective countries. The government of the UK has increased its focus on rolling out initiatives with the goal of reducing the emission of greenhouse gases by rapidly installing smart meters across the country. Moreover, Germany is also focused on following a resembling strategy as of the above-mentioned countries. Therefore, these factors are expected to boost the growth and demand for home energy management solutions in the regional market during the forecast period. The global home energy management systems market reached a value of US$ 2.1 Billion in 2021 and it is expected to reach US$ 6 Billion by 2027. Key players in this competitiveness landscape are Honeywell International, Inc., Nest Labs, Inc., Vivint, Inc., General Electric Company, Ecobee, Inc., Alarm.Com, Comcast Cable (Xfinity), Panasonic Corporation, Ecofactor, Inc. and Energyhub, Inc.

1 Introduction

1.1 Context

What if Europe increases the production and deployment of clean energy technologies needed to achieve the targets set in the latest energy policy? Would this be enough? Unfortunately, not. It doesn't come as a surprise that without a proper integration of these technologies into the system the targets will be missed even though a lot of effort has been put on generating clean energy.

To make this possible, a 'prepared grid' is needed that can connect in the most efficient manner the supply with the demand. Despite being apparently simple, this matching task has become quite complex due to two main changes in the energy production. First, Renewable Energy Sources (RES) are variable by nature, and this represents a big change when compared with conventional power plants, which are dispatchable, meaning that they can generally be ready to produce when most needed. Second, the power system has been conceived several decades ago with the objective of injecting electricity produced from big power plants into Transmission Networks (TN), down to Distribution Networks (DN) to finally deliver it to consumers. The decentralisation of RES puts such a system under pressure, given that generation can happen now directly at the distribution level. These two simple considerations, without entering more technical explanations about frequency, voltage, inertia, reactive power, etc., should convince the reader that it is not enough to install photovoltaic panels (PVs) on every rooftop to solve the energy problem. To adapt power grids to the changing paradigm of a RES-based decentralised system the concept of Smart Grids (SG) was introduced more than a decade ago. A smart grid can be imagined as a network that uses information technology to deliver electricity efficiently, reliably, and securely. Several names have been used to indicate SG in these years, "electricity with a brain," "the energy internet," or "the electronet." According to the National Institute of Standards and Technology (NIST) a SG is "a modernized grid that enables bidirectional flows of energy and uses two-way communication and control capabilities that will lead to an array of new functionalities and applications." The IEC, in its 2010 Smart Grid Standardization Roadmap (SMB Smart Grid Strategic Group, 2010) identified as smart technologies, those which improve the observability and/or the controllability of the power system. Hence, SG technologies help convert the power grid from a static infrastructure to be operated as designed, to a flexible, "living" infrastructure operated proactively. Back in 2010, some examples of the need of SG technologies integration were already listed in the IEC roadmap. China was promoting the development of SG because of the high load increase and the need to integrate renewable energy sources. The Indian power system being characterized by high inefficiency due to high losses (technical as well as very high non-technical losses) was developing and testing some potential SG solutions as smart metering (SM) and flexible power system operations. Countries with high portion of overhead lines in the distribution grid were observing an increase in the frequency of outages due to the worsening of weather conditions. The number of outages, outage duration and energy not delivered in time could in fact be reduced by using smart grid technologies.

Already in 2010, the SG was envisioned as the product of the following parts:

- Customers / Prosumers:
    - A smarter energy consumption, lying at the interface between distribution management and building automation, can enable demand response and provide services to the grid.
    - Local Production as a future driver of Smart Grid requirements.
    - Smart Homes, i.e. homes equipped with a home automation system for enhanced living conditions and a more efficient energy usage. Home automation systems can interconnect within a common network infrastructure a variety of control products for lighting, shutters and blinds, HVAC, appliances and other devices. This can enable energy-efficient, economical and reliable operation of homes with increased comfort.
    - Building Automation and Control System in buildings, including the instrumentation, control and management technology for all building structures, plants, outdoor facilities and other equipment capable of automation. All these products and services required for automatic control, including logic functions, controls, monitoring, optimization, operation, manual intervention and management, can improve the energy efficiency and the operation reliability of buildings.
- Bulk Generations:

  - Smart Generation based on power electronics can support the control of harmonics, fault ride-through and fluctuating generation from renewables. Moreover, it can deliver the additional flexibility required to displace conventional Fossil Power Plants and to deal with increased variability of renewables.

- Power Grid (Transmission and Distribution):
  - Substation Automation & Protection as the backbone for a secure transmission grid operation.
  - Power Quality and Power Monitoring Systems to supervise all activities and assets/electrical equipment of the grid. These systems can be used as "early warning systems" and are a fundamental tool to detect grid faults and analyse their causes.
  - The Energy Management System (EMS) as control centre for the Transmission Grid. Based on an open architecture to enable an easy IT integration, it can enable improved monitoring and control of the grid, optimizing its performance.
  - Decision Support Systems and System Integrity Protection Schemes to replace traditional protection devices in order to protect the primary equipment (e.g. transformers) from fatal fault currents, and more generally avoid instabilities and blackouts in the power systems. System Integrity Protection Schemes enhance the target of protection devices and protect the primary equipment (e.g. transformers) from fatal fault currents in such a way that uncontrollable chain reactions, initiated by protective actions, are avoided by limited load-shedding actions.
  - Power Electronics as the "actuators" of the power grid. Systems like HVDC and FACTS enable actual control of the power flow and can support a higher transport capacity without increasing short circuit power.
  - Asset Management Systems and Condition Monitoring devices to optimize the Operation Expenditures (OPEX) and Capital Expenditure (CAPEX) of new investments by Transmission System Operators (TSOs) and Distribution System Operators (DSOs).
  - Distribution Automation and Protection: the introduction of advanced distribution automation concepts enables automatic self-configuration features, reducing outage times to a minimum ("self-healing grids"). Another step further is the use of distributed energy resources to create self-contained cells ("MicroGrids"). MicroGrids can help to assure energy supply at low voltage levels even when the transmission grid has a blackout.
  - The Distribution Management System (DMS) is the counterpart to the EMS and is therefore the control centre for the distribution grid. In countries where outages are a frequent problem, the Outage Management System (OMS) is an important component of the DMS. Other important features include fault location and interfaces to Geographic Information Systems.

- Communication:
  - Communication is the backbone of Smart Grid. Effective exchange of information on a syntactic and semantic level enables advanced monitoring features and smart control actions in the grid.
  - With increased exchange of data in the Smart Grid for observability and controllability, it is crucial to ensure the security of the transmitted information, to avoid the possibility of malicious actions or limit their potential negative impact on the physical components of the system.

1.2 Scope

This report addresses the Clean Energy Technology Observatory Sub-Task A.2 in relation to the following smart grid relevant topics:

- *Digital infrastructure for smart energy system (enabling technologies and infrastructures facilitating data access and data exchange across the energy system including smart meters, home energy management systems, smart charging);*
- *Transmission and Distribution related technologies (including HVDC, Superconductors, PE, DC technologies);*

Taking into account the strict technological and economical interactions between these areas in the wider context of the smart grids, the relevant findings have been presented in a unique report. Moreover, given the broad set of considered technologies, a thorough assessment is out-of-scope here. The focus for this CETO exercise has been put on five enabling technologies:

- *Transmission innovation (TI)*
- *Grid-Scale Storage Services (GSSS)*
- *Electric vehicles smart charging (EVSC)*
- *Advanced meter infrastructure (AMI)*
- *Home energy management systems (HEMS)*

Transmission innovation includes all those technologies that are (or planned to be) put in place at the transmission level to enhance the performances and the operation efficiency of this important section of the power grid. One of the major difficulties encountered when discussing innovation in TN has been whether makes sense to consider conventional grid expansion as a smart grid approach. Despite cable reinforcing does not sound smart nor are new, adequate TN upgrades required to integrate increased levels of RES production into the current energy system. Being these kinds of interventions cost intensive, we have finally decided to include them in this discussion given also the impact that they will have on the request of raw materials on which the paved energy transition currently relies.

As mentioned, the intermittent nature of RES represents one of the biggest challenges for the power system and for the whole system as a whole. In this sense, storage represents a game-changing resource that can support the efficient and robust operation and planning of the new electricity grids. Apart from mitigating the uncertainty introduced from RES, storage grid services can help reduce cost for transmission network expansion and support the regulation of the electricity grid at different levels (e.g. voltage or frequency regulation) and timescales (from milliseconds to hours).

Similar improvements can be obtained at the distribution grid level by leveraging on smart charging off electric vehicles. Smart charging optimises the dispersion of power and leads to considerable savings for grid operators, mainly DSOs, charge point operators, charge point owners and EV drivers. Smart charging can offer new revenue models by monetising the flexibility offered by EVs charging behaviour. An acceleration in smart EV deployment by 2030 will not only help to efficiently integrate the increasing EVs charge power demand with the electricity grid, but it can also bring in significant financial benefits to EV users as well.

Data exchange is at the core of many, if not all, the functionalities offered by the smart grid integration. Advanced metering infrastructure make communication possible, for instance, by permitting data exchange between consumers (or prosumers) and energy service providers. This simple mechanism enables end-users to be active members of the smart grid, by adjusting consumptions to avoid energy peaks hence helping grid operators to make the most out of the grid potential.

To make this possible, home energy management systems are a key tool for end-users to monitor and control different devices and appliances in a home. HEMS provide communication between different devices which may operate through a different communication technology, which require higher levels of interoperability.

In the following sections, each of these five enabling technologies is described with a special focus on technology development trends (and technology readiness level), value chain and market development.

1.3 Methodology and Data Sources

Given the peculiarity of the analysed technologies and the consequent lack of consolidated data, the objective has been to provide and discuss the potential role that they are planned to have in the energy transition market, rather than present a thorough assessment of the same. The analysis also takes account of on-going JRC studies on clean energy technology competitiveness (CINDECS) and on research and innovation strategies being developed for the SET-Plan and the Clean energy Technology partnership.

Data sources include:

- *Technical reports by public institutions and private entities*

- *Scientific review papers on technology state-of the-art*
- *ENTSO-E energy scenarios*
- *CORDIS database for H2020 and HE projects*
- *Contacts with relevant stakeholders*

2 Transmission Network Innovation

The integration in the European energy system of Clean Energy Technologies (onshore and offshore wind energy, solar photovoltaics, renewable fuels, renewable hydrogen, batteries, heat pumps for building applications) will require a 'prepared' grid.

Different options can be considered depending on the size and on the electrical characteristic of each of these technologies. Wind energy (onshore and offshore) and large storage systems are usually connected to Transmission Networks. Solar photovoltaics, batteries and heat pumps are connected to Distribution Networks.

An inadequate dimensioning of the network capacity can lead to a curtailment of the energy produced by the clean energy technologies and, the consequent prices gap between cross border zones (even within the same MS).

The TYNDP (Ten Years Network Development Plan) aims to properly identify those interconnection projects which are key to integrate the massive amount of renewable production into the energy system.

Despite being a fundamental term in the integration equation, network expansion is not the only one. New smart technologies need to be deployed at the transmission level that increase current performances and make the whole system more resilient.

2.1 Technology Development and Trends

The European Green Deal, with the aim of making Europe the first climate-neutral continent by 2050, represents a profound societal transition involving a massive deployment of large-scale renewable sources, a set of innovative low carbon technologies, a deeper electrification but also a new smart sector integration approach. To achieve these ambitions, the power grid has a key role to play by enabling a cleaner energy integration across the economy and by making electricity supply reliable and secure even under worsened climate conditions. A timely development of grid infrastructure is key to the EU recovery and the integration of renewable energies, including the respective potential for job and value creation. Six key drivers, have been identified from ENTSO-E, the Transmission System Operator association, that will shape the European power system towards and beyond 2030: (ENTSO-E, 2021)

1. Market design will need to evolve to cope with future requirements and challenges.

2. Unleashing the potential of distributed flexibilities in the whole network will require a shift of paradigms, supported by significant changes in the power system.

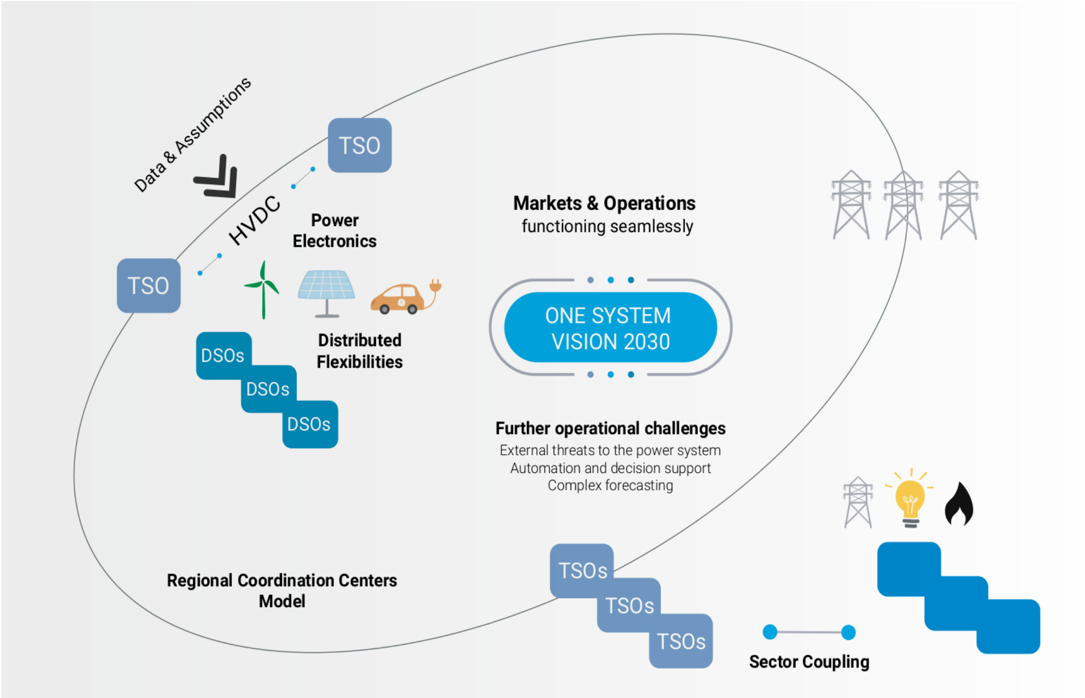
3. A 'One System View' will be essential to ensure efficient energy system integration.

4. Efficient development of offshore renewable sources and the offshore grid will require a holistic view across time, space and sectors, both onshore and offshore.

5. The migration from traditional AC based to Hybrid AC/DC networks will pose new challenges and needs to be supported by an accelerated pace of innovation.

6. The governance of this pan-European system of systems will involve multiple stakeholders.

Figure 1: ENTSO-E's System of Systems Vision for the European Energy Transition (2021).



Source: ENTSO-E Vision Week

In this context, TSOs will play a key facilitation role together with Distribution System Operators (DSOs), supported by Regional Coordination Centres and in dialogue with stakeholders.

The transformation of the power system will rely on both increased cross-border cooperation and stronger adaptation to local needs. This will entail a shift in the tasks of TSOs. Although traditional CAPEX-intensive investments towards expanding and maintaining the grid infrastructure will still predominate, TSOs will face a number of new challenges for which riskier, more OPEX-oriented activities must be adequately considered.

To meet the European energy policy goals and the targets of the EU Recovery Plan, the TYNDP[1] for year 2020 highlighted a total CAPEX of EUR 135 billion for projects.[2] Looking at the commissioning year, the median value corresponds to 2027, but there are some projects which can reach up to 2040. Projects wanting to obtain the status of projects of common interest (PCIs) shall be part of the latest available TYNDP to be eligible as PCI, according to Regulation (EU) 347/2013 Annex II 2 (3).[3]

Over the last ten years, TYNDP projects have strengthened many new cross-border interconnections helping maintain adequacy and exchanging between countries especially during stressful times. For instance, electricity exchanges in the ENTSO-E area have increased from 347 TWh in 2010 to 435 TWh in 2018.

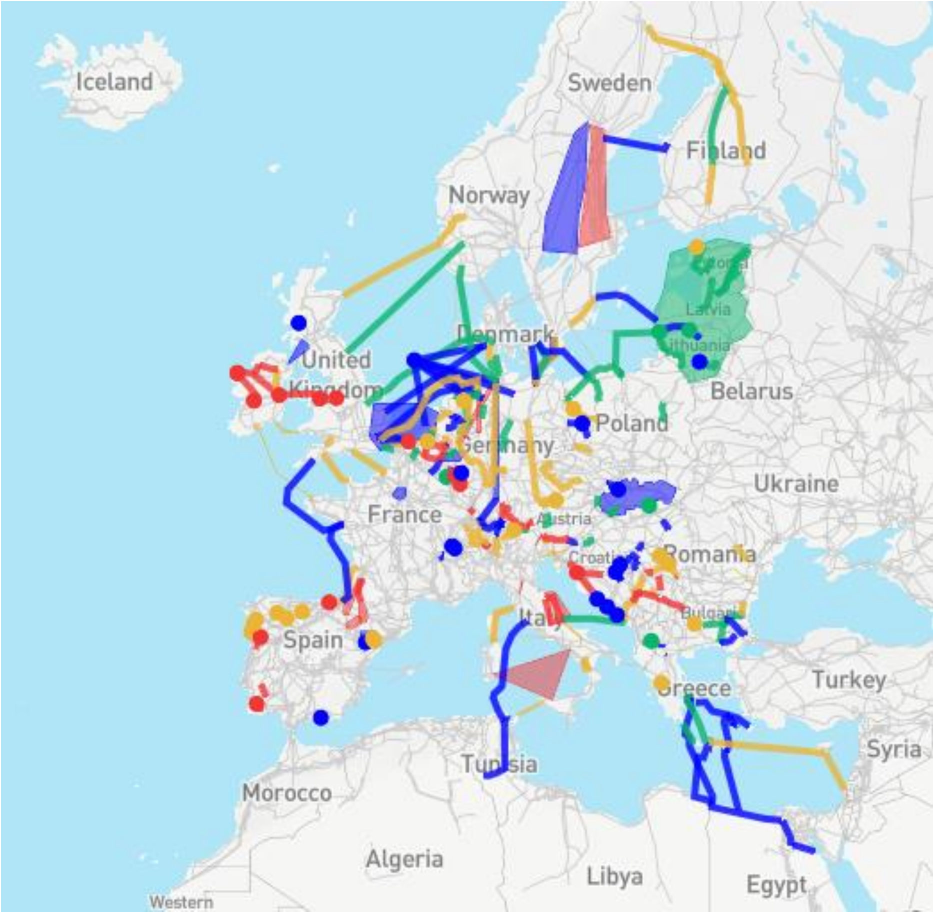
The construction and commissioning of projects projected for the next 10 years could ensure the creation of 1.7 million jobs across Member States. (ENTSO-E, 2021).

[1] The TYNDP is supported by stakeholders who contribute actively to its elaboration via open workshops, public consultations, discussions and meetings.

[2] This includes only transmission projects which amount to a total of 154.

[3] The PCI selection is a process separate from the TYNDP process, under the responsibility of the EC Regional Groups led by the European Commission.

Figure 2: Map of all the TYNDP projects



Source: (ENTSO-E, 2022).

However, one of the biggest barrier to the smooth deployment of these projects is the delay due to "external factors". In particular, those referring to the permitting procedures and the intensive stakeholder dialogue to address public and private concerns. Most of the case studies performed have confirmed this fact: public acceptance and permitting processes are considered the main reasons for project implementation delays and cost increase, meaning that projects were re-scheduled or delayed.

2.1.1 R&D Solutions and Strategy

As mentioned, network expansion measures and upgrades need to be complemented with emerging technological solutions. Currently the Technopedia webpage[4] of ENTSO-E reports 65 different technologies with a different Technology Readiness Level (TRL) that TSOs are considering for further development and integration into transmission grids. A subset of the most mature ones (those with TRL between 8 and 9) is briefly discussed in the following.

High Temperature Superconductor (HTS) Cables are made of special superconducting materials that are cooled down to extremely low temperatures (e. g. – 180 °C or even more) using liquid nitrogen (or liquid helium for MgB2). This allows to activate the superconductivity phenomenon (very low resistance) which provides five times the current of a conventional cable system with the same outer dimensions. Moreover, contrary to the traditional cables, do not emit any heat to the environment. Such technology requires special cable joints and specific cable termination for extreme temperature differences and permanent cooling for keeping cryostat. HTS cables offer several advantages compared to conventional cables, depending on the case study:

[4] ENTSO-E Technopedia - ENTSO-E (entsoe.eu)

1. Easier and shorter installation time.

2. Low impact on the environment.

3. High Power carrying capacity.

From an implementation point of view, the Shingal Project in South Korea is the first-of-a-kind commercial project and has achieved a TRL of 8. In particular, several projects have been discussed in Jeju (South Korea) with 154 kV and Long Island (US) with 138 kV. The operation of a full-scale 320 kV MgB2 monopole cable system that can transfer up to 3.2 GW was demonstrated (demonstration nb. 5 of the project) in Europe in the BEST PATHS project in 2017.

Static Synchronous Compensator (STATCOM) are fast-acting devices capable of providing or absorbing reactive current thereby regulating the voltage at the point of connection to a power grid. The STATCOM design and fast response makes the technology very convenient for maintaining voltage during network faults, enhancing short term voltage stability. With a TRL equal to 8 (System ready for full-scale deployment if classical design and control is used), a first German hybrid STATCOM facility is in operation since 2018 to dynamically support the voltage and enhance the power quality at the 380 kV level.

Voltage Source Converters (VSC) are self-commutated converters to connect HVAC and HVDC systems using devices suitable for high power electronic applications. This allows for independent rapid control of both active and reactive power and black start capability. The VSC technology provides several technical advantages, such as resilience to commutation failure, ancillary services and reactive power control (and consequently voltage control).

VSC-HVDC is best suited to interconnecting remote generation facilities (e.g. offshore wind far away from shore, typically > 80 km) to the main power grid; performing a black start to start-up connected offshore wind farms or re-energising network sections; and contributing to power system and voltage stability thanks to its fast reactive power flow and voltage control at its terminals. It is expected to support Multi-Terminal HVDC (MTDC) applications, which form the backbone of potential offshore grids (such as the one in the North Sea) implementation.

Adaptive Protection Technology is used to tackle the growing complexity in operating power systems as the increasing shares of power electronic connected generating units, a lack of short circuit current injection to correctly detect faults, and increased harmonics that can falsely trigger traditional protection relays. Adaptive protection schemes result from the application of microprocessors in the area of protective relays and are growing in importance in the electrical power systems. They enable grid operators to have flexible protection schemes in response to changes in the power system. Wide Area Monitoring System (WAMS) is an enabling technology based on an information facility with monitoring purposes to improve situational awareness and visibility within power systems. Based on Phasor Measurements Units (PMUs), WAMS allow monitoring transmission system conditions over large areas in view of detecting and further counteracting grid instabilities. As mentioned above, such an early warning system contributes to increasing system reliability and can be considered as an extension and enabler of an adaptive protection system. In US, the National Electric Reliability Council has shown in an ex-post study that the malfunctioning of relays has contributed to 70% of US black-outs. Adaptive protection technologies represent therefore a potential facilitator of the reliability, resilience and security of the future power system.

Phase Shifting Transformers are specialised type of transformers, typically used to control the flow of active power on three-phase electric transmission networks. It is a simple, robust and reliable technology. Preventive and curative control strategies are implemented for power flow controllability. In the preventive mode, the permanent phase shift allows redistributing the power flows and relieves network stresses in the event of line outage. In the curative mode, the phase shift is small (sometimes down to zero) in normal operation, but it is automatically controlled to reduce the power flow on the overloaded lines and to avoid a tripping out. The active redirection of power flows allows exploiting lines closer to their thermal limits.

Circuit Breakers (CB) enable the power flow to be controlled by connecting or disconnecting components from HV grid and switching off disturbances. They are essential for a reliable operation transmission system. Due to very high switching performance requirements in the EHV grid, only SF6 gas is used. The latter has very high global warming potential. Hence, many new developments of SF6 free CB in HV networks have recently been observed. Nevertheless, there are no examples in EHV yet.

Digital fault recorder (DFR) are intelligent electronic devices (IED) that sample binary data during power system transients, using communications to retrieve fault, disturbance and sequence of event records, captured by protection relays. When triggered by conditions detected on the power system, data on harmonics, frequency and voltage levels are stored in a digital format. The growing need for reliable power system operation, along with the growing demand for digital substation, are expected to drive the digital fault recorder market in the future. Asia Pacific accounted for the largest share of the global DFR Market in 2017.

The Dynamic Line Rating (DLR) of overhead lines (OHL) uses the fact that their ampacity, (that is the current they can deliver) depends on the environmental conditions. They are commonly designed by taking into account extreme summer weather conditions. As less severe weather conditions exist for the remaining of the year, the ampacity of the existing lines can be significantly increased (up to 200 %). The major task thereby is to measure the present conditions and estimate future environmental ones, calculate the current carrying capacity, integrate these results to dispatch centre processes, and consider adequate security margins. The highest potential for DLR is observed in areas of high wind RES, as convective cooling and loading of overhead lines are strongly coupled. An increase in ampacity supports grid operators in making more efficient use of existing grid assets and avoiding congestion restrictions.

In a nutshell, the subset of technologies presented so far aim at making the transmission system more efficient, reliable and controllable. In terms of Research and Development, a broader picture is offered by the Research Development and Innovation (RDI) strategy set by the TSOs in the ENTSO-E association. The strategy lays out thirteen project concepts to be initiated by TSOs in collaboration with key stakeholders and supported by policy makers and regulatory authorities in the coming years. (ENTSO-E, 2021).

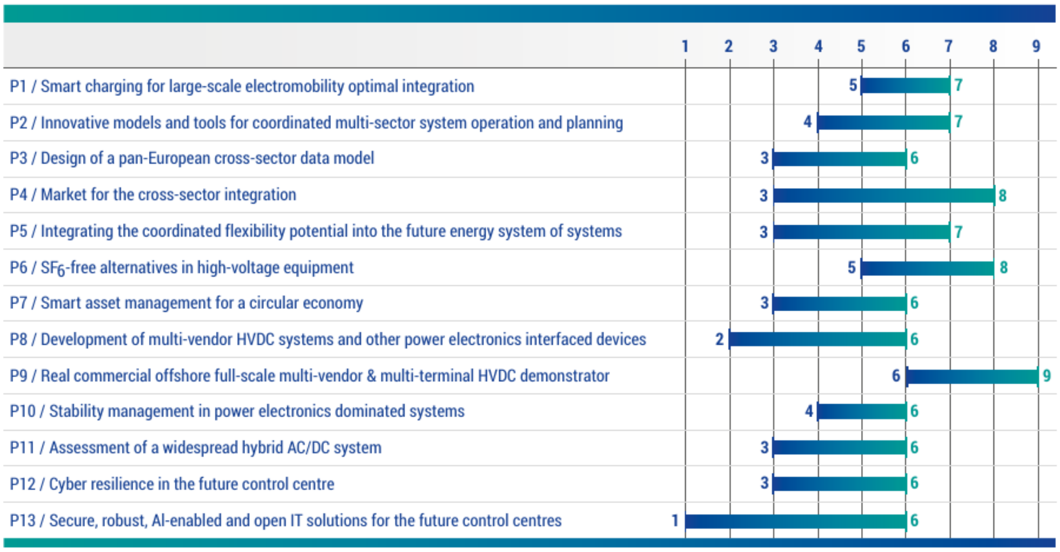
The RDI strategy relies on six flagship areas as depicted in ***Figure 3***:

Figure 3: ENTSO-E RDI clusterisation into flagship areas (2021)

Source: (ENTSO-E, 2021)

The projects are distributed across the 6 areas with a higher presence in the cross-sector integration area. All thirteen proposed project concepts have a clear, specific system challenge focus. They aim to increase their TRL and the ability to integrate the coming solutions in TSO core businesses. The majority of projects shows a TRL range between 3 and 6, corresponding to proof of concept establishments and prototype system verification, respectively. Only for a restricted number of them, higher TRL levels are reached, where the system has been integrated through a pilot demonstration (TRL 7), or incorporated in commercial design (TRL 8) or it is considered ready for fully-scale deployment (TRL 9) (Figure 4).

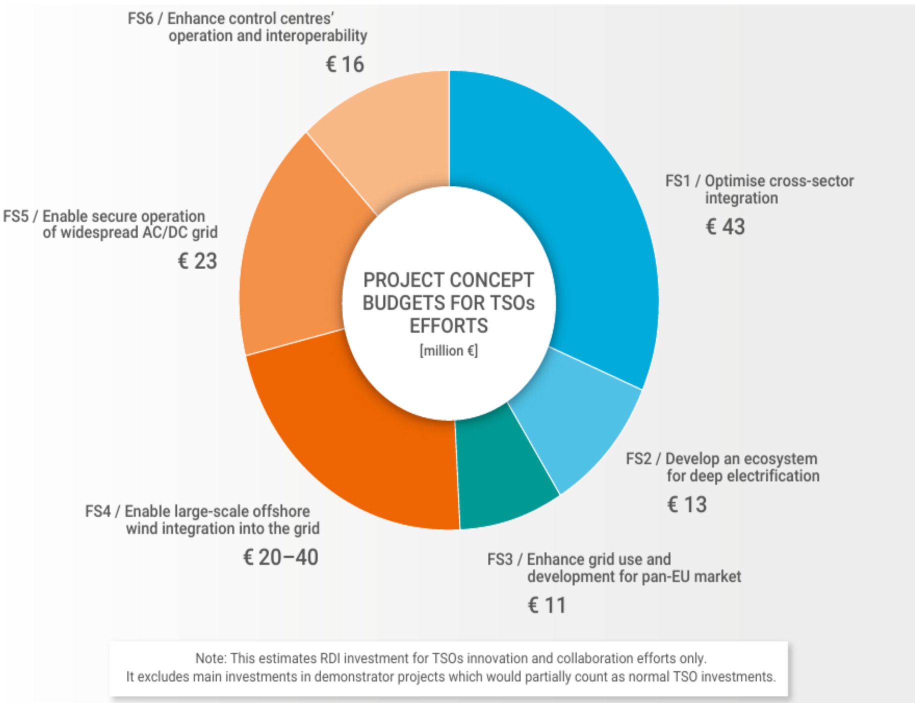
Figure 4: ENTSO-E RDI projects list with the TRL range.



Source: (ENTSO-E, 2021)

Looking at the planned budget for the listed projects, the two areas which account for the larger amount of investments are: that aiming at optimising cross-sector integration together with the integration of large scale offshore wind integration. Together these two areas need investments for EUR 63 – 83 m (Figure 5). Investments into cybersecurity and interoperability improvements have also been planned. It is worth mentioning that the new RDI strategy is aligned to previous RDI roadmaps and, builds on the outcomes of several EU-funded-projects under the Horizon 2020 umbrella. The H2020 projects on which the strategy has been built are: MIGRATE, OneNet, INTERRFACE, OSMOSE, PROMOTION, FARCROSS, FutureFlow, EU-SysFlex, CROSSBOW, CoordiNet, TRINITY, FLEXITRANSTORE, FlexPlan, INCIT-EV, TDX-ASSIST, SmartNet, SDN-microSENSE. The majority of them was focused on flagships 2, 3 and 6.

Figure 5: RDI TSOs investments by flagship areas



Source: (ENTSO-E, 2021)

2.2 Value Chains

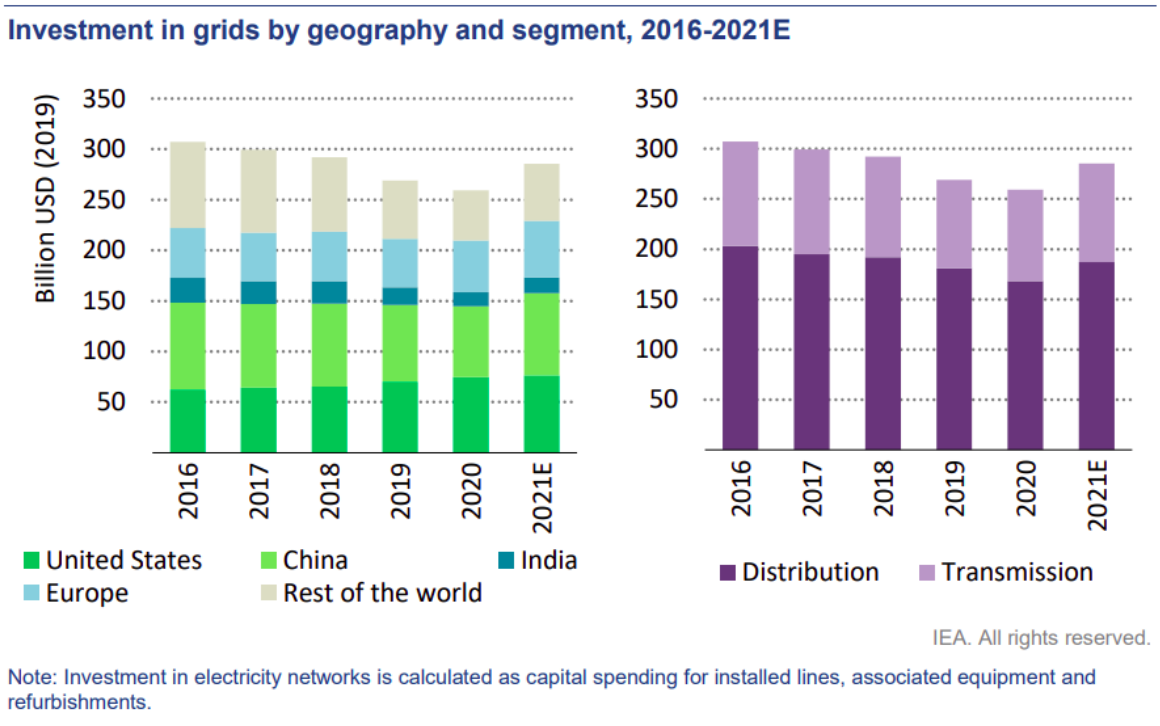
Providing the value chain for a complex system as the transmission grid it is not an easy task due to its interdependence with other branches of the electricity system. An extensive research in the power analysis and economics literature has shown that currently there is a lack of studies on this matter.

From a practical perspective, deploying both offshore wind generation and the necessary infrastructure is estimated to lead to economic benefits between EUR 1.4 bn and 1.6 bn annually (total CAPEX of EUR 65 bn), additional RES integration between 13.5 TWh and 19.2 TWh per year and a reduction of CO2 emissions between 12,260 Mt and 15,900 Mt by 2030. One of the major risks related to the missing grid capacity is that of creating congestions in the grid, which are often resolved via expensive and CO2-emission intensive re-dispatch measures. This might clearly undermine the achievements of climate targets.

2.3 Markets, Trade and Resources

According to the IEA (IEA, World Energy Investment 2022, 2022), after declining for the fourth consecutive year in 2020, spending on electricity grids is expected to go up substantially starting in 2021. Most of the 2020 decline stemmed from a reduction in China and several EMDEs, which more than outweighed increases in the United States and Europe (Figure 6). In China, the majority of the drop came in the distribution sector, as targets for rural power grid expansion had been met and focus shifted to transmission, which represents a smaller share of grid investments. However, there are large expansion plans expected for 2021 – especially in China and Europe – which are set likely change this trend.

Figure 6: Global investments on power grids.



Source: (IEA, World Energy Investment 2022, 2022).

In Europe, for example, the 2021-30 grid expansion plans provide the foundation for increased investment, supported by the recovery plans. In the United States, the proposed American Jobs Plan includes measures to build a more resilient electricity transmission system as part of the drive for carbon-free electricity by 2035. This includes the creation of a targeted investment tax credit and efforts to better leverage existing rights-of-way along roads and railways for high-voltage lines. These kinds of measures underline the broader importance of policies and regulation in facilitating network investments, by incentivising connections to the grid, especially for new wind and solar projects; simplifying procedures to make public land available for electricity infrastructure; speeding up response times; or rethinking authorisation procedures for minor categories of projects.

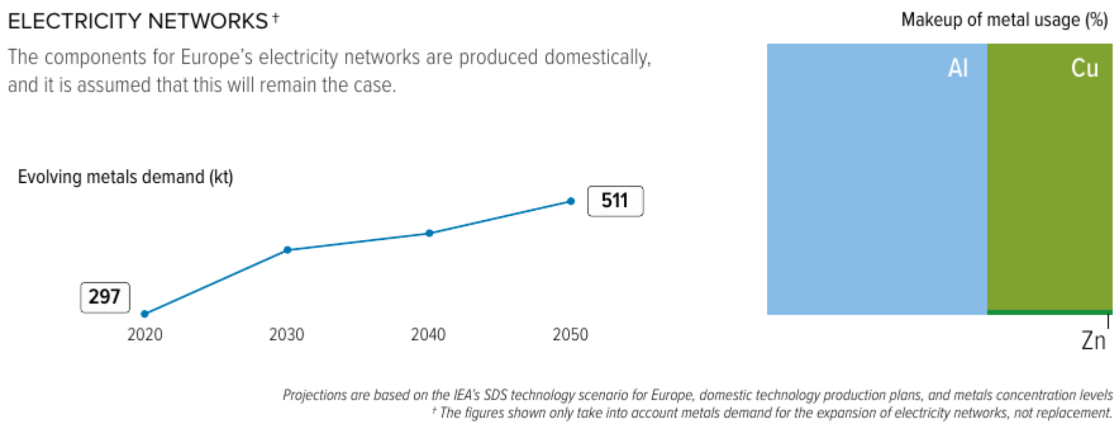
Market players like Prysmian Group, Nexans, NKT are among the leading players in the global high voltage cables market. Several other players are involved in LV, MV and HV Cable Installation, Jointing, Substation and Electrical Equipment, as reported in Figure 7.

Figure 7: Key players in the transmission sector.

Source: (Derrick, 2022).

As known, electricity network expansion requires significant volumes of copper and aluminium (cables, lines and transformers). Moreover an increasing number of chips (silicon) will be needed to make the whole system more digitalised. An assessment of the resources needed in the sector can be gained from the KU Leuven analysis on the clean energy request of materials. An emerging insight is that an important demand for energy transition metals demand (responsible for 35-45% of the total amount of copper and aluminium) comes from electricity networks and solar photovoltaic production.

Figure 8: Projection of metals demand for electricity networks



Source: (Leuven, 2022)

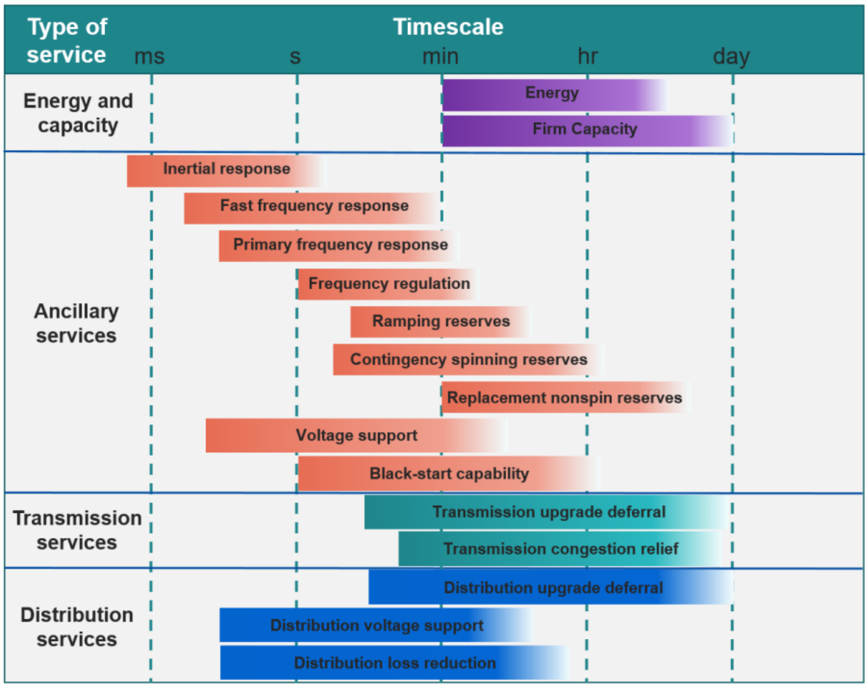
In a base case, total copper mine output could grow from 20.5 Mt in 2020 to 23-24 Mt in 2030, and in a full potential case, just over 30 Mt. Chile and Peru are the major producing countries, and this is expected to remain by 2030. Refining copper capacity is expected to grow from 25 Mt in 2020 to 29 Mt in 2024. China is the major producer of refined metal. Chile, Japan, and the DRC are the top 3 non-China producers. There are no major changes expected in this supply profile. Note that in terms of materials needs, silicon will be also relevant given its importance in the semiconductor and power electronic devices.

3 Grid-Scale Storage Services

Storage represents a key technology that can facilitate the decarbonisation of the electricity grid and support the green transition of the power sector (European Commission, 2019). As power systems move from their traditional centralized structure relying on fossil fuels to a new dynamic and distributed paradigm employing renewable generation and digitalized assets, it is necessary to adopt the right mix of new technologies to drive this transition in a cost-effective and reliable way. In this regard, storage represents a game-changing resource that can support the efficient and robust operation and planning of the new electricity grids. The flexibility of storage can be used to accommodate the increasing levels of generation variability and uncertainty introduced by renewable sources, reduce the costs for network expansions, and support the regulation of the electricity grid at different levels (e.g. voltage or frequency regulation) and timescales (from milliseconds to hours). This section will focus on the role of electro-chemical storage and in particular of lithium-ion (Li-Ion) batteries in supporting the operation and expansion of the power systems. As a result of their cost-efficiency, technical characteristics and spillover effects from electromobility, Li-Ion batteries are currently the most rapidly growing among the emerging storage technologies for power system and smart grid applications (IEA, 2020). The interested reader can find a detailed discussion on lithium-ion batteries in the CETO report on batteries, which also includes information on recent developments concerning flow and sodium-ion storage. Conversely, in this section, the specific role of lithium-ion batteries for system integration and provision of grid services will be discussed in detail. Building up on the analysis presented here, the scope of future issues of the report will be expanded to also include alternative storage technologies.

A summary of the main grid services that storage can provide in the power system, classified by type of service and timescale, is presented in Figure 9.

Figure 9: Classification of storage grid services



Source: JRC elaboration from (NREL, 2021)

3.1 Technology Development and Trends

3.1.1 Technology Readiness

This section describes in detail the different type of storage grid services, assessing their current maturity and penetration in the electricity sector. The main barriers for a wider and more effective use of the storage resources are discussed on a case by case basis.

Energy and firm capacity

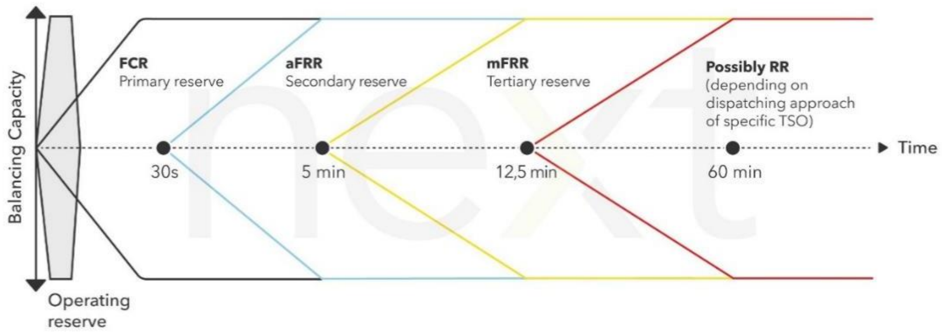
Storage assets can be used to support system adequacy by providing additional energy during exceptional peak loading periods and contingency events. Ad hoc mechanisms for capacity remuneration have been introduced in recent years in many European countries, for example in the form of capacity auctions (Shittekatte & Meeus, 2021). However, as reported by the latest Market Monitoring Report by ACER, the capacity contribution by storage in the nine analysed member states with capacity mechanisms already in place has been lower than 1% in both 2020 and 2021, with the main share of capacity being provided by traditional resources.

The limited capacity provision by storage batteries is mostly due to the fact that they can provide their rated power for only limited amounts of time (generally no more than 3-4 hours). As a result, they must be de-rated to participate to the capacity remuneration mechanisms that are currently in place, which require the provision of the capacity support over a longer time interval of several hours. For example, in the case of a capacity mechanism that requires energy provision for 8 hours, a storage device with a capacity of 4 hours (it takes 4 hours to fully charge or discharge at full power) will have to be derated by 50%. In other words, it will be possible to contract only 50% of its rated power. The introduction of ad hoc mechanisms that are tailored for storage and consider its intrinsic energy limitations could facilitate a larger capacity support by storage.

Ancillary services - Frequency response

Storage can provide a substantial support in the day-to-day operation of the electricity grid over a wider array of different aspects. Currently, one of the most relevant contributions by storage regards frequency regulation, i.e. the set of services that maintain the balance between generation and demand in the electricity grid and correct variations of the network frequency from its nominal value. A classification of the different services according to their activation time and duration, as envisaged by ENTSO-E, is reported in Figure 10.

Figure 10: Balancing services classification by ENTSO-E



Source: (Next, 2022).

Within this framework, the primary reserve or Frequency Containment Reserve (FCR) represents the fastest service and constitute the energy reserve that is activated in the first few seconds to stabilize a frequency imbalance. Given their low response time and high ramping capabilities, storage assets are particularly suitable for the provision of this service (Stein K, 2018) and their market share has steadily increased in the last few years as a result of favourable FCR prices. As of the end of 2020, 700 MW of electro-chemical batteries have been built to participate to the common FCR platform in Western Europe, making up about 50% of the aggregate 1.4 GW market (Forsyth, 2022). Similar trends can also be found in the United States (EIA, 2021) and in China (Dudley, 2020). The providers of FCR are generally remunerated with daily and hourly contract types, considering a time resolution between 15 and 60 minutes. Countries like Austria, Slovenia and Germany consider a resolution of 15 minutes, with an average remuneration of 5 €/MW per 15 minutes in 2022. Conversely, the FCR service in countries like Greece and France envisages a 30 minutes resolution and in 2021 has been remunerated at an average price of 8.7 €/MW per 30 min in France and 11.3 € per 30 min in Greece (Energy Transition Expertise Centre, 2022). In parallel to the decrease of FCR revenues, the framework for storage participation to secondary reserve or automatic Frequency Restoration Reserve (aFRR) is becoming more favourable. The deployment of the Europen PICASSO platform for aFRR procurement will lead to the revision of the aFRR market rules that currently, in most countries, do not envisage storage participation. If this process continues as expected, storage could provide up to a third of the total aFRR volumes in Western Europe. Positive signals come in this regard from Belgium, where the secondary reserve provision is already open to storage participation and more than 30MW of storage assets participate to the national aFRR market (Cameron, 2022).

Similar opportunities could also arise for storage in the provision of tertiary reserve or manual Frequency Restoration Reserve (mFRR) and replacement reserve (RR), as the new European platforms for the procurement of these services (MARI and TERRE, respectively) are currently under development. However, the potential participation of storage remains uncertain, as the longer time scales of this services do not align well with the limited energy capabilities of the storage assets.

Outside of the traditional framework for frequency services presented in Figure 10, new opportunities for storage are arising with the introduction of "fast" or "ultra-fast" frequency response services that require response times below 30 seconds, in order to counterbalance the reduced system inertia and the increased frequency transients caused by a larger penetration of asynchronous renewable generation. These services are particularly suitable for storage assets, which generally have response times in the order of milliseconds. An example in such sense is the introduction of the Fast Reserve service in Italy (Terna, 2020), where the TSO has recently procured from storage assets 250 MW of frequency response with a required activation period of 1 second. The service, structured according to 5-year contracts, is remunerated between 2.1 and 6.1 €/MW/h. A Fast Frequency Response service is also in place in Ireland (Eirgrid, 2022), where the response must be provided within 2 seconds, with a premium payment for faster delivery.

Transmission Upgrade Deferral and Congestion Relief

Congestion issues are becoming more and more relevant at the transmission level, as a result of the increasing penetration of intermittent renewable source and a growing electricity demand. Storage assets can be installed at critical points of the transmission grid to alleviate these issues while avoiding costly expansion investments of the infrastructure (IRENA, Innovation Landscape for a Renewable-Powered Future: Solutions to Integrate Variable Renewables, 2019). The economic convenience of these solutions remains to be confirmed, since this type of storage use would be necessary only for a limited amount of times over the year. As a result, most of the preliminary analyses for commercial business cases tend to include the transmission upgrade deferral in a paradigm of revenue stacking, considering a storage asset that performs other services at the same time (Marnell, Obi, & Bass, 2019). Currently, different pilot projects are being developed by the grid operators to test the validity of this storage application. The German Federal Network Energy has announced two ambitious grid booster projects with an aggregate storage power of 450 MW to reduce congestion management costs (Global Transmission Report, 2022). The Italian TSO Terna has already installed a 35MW battery to alleviate congestion on a section of its 150kV grid in the South of Italy (IRENA, Innovation Landscape for a Renewable-Powered Future: Solutions to Integrate Variable Renewables, 2019). Similarly, the French TSO RTE is developing the project Ringo, with the planned installation of three battery systems (about 10-12 MW each) to increase the integration of renewable energy and optimize power flow on the network.

Distribution Upgrade Deferral

As a result of increasing renewable penetration and electrification of transport, the grid congestion issues mentioned in the previous paragraph for the transmission infrastructure are also relevant at the distribution level. Expansions of the distribution infrastructure, which entail the replacements of transformers and MV feeder lines are generally quite capital-intensive. For this reason, storage assets are being evaluated as an alternative option that can avoid grid interventions through a charge/discharge process that injects energy at peak demand times and absorbs energy when production from renewables is higher. Many projects of this kind are being developed in the US, including a 3MW battery in the Hudson's Valley (Orange & Rockland, 2021), a 2 MW/8 MWh battery in Arizona (Fluence, 2018) and a 2.5 MW/3.9 MWh battery in Southern California (Energy Storage North America, 2018). These investments are carried out by vertically integrated utilities that directly benefits from the cascading positive impacts of the storage assets on the distribution network and can avoid costly infrastructure expansion. In Europe, the Clean Energy Package has recognized a role for DSOs in procuring flexibility to reduce CAPEX-heavy network investments, acknowledging the current limitations in electricity markets and grid regulations for flexibility procurement. On the same line, the recently adopted Directive on Common Rules for the Internal Market for Electricity (European Parliament, 2019) states that "DSOs should be enabled, and provided with incentives, to use services from DERs such as demand response and energy storage".

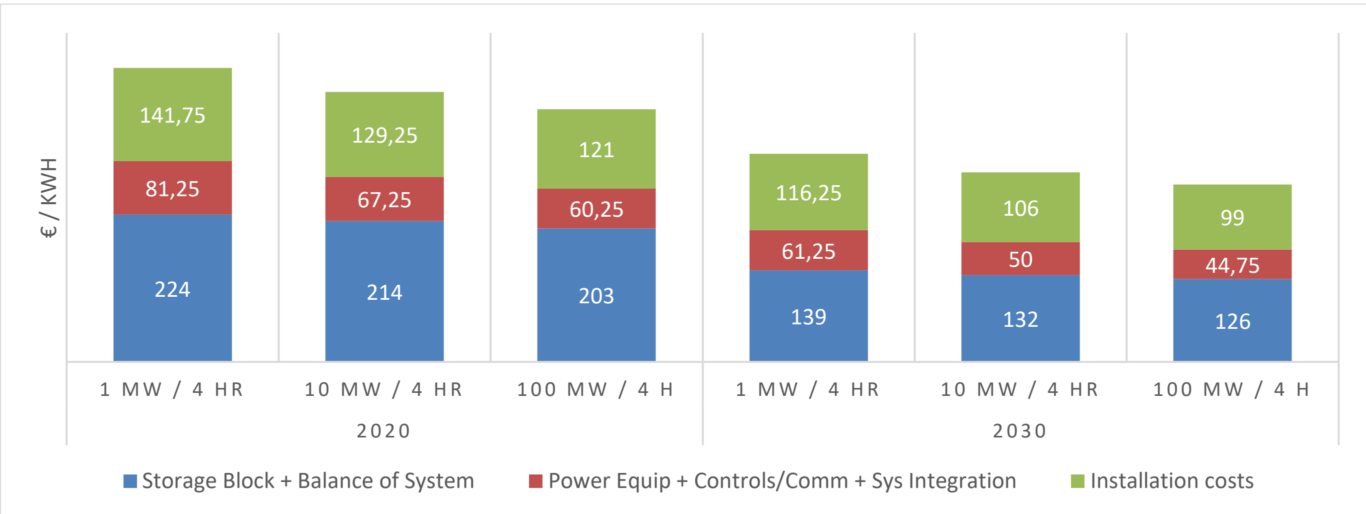
Voltage Support

Storage assets can represent an important resource for the voltage regulation of the grid. As the penetration of renewable generation at medium and low voltage increases, the regulating devices installed at the substations may not always be effective. Therefore, storage can represent an alternative source of reactive power for voltage support that can be installed at different critical points of the network. This possibility has been investigated quite extensively in the scientific literature (Stecca, Ramirez Elizondo, Batista Soeiro, Bauer, & Palensky, 2020) and is currently being implemented in some pilot projects like the Interflex project in the Netherlands (Bhattacharyya, Van Cuijk, & Fonteijn, 2019). Moreover, the requirement for distributed generation to follow voltage droop curves and therefore contribute to voltage regulation is being extended also to storage at the grid code level in many countries, including for example Italy (CEI, 2022) and Germany (VDE, 2018).

3.1.2 Costs and Revenues

In terms of cost analysis for grid storage projects, it is important to highlight that the cost of the fundamental storage components (i.e. battery cells) constitutes only a part, albeit very relevant, of the overall asset cost. One of the most detailed studies on this point has been conducted by the US Department of Energy (US Department of Energy, 2020). Figure 11 shows the current and projected unitary cost breakdown (expressed in $/kWh) of battery projects of different sizes, calculated according to the information in (US Department of Energy, 2020). If one considers the case, of a battery asset of medium size (10MW) which requires 4hr to complete a full charge or discharge, it can be seen that the current cost of the storage block (including battery modules/racks and battery management system) and of the balance of system, which includes the costs for the containers, cabling/ switchgear and heating/ventilation corresponds to about 52% of the total. The remaining half of the total costs are associated to many different other factors, which range from the power equipment (converters, breakers, communication interface, etc.) to the project installation (engineering and construction, project development, grid integration, etc.). This is a relevant element to consider when analysing the cost reduction expected over the next few years. While the reduction of the battery cost by 2030 is expected to be in the order of -40%, the other cost components will see smaller improvements. As a result, the overall costs of storage grid assets are estimated to decrease by about -30% in the next 8-10 years.

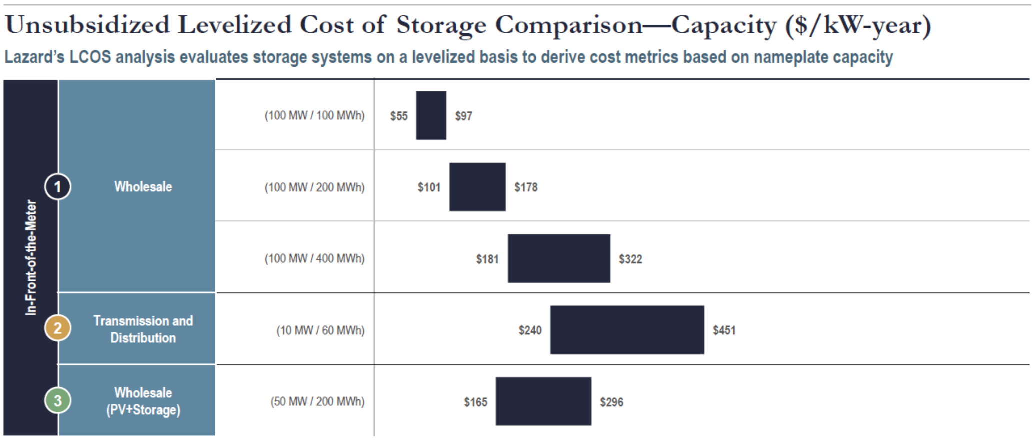
Figure 11: Unitary cost breakdown of storage projects



Source: JRC elaboration of (US Department of Energy, 2020)

A fundamental metric that summarizes the costs of storage assets and their associated competitiveness and profitability is the Levelized Cost of Storage (LCOS). This quantity can be interpreted as the minimum volume remuneration (on a kW-year or MWh basis) that can ensure the break-even for the storage investment over its life-time. One of the most accurate analysis in this regard is provided by Lazard (Lazard, 2021) and its key findings are reported in Figure 12.

Figure 12: Unsubsidized Levelized Cost of Storage Comparison



Source: (Lazard, 2021)

The LCOS estimates are consistent with the analysis presented in the previous section. In the wholesale scenario, when storage is utilized to provide short-term frequency regulation, energy arbitrage and capacity support, the break-even of the storage investment requires lower remuneration. The results also indicate that power-intensive storage assets (i.e. batteries with high power but relatively short duration) are currently more cost-effective, with the LCOS of the 100MW/100MWh being significantly smaller than the one of larger batteries. As a result of low remuneration for more energy-intensive services (such as capacity support), the additional revenues associated to a larger energy capacity do not recover the corresponding higher investment costs (see the high Storage Block costs in Figure 11). The high LCOS in the second "Transmission and Distribution" scenario in Figure 12 is also consistent with previous discussions: the utilization of storage assets to defer investments in the transmission and distribution network is currently not cost-effective and cannot economically sustain by itself storage investments.

3.1.3 Impact of EU-supported Research

The fundamental role of storage technologies in supporting the resilience and security of the energy system is well highlighted in the Strategic Energy Technology Plan of the Commission (European Commission, 2021). Its Flagship Initiative 1 "Develop an optimized European power grid" identifies the cost reduction of storage solutions to support system stability as a key target that should be achieved by addressing the energy markets design, refining the current system planning practices and enabling full deployment of the storage flexibility by revised regulatory frameworks and new cost-benefit analysis tools. The subject of grid-scale services provision by storage assets has been widely investigated in the context of H2020 projects, particularly in the programmes "Societal Challenges – Secure, clean and efficient energy" and "A single, smart European electricity grid". The relevance of storage grid services is highlighted by the several Horizon 2020 topics which are strictly related to this subject, including for example "Demonstration of system integration with smart transmission grid and storage technologies with increasing share of renewables" and "TSO – DSO – Consumer: Large-scale demonstrations of innovative grid services through demand response, storage and small-scale (RES) generation". A general review of the Horizon 2020 programme indicates that 36 different research projects have analysed in some form the topic of electricity network solutions that envisage a significant participation of storage technologies, with a total funding of 357.5 M€, of which 277.5 M€ from the EU budget. Of these 36 projects, 17 explicitly analyse the topic of grid-scale service provision from storage assets, with a total funding of 145.7 M€ (EU budget of 112.3 M€).

In the Horizon Europe programme, the role of storage in the provision of grid-scale services is considered in the wider context of the "Climate, Energy and Mobility" cluster and in particular in its destination "Sustainable, Secure and Competitive Energy Supply". In the 2021-2022 work programme of the cluster, 6 different topics include in their scope the role of storage in supporting system operation, for an overall total budget of 147 M€.

3.2 Value Chains

The interested reader can refer to the relevant TA.1 section of this report for a detailed description of the storage batteries value chain. This section focuses instead on the projected value and on the environmental/economic performance of storage batteries that provide grid services and support the operation and planning of the electricity system. It is in general difficult to provide an accurate estimate on this topic that isolates the specific contribution of storage technologies, as the whole-system benefits of storage grid services (for example in terms of additional flexibility) must be analysed in a holistic perspective that also considers other system features and interventions, such as the associated generation mix (renewables penetration, centralized/distributed generation), electrification of demand and utilization of alternative technologies and energy vectors (e.g. carbon capture and storage, hydrogen). Moreover, value analyses on power system technologies typically consider generation, transmission and distribution assets as separate elements. This traditional approach may undervalue storage technologies, which often cross between these asset classes. Finally, the impact of storage on deferral of network investments and on enabling renewable energy historically has not been captured and valued (NREL, 2021).

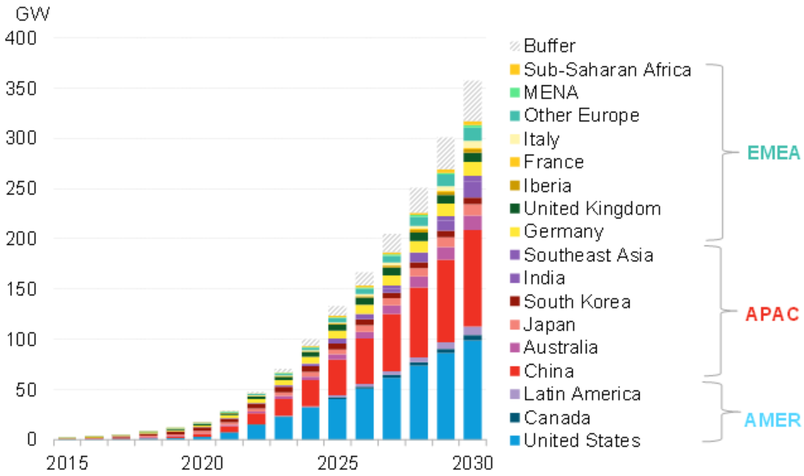
Under these premises and limitations, some indications on the environmental and economic impact of storage on the electricity grid can be obtained by a comparison of relevant energy scenarios which envisage different levels of battery storage penetration. In particular, the National Trends and the Distributed Energy scenarios presented in the ENTSO-E TYNDP (ENTSO-E, 2021) have been considered. The National Trends scenario is obtained by combining the National Energy and Climate Plans of the different states and envisages a total of 22 GW of battery storage in the power capacity mix by 2030, with a further increase to 41 GW by 2040. Conversely, the Distributed Energy scenario relies on a strong decentralized drive towards decarbonisation, with maximization of renewable energy production in Europe and a strong decrease of energy imports. In this second scenario, the penetration of battery storage is estimated to be 97 GW in 2030 and 173 GW in 2040. If the forecast emissions of the electricity generation are compared in the two scenarios, it can be seen that the additional battery storage capacity of 75 GW by 2030 (of 132 GW by 2040) in the Distributed Energy scenario with respect to the National Trends case contributes to a reduction of 55 tCO_2/MWh in the carbon intensity of power generation by 2030 (reduction of 33 tCO_2/MWh by 2040). In absolute terms, the additional storage in the Distributed Energy scenario contributes to a -52% reduction by 2030 of the total electricity generation emissions (-45% by 2040) with respect to the National Trends.

A quantitative evaluation of the benefits and value of storage batteries for power systems can also be provided by sensitivity studies, which assess how variations of the storage capacity with respect to foreseen scenarios can impact system performance. Useful indications in such sense are provided by NREL (NREL, 2022), which has evaluated the effect of storage in a 2050 energy scenario characterized by high costs of natural gas and low costs of batteries. Within this framework, it is estimated that a 5% increase of installed battery storage leads to an approximate -1.7% reduction in generation costs and a -3% reduction of congestion hours on critical transmission lines. Overall, the marginal value of battery storage estimated with this approach corresponds to about 12$/kW-yr. It should be emphasized that this incremental evaluation considers an operating point where the storage targets of the scenario have already been reached. If less storage is installed in the system, its marginal value increases significantly. Considering an initial storage penetration equal to 80% of the storage target (rather than 100%), the marginal value of storage is equal to about 18 $/kW-yr. The cannibalization effect of storage and the diminishing returns that are ensured by additional storage capacity are also confirmed in a recent study for the UK system (Strbac, et al., 2020), where the marginal value of storage in 2050 ranges between 5.5 £/kW-yr when 10 GW of storage are installed to 1 £/kW-yr when 25 GW of storage are already operating in the system.

3.3 Markets, Trade and Resources

The EU positioning in the global market of storage grid services is evaluated considering the current and projected penetration of stationary storage in the electricity grid. One of the most updated analyses in this regard is provided by BloombergNEF (BloombergNEF, 2021) and is summarized in Figure 13. The analysis includes stationary batteries for ancillary services, energy shifting and T&D investment deferral, together with customer-sited and other applications.

Figure 13: Global cumulative energy storage installations, 2015-2030.

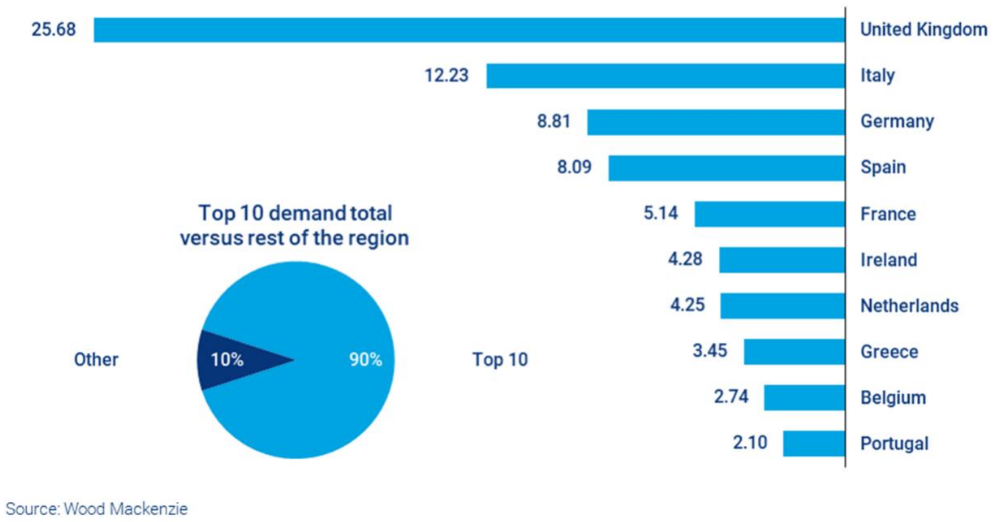


Source: (BloombergNEF, 2021)

As it can be seen, the penetration of stationary storage in the grid is expected to grow with an exponential rate in the next few years, reaching a cumulative 160GW of power by 2026 and 360 GW by 2030. It should be emphasized that, while most of the consulted sources agree on the expected growth trend of the technology penetration, there are different estimates (likely due to heterogeneous hypotheses and methodologies) on the future amount of installed power. For example, the latest report by Wood Mackenzie (Wood Mackenzie, 2022) indicates an estimated grid storage penetration of about 500 GW by 2030, while IEA (IEA, 2021) foresees about 63 GW by 2026. In all the different analyses, clear trends emerge on the geographical distribution of the storage capacity, with the US and China having the largest shares of the new storage capacity, followed by Europe and Pacific Asia (excluding China). The lower storage capacity expansion in Europe compared to the US can in part be explained by a stronger grid in EU and the different structure and functioning of their power systems. The presence in US of vertically integrated utilities favors the development of storage assets within a larger whole-system portfolio, enhancing their economic competitiveness while accounting for their impact on system efficiency and reliability. On the other hand, as a result of the unbundling of the European power systems, the storage projects in the EU are generally carried out on a merchant basis, with potentially higher risks and financing barriers (Wood Mackenzie, 2020). However, progress is being made in Europe to facilitate storage investments. For example, the requirement of fair storage participation to capacity and ancillary markets introduced by the Commission in its Clean Energy Package represents a step in the right direction. More generally, regulatory actions that adapt the current ancillary services framework to the particular features of storage and allow to account and correctly price its flexibility capabilities will significantly strengthen the storage case in a merchant framework and facilitate efficient and cost-effective investments.

More details on the European scenario are provided by the analysis of Mood Mackenzie (Wood Mackenzie, 2022), which forecasts a 20-fold expansion of storage capacity in Europe in the next ten years, with an aggregate 45 GW/89 GWh of grid battery storage assets in 2031. A distribution by country of the new grid-scale storage capacity is reported in **Figure 14**.

Figure 14: Top 10 European grid-scale energy storage markets; new capacity 2022 - 2031 (GWh).

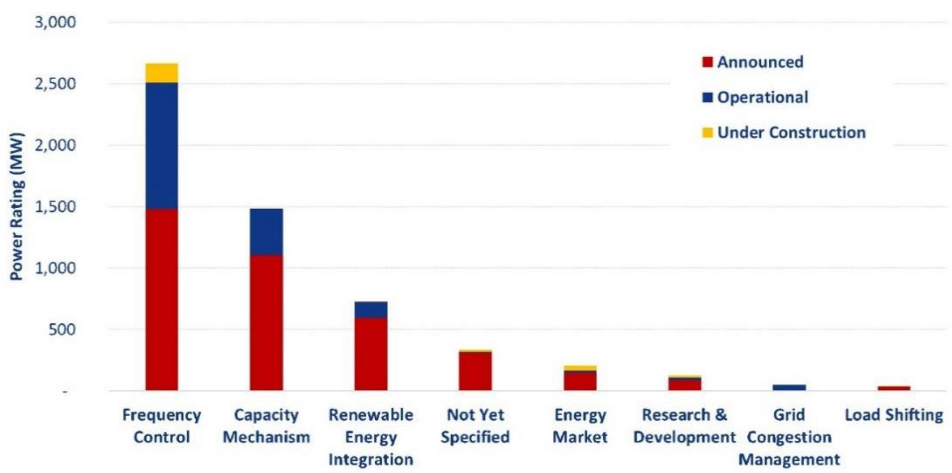


Source: (Wood Mackenzie, 2022)

In the next 10 years, the top 10 markets in Europe are expected to add about 73 GWh of new storage capacity, amounting to about 90% of the total new deployments. The biggest share will come by large from the United Kingdom, followed then by Italy, Germany and Spain. The largest expansion of storage in the United Kingdom is driven by two main factors: increased flexibility requirements of its future decarbonized power system, which is relatively small and not synchronized with continental Europe, and the maturity of the UK regulation in sustaining merchant storage projects.

A shorter-term analysis on the current and projected applications of the European grid-storage assets is provided by Clean Horizon. The findings, as reported by Energy-Storage News (El Chami, 2020) and shown in **Figure 15**, are consistent with the analysis presented in the previous Technology Readiness section. For the mapped assets, the most common grid application for storage is the provision of frequency control services, followed up by a much smaller contribution to capacity mechanisms. Storage contributions in these areas will further increase in the upcoming year, whereas the support to grid congestion management and network investment deferrals is expected to remain negligible.

Figure 15: Most common applications for European large-scale energy storage systems



Source: (El Chami, 2020)

4 Electric Vehicles Smart Charging

The number of electric vehicles (EVs) is growing rapidly and this proves to have a significant impact on the electricity network. Sales of electric vehicles (EVs) doubled in 2021 from the previous year to a new record of 6.6 million, bringing the total number of electric cars on the world's roads to about 16.5 million. This is triple the amount in 2018. Along with the increasing EV sales, the global market value of electricity for EV charging is projected to grow over 20-fold, according to the International Energy Agency's (IEA) Announced Pledges Scenario (APS), reaching approximately USD 190 billion by 2030. This is equivalent to about one-tenth of today's diesel and gasoline market value (IEA, Global EV Outlook 2022, 2022). That is, the overall market and commercialization for smart EV charging has not yet reached a fully mature stage, however it is emerging fast demonstrating double-digit annual growth rate.

Although newly installed EV charging infrastructure (including fast EV chargers, public EV chargers, etc.) does not presuppose smart EV charging operation, the growing number of EVs sales along with the increasing installation of new EV charging stations, are expected to boost smart EV charging. Smart charging optimises the dispersion of power and leads to considerable savings for grid operators, charge point operators, charge point owners and EV drivers. Smart charging also requires new revenue models in monetizing the flexibility of charging EVs. An acceleration in smart EV deployment by 2030 will not only help to efficiently integrate the increasing EVs charge power demand with the electricity grid, but it can also bring in significant financial benefits to the EV users.

For most of the smart EV charging required system components (e.g., bidirectional converters, connectivity modules, smart energy optimization software, e-mobility and roaming, etc.) is already available. Thus, the focus this year is mainly on technological and digital developments in smart EV charging, with respect to electricity grid support and services. We examine how smart (coordinated) EV charging in a power system can help to overcome issues associated with large-scale EV penetrations. We present the most important leading smart EV charging demonstration projects and we discuss the current and future commercialization potential of smart EV charging. Finally, we provide an overview of the current situation in global smart EV charging presenting the key players and the leading countries of the market.

4.1 Technology Development and Trends

For most of the smart EV charging required system components (e.g., bidirectional converters, connectivity modules, smart energy optimization software, e-mobility and roaming, etc.) is already available. Thus, the focus this year is mainly on technological and digital developments in smart EV charging, with respect to electricity grid support and services. We examine how smart (coordinated) EV charging in a power system can help to overcome issues associated with large-scale EV penetrations. We present the most important leading smart EV charging demonstration projects and we discuss the current and future commercialization potential of smart EV charging. Finally, we provide an overview of the current situation in global smart EV charging presenting the key players and the leading countries of the market.

4.1.1 Forms, types and maturity of smart EV charging

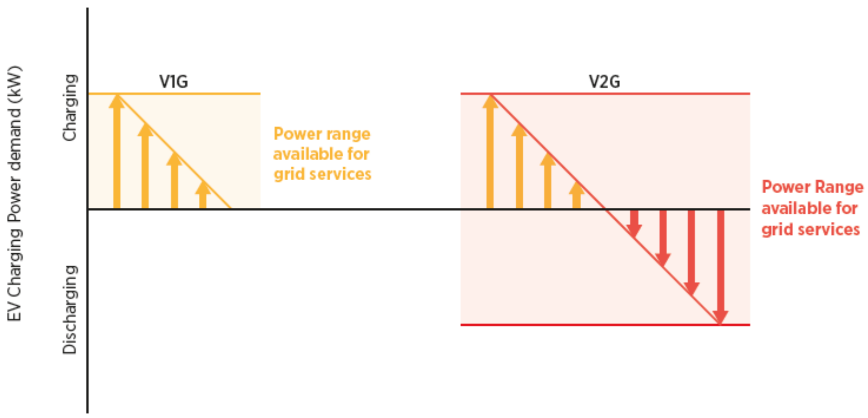
Smart charging includes different pricing and technical charging options. The basic technical options are summarized below:

Smart EV Charging comes in three forms – V1G, V2G, and V2H-B.

- V1G – unidirectional, controlled charging, where charging infrastructure adjusts its rate of charging, based on grid requirements.
- V2G – vehicle-to-grid charging, where the vehicle's battery is used to return energy to the grid during periods of high demand, and the vehicle is charged during off-peak times. The vehicle remains connected, and the smart charging management system adjusts the direction accordingly.
- V2H-B – Vehicle to home or building, where the stored energy within the vehicle's battery provides power to the home or building, based on the immediate requirements. The battery is recharged when demand is reduced.

The difference between unidirectional V1G and bidirectional V2G is illustrated in Figure 18. In the V1G, the driver, the EV charging site host or the aggregator can be rewarded only for adjusting their rate of charging up and down compared to the initial charging power (3 kW is assumed for illustration). In V2G, EVs can charge and discharge electricity from and to the grid, respectively. The size of the "bids" for grid services corresponds to the capabilities of the EV and the requirements in the given market.

Figure 16: Example of unidirectional (V1G) versus bidirectional (V2G) grid services provision



Source: (IRENA, Innovation Outlook, Smart Charging for Electric Vehicles, 2019)

Table *1* below shows the most common types of smart charging and their maturity stage. Applications around bidirectional charging are medium technology-mature but they are in advanced testing stage with many pilot projects running in the EU.

Table 1: Types of smart charging and maturity

Type of application	Smart control over charging power	Possible uses	Maturity
Uncontrolled but with time-of-use tariffs	None	Peak shaving with implicit demand response; long-term grid capacity management (both transmission and distribution system operators)	High (based on changes in charging behaviour only)
Basic control	On/off	Grid congestion management	High (partial market deployment)
Unidirectional controlled (V1G)	Increase and decrease in real time the rate of charging	Ancillary services, frequency control	High (partial market deployment)
Bidirectional vehicle-to-grid (V2G) and grid-to-vehicle (G2V)	Instant reaction to grid conditions; requires hardware adjustments to most vehicles and EVSE	Ancillary services including frequency control and voltage control, load following and short-duration integration of renewable energy	Medium (advanced testing)
Bidirectional vehicle-to-X (e.g., V2H/V2B)	Integration between V2G and home/building management systems	Micro-grid optimisation	Medium (advanced testing)
Dynamic pricing with EVs (controlled)	EVSE-embedded meters and close-to-real-time communication between vehicle, EVSE and the grid	Load following and short-duration integration of renewable energy	Low

Source: (IRENA, Innovation Outlook, Smart Charging for Electric Vehicles, 2019)

Unlike more mature V1G solutions, V2X has not yet reached full market deployment, with the exception of Japan where commercial V2H solutions have been available since 2012 as back-up solutions in case of electricity blackout.

Main smart EV charging actors: infrastructure and service providers

The two main actors in EV charging are the E-mobility Service Providers (EMSPs) and the Charge Point Operators (CPOs), and have two different roles. To put it bluntly, CPO's own the charging infrastructure and EMSP's enable the access of the end-users to the charging points and the provided services. The roles can be separated or one market player can act as both. Thus:

- EMPS's serve EV drivers by enabling access to a variety of charging points around a geographic area. With the service, drivers can find available charging stations, start and stop charging and pay with various methods.
- A CPO operates a pool of charging points and makes sure that the network runs smoothly. A CPO provides value by connecting smart charging devices to EMSP's. CPO's deal with diagnostics, device maintenance, and station pricing. As a separate service, CPOs rely on other EMSPs to provide access to their charging stations. This can be enabled through roaming networks.
- Roaming: Roaming networks enable EV drivers to use charging stations of various service providers, even if they are only a customer of one service provider.

On top of the aforementioned actors, smart EV charging requires the use of specialized energy management systems and cloud computing that brings real-time data from connected charging devices and charging events to the charging station owner's perception. As stations are connected to the cloud, they can be managed based on various signals: such as fickle energy production, local electricity consumption, amount of other vehicles being charged or electrical devices being used on a nearby premise (Virta, 2020)

Main drivers to apply smart charging technology

There are four drivers for that need to be taken into account when applying smart charging technology (GreenFlux, 2021):

- **Grid constraints**: Power usage by electric vehicles fluctuates over the day, as the number of vehicles charging on a location may vary throughout the day and batteries are filled up and gradually stop charging. If demand surpasses the local maximum capacity, power failure may be the result. Smart charging adjusts the charge moment and speed by considering both the electricity demand of the building and that of the charge points.
- **Dynamic energy prices**: In 2020 CPR, we identified dynamic energy prices as a key element to enable effective smart EV charging. Indeed, time varying energy prices offer more capabilities to optimize smart EV charging.
- **User requirements**: User requirements are an important factor that needs to be considered when discussing smart EV charging. To offer EV drivers the best charging experience, a way for users to interact with smart charging is required. This can be achieved, for example, through mobile applications.
- **Local renewable energy**: Smart EV charging takes advantage of local renewable energy sources. In the event that local energy is available, smart charging can send this energy directly to the charge point. This results in additional capacity and faster charging with clean, free energy.

4.1.2 Overview of smart charging deployment and pilot projects

The number of projects, pilots, and demonstrations have grown alongside development of the larger EV market. V2G projects have largely been highly sophisticated, meant to test implementation challenges, battery impacts, and economic potential under a variety of grid service applications. An overview of the projects is provided in **Table *2*** below.

Table 2: Smart EV charging deployment and pilot projects.

Type of charging	Examples of projects
Uncontrolled time-of-use tariffs	China, Germany, Japan, the UK, the US
Basic control	My Electric Avenue, Scottish and Southern Energy Power Distribution and led by EA Technology, UK (100 households testing Esprit system)
	Pepco, Maryland, US: 200 households Consolidated Edison, New York, US: off-bill incentive for managed charging Xcel Energy, Minnesota, US: 100 households
	United Energy – Victoria, Australia (2013)
Unidirectional controlled (V1G)	Green eMotion, the EU project (2015): reduction of grid reinforcement cost by 50%
	Sacramento Municipal Utility, California, US: reduction of grid upgrade expense of over 70%
Bidirectional vehicle-to-grid (V2G)	eVgo and University of Delaware project in US with transmission system operator PJM, led by Nuvve; Interconnection – commercial operation
	Nuvve, Nissan, Enel, in England and Wales with transmission system operator National Grid – operating pre-commercially
	Nuvve, DTU, Nissan, PSA, Enel project in Denmark, with transmission system operator energinet.dk ("Parker Project") – operating trial
	Nuvve, NewMotion, Mitsubishi project in the Netherlands, with transmission system operator TenneT – commercial trial
	Jeju, Republic of Korea project developing fast and slow V2G; Toyota city project with 3100 EVs
	Renault, ElaadNL and Lombo Xnet, project in Utrecht, the Netherlands – AC V2G
	Nissan, E.ON Drive, Imperiac College London e4Future project, The drive towards a low-carbon grid, Unlocking the value of V2G fleets in Great Britain.
Bidirectional vehicle-to-X (V2X) (e.g., V2H)	ElaadNL and Renault in Utrecht, the Netherlands: 1 000 public solar-powered smart charging stations with battery storage around the region in the largest smart charging demonstration to date. Increase in self-consumption from 49% to 62-87% and decrease in peak of 27-67%
	DENSO and Toyota intelligent V2H (HEMS and V2G integrated model), Nissan (V2H) – all of Japan (7 000 households, commercial operation)
Dynamic pricing with EVs (controlled)	Nord-Trøndelag Elektrisitetsverk Nett in Norway
	San Diego Gas & Electric in California: trialling prices posted one day ahead
Second-life battery	BMWi and PG&E ChargeForward pilot programme in California

Source: (IRENA, Innovation Outlook, Smart Charging for Electric Vehicles, 2019).

Smart charging standards and main challenges

Standardization efforts to support electro mobility have historically focused on traditional electrotechnical issues, such as plugs, outlets and electrical safety. However, in order to ensure compatibility and communication between charging points, electricity distribution networks and electric vehicles, appropriate communication interfaces and data models also need to be standardized.

Table 3: An overview of the existing standards

Code	Title	Application	Development
IEC 61851	Electric Vehicle Conductive Charging System	Safety requirements for charging with plugs and cables (AC or DC) and the basic communication between the charging station and the EV	Published
ISO 15118-2	Road vehicles — Vehicle to grid communication interface	Detailed communication between an EV (battery EV or a plug-in hybrid EV) and a charging station	Currently under review
ISO 15118-20	Road vehicles — Vehicle to grid communication interface – Part 20: 2nd generation network and application protocol requirements	High-level communication between a charging station and an EV for the control of charging services	To be published at the end of 2020
IEC 63110	Management of Electric Vehicles charging and discharging infrastructures	Remote management of charging stations by charging station operators and their integration with energy management systems	To be published in mid-2021
IEC 63119	Charging Service Providers	Roaming and payment in the context of EV charging services	To be published in 2022
EN 50549	Requirements for generating plants to be connected in parallel with distribution networks	Definition of technical requirements for the protection functions and the operational capabilities for generating plants	Published
EN 50491-12-2	Smart Grid interface and framework for Customer Energy Management	Management of power flows inside buildings, including exchanges with EV charging	To be published in 2021

Source: (ECOS, 2020).

Several aspects have been addressed in the regulation within the EU in this matter but there still work to do on setting standards for operations that ensure interoperability between equipment, users, service providers and back-end systems. There are multiple available options in the industry, therefore, standardized unique identifiers, data models, attribute lists and common data structures should be specified to enable a whole interoperability.

The main standardized aspects of electromobility so far are:

- IEC 62196 plugs, socket-outlets, vehicle connectors and vehicle inlets (CCS and Type 2 are the two standard vehicle connectors to be used within Europe).
- IEC 61851 Electric vehicle conductive charging system.
- IEC 61980 Electric vehicle wireless power transfer (WPT) systems.
- ISO 15118 Road vehicles - Vehicle to grid communication interface.

The main challenges to be addressed regarding interoperability and standards are (SNET, 2022):

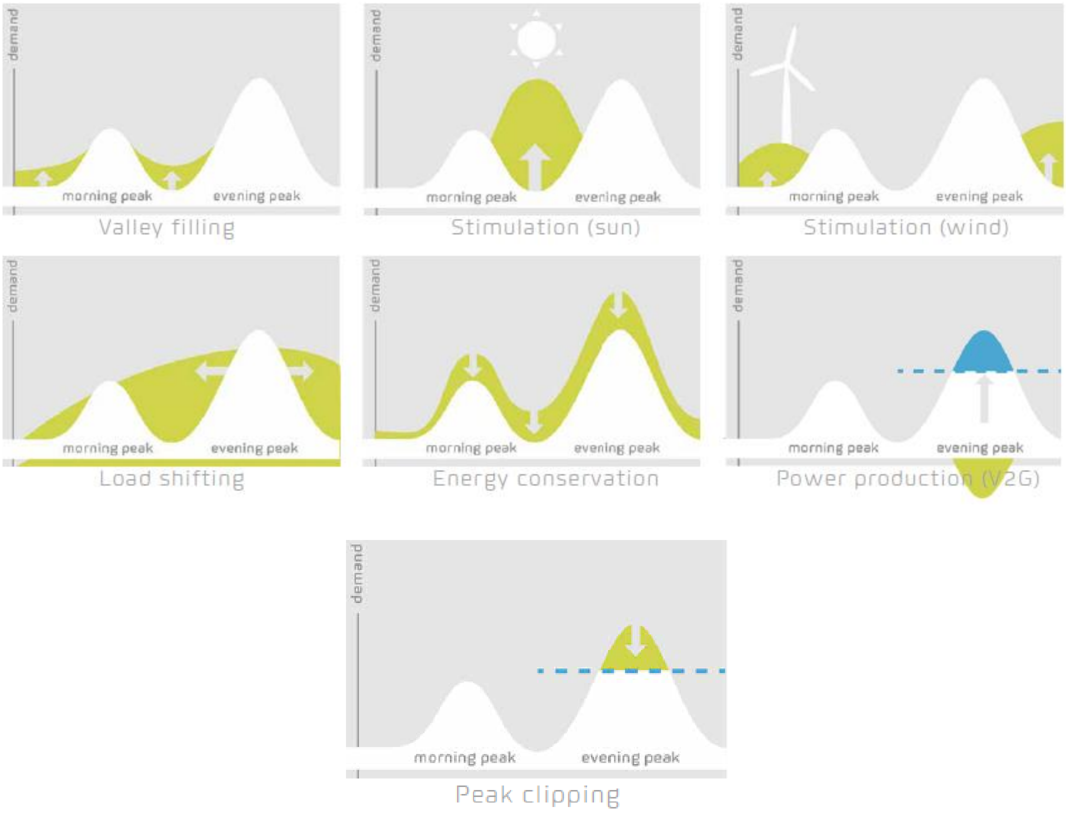
- The existence of a widespread used communication protocol between charging points and CPOs. One of the most extended is the Open Charge Point Protocol (OCPP), which offers a uniform solution for the method of communication between charge point and central system. With this protocol, it is possible to connect any central system with any charge point, regardless of the vendor.
- The existence of a widespread used communication protocol between the CPOs and other players. The Open Charge Point Interface protocol (OCPI) supports connections between electric mobility service providers (EMSPs) who have EV drivers as customers, and CPOs who manage charge stations.

Implications of smart EV charging within the energy ecosystem

In this subsection, we provide a brief overview of the main techniques that can be used for smart EV charging, and potentially for providing ancillary services to the electricity grid. We also examine the main challenges and the potential impact smart EV charging could have on current power systems. Finally, we present the main challenges and opportunities that might arise with smart EV charging.

Depending on the basic profile, a number of smart EV charging techniques can be applied. There are a number of options to optimize smart charging sessions. The most widely known are presented in **Figure 17:** Simplified representation of smart charging techniques.

Figure 17: Simplified representation of smart charging techniques



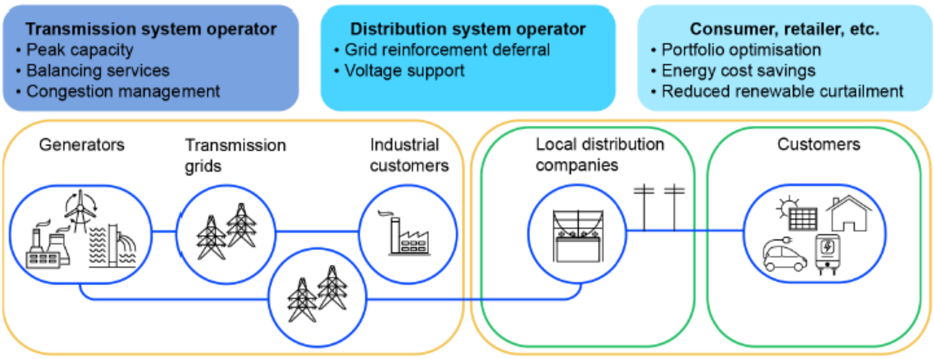
Source: (Elaad, 2020)

- *Valley filling:* more or faster charging at periods of low energy demand.
- *Stimulation*: faster charging when more sustainable (or cheap) electricity is available.
- *Load shifting:* slower charging at times when peak loads are imminent; EVs then charge faster at other times.
- *Energy conservation:* at the time of charging, the speed is reduced to less than the technical maximum for the entire charging period.
- *Peak clipping/peak shaving: less rapid charging at times when there is a risk of peak loads.*
- *Power production:* resupply of energy from the EV.

4.1.3 Smart EV charging grid integration and impact on power systems

Smart EV charging will be key to maximizing synergies between EVs, renewable energy (RE) generation and grid services. Different EV charging strategies may have somewhat different impacts based on the energy system's characteristics. Smart charging can provide services along the power supply chain, such as balancing/ancillary services, voltage and frequency support, reduced renewable curtailment, etc., (**Figure 18**).

Figure 18: Smart EV charging services to the power system



Source: (IEA, Global EV Outlook 2022, 2022)

According to a McKinsey study (McKinsey&Company, 2018), electric vehicles are unlikely to create a power-demand crisis in the short to medium term, but they could reshape the load curve (which at local level might create some problems to the electricity grid, as discussed next). The same analysis suggests that the projected growth in e-mobility will not drive substantial increases in total electrical-grid power demand in the near to midterm, thus limiting the need for new electricity-generation capacity during that period. In accord, grid simulation results based on German distribution grid case studies (Vertgewall, 2021) show that until EVs reach around 20% of all vehicle stock, grid upgrade requirements are rather sparse and mostly focused on transformers that require upgrades to deal with voltage control.

While at a system level, the effect of smart EV charging will be relatively small; at local level, the challenges are bigger. The changing load curve will lead to challenges at a local level because the regional spread of EVs will most likely vary—in some cases, significantly. Rural areas, with relatively weaker grids might be the first to require upgrades. However, even in such a case, the forecast changes in the load curve in residential areas with a 25% local EV penetration indicate that despite the significant growth in local peak-load (30%), the peak-load growth in residential areas is not as dramatic. That is because while a single EV can easily double peak consumption at the individual household level, the aggregation across many households (those with and without EVs) reduces the relative increase in peak load at a substation, even considering the effects of high-peak outlier days.

One should note that for highway charging electric cars and trucks, the situation is somehow different. When transport corridors are located in areas with existing grids, the installation of chargers does not face major barriers, provided that the grid is not already congested. But to provide charging in more remote locations, grid upgrade costs can become a barrier. Thus, highway charging for electric cars and trucks requires significant investment in grid upgrades. (IEA, Global EV Outlook 2022, 2022).

Considering the text above, the question that arises is: can smart EV charging strategies mitigate the overall impact caused by the increasing EV penetration on the grid? **Table *4*** below, presents a number of useful insights derived from several studies on the field.

Table 4: Studies assessing the impact of EV charging strategies

Report	Power system studied	Scenario	Main issues and key indicators	Main findings

RMI, (Rocky Mountain Institute, 2016),	5 selected US states: California, Hawaii, Minnesota, New York, Texas	23% EV penetration in the fleet in 2030, i) uncontrolled charging mode, ii) optimized charging mode	Peak load increase with high EV penetration, which will increase the generation and distribution grid capacity	A big difference in peak load is found in the two scenarios. For example, in California: i) all EVs in uncontrolled charging mode would increase the peak load by 11.14%; ii) with smart charging, this would increase the peak load by only 1.33%. Smart charging can help optimise the grid resources and avoid having to invest in new peak generation capacity.
Taljegard, (Taljegar D, 2017)	Denmark, Germany, Norway, Sweden	100% EV penetration in 2050, i) including electric road systems (ERS); ii) including ERS and V2G	EV charging correlates with the electricity system peak load and thereby increases the need for peak power capacity and an increase in CO2 emissions	i) If no V2G is applied, the ERS would increase the peak of the net load curve by 20% in Scandinavia and Germany (from 127 GW to 152 GW); ii) If V2G is applied, passenger EVs will smoothen the net load curve in the Scandinavian and German electricity system so that the hour with maximum net load is reduced by 7% (from 127 GW to 118 GW).
McKenzie et al., (McKenzie, 2016)	Island of Oahu, Hawaii, US	Over 130 000 EVs on Oahu by 2045, and 260 000 with US Energy Information Administration high oil price; 23% of electricity produced from renewables, very high solar and wind penetration following the Renewable portfolio Standards	Given the island's mix of renewable resources, without EVs, 10% to 23% of combined solar and wind energy would need to be curtailed	With smart charging (i.e., if EV charging perfectly tracked the solar and wind profiles), then up to a 18-45% reduction in renewable energy curtailment, depending on the charging behaviors and on the type of smart charging
Chen and Wu, (Liukai Chen, 2018)	Guanzhou region, China	Case based on real typical daily summer load curve in Guangzhou with 1 million EVs	EV charging correlates with the electricity system peak load and thereby increases the need for peak power capacity	One million EVs will increase the peak load of the grid by 15% without any charging control. However, the fluctuation will be reduced by 43% without V2G technology, while it can be reduced by 50% if V2G is available.

Source: JRC based on literature review

Results indicate that compared to uncontrolled EV charging, smart EV charging techniques can reduce reverse power flows and transformer overload, increasing the hosting capacity of distribution grids. It also helps mitigate overvoltage in low-voltage grids with high shares of renewable energy. Moreover, the system-wide effects of smart charging are expected to be more significant in isolated systems than in interconnected systems.

The importance of implementing smart EV charging techniques is also highlighted in a position paper (Grids, Position paper on Electric Vehicles Charging, 2020) of the European Distribution System Operators (EDSO) for smart grids on EVs charging infrastructure. With wide spread electric mobility, the electricity system will be dramatically affected, facing new consumption patterns and congestions at the same time as vast amounts of new renewable and distributed energy resources is to be incorporated into the grids. In the same direction, smartEN sets a number of priorities (Grids, Making electric vehicles integral parts of the power system, White paper, 2019) (such as easing EVs interaction with the electricity grid to reveal the value and benefits of their flexibility, eliminating barriers to the aggregation of EVs, etc.) to make EVs integral part of the power system. Electric vehicles (EVs) were not developed for the power sector as a grid flexibility solution. Their primary purpose is to serve mobility needs. However, an integrated perspective on the interaction between transport and energy is required to drive the decarbonisation of the transport sector, to ensure the best energy system efficiency, to leverage their contribution to the decarbonisation of electricity and to empower consumers.

To sum up, existing grids in major EV markets should be able to handle the added demand by 2030. However, grid upgrades will be needed for heavy-duty EVs, frontrunner cities and in developing and emerging markets. Cities and suburban areas with a high concentration of electric-vehicle stock might also encounter challenges integrating the EVs. Smart EV charging techniques could mitigate the undesirable impact due to the increasing EVs penetration onto the electricity grid. Fast approval times for grid upgrades will be essential to ensure adequate charging networks by 2030; however, adoption of digital technologies and smart charging can alleviate the need for grid upgrades.

Challenges and opportunities for smart EV charging

Uncoordinated EV charging risks compounding concerns for grid operators to balance supply and demand, as well as placing additional pressure on networks. This could necessitate additional investment in peaking resources, as discussed earlier. An effective approach to minimize the need for grid investment due to EV loads will be to make network constraints known at a granular level, identifying areas that are under the most stress, including at the distribution system level. The most significant challenges the deployment of smart EV charging faces are: (IEA, Global EV Outlook 2022, 2022):

- *Lack of distribution grid transparency:* Network operators in medium and low voltage systems may not be able to forecast or have adequate data on real-time loads at a geographically granular level.
- *Lack of demand-response technologies on a large-scale at the load level:* Technologies to send and receive detailed signals for individual loads exist. However, their current application is limited to a few pilot projects and businesses.
- *Inadequate market framework:* The market design and regulatory framework in most countries does not provide a mechanism for contracting flexibility services between DSOs and consumers.

On the other hand, as discussed above, smart EV charging can offer great opportunities to power systems. EVs and their batteries, through the smart charging techniques (bidirectional managed or vehicle-to-grid, unidirectional managed charging, off-peal charging, etc.), could provide a huge reservoir of flexibility to facilitate the energy transition. New sources of flexibility can help to ensure that power systems are in balance at all times.

Table *5* gives an overview of the current situation in several countries to support smart EV charging roll out.

Table 5: Elements required to roll out smart EV charging: what is the status?

Country/ state	Time-of-use tariffs		Ancillary services procured on a market basis	Flexibility service providers can participate in energy markets	Smart charging policies or standards are in force
	Peak/ off-peak, night/day	Hourly			
Australia	√		√	√	
Chile	√		limited	in progress	
China	√		√	√	in progress
France	√	in progress	√	√	√
Finland	√		√	√	
Germany	√		√	√	√
Greece	√			√	√
India	√		√		in progress
Italy	√		√	√	√
Japan	√	√	√	√	in progress
Korea	√		√	√	in progress
Netherlands	√		√	√	in progress
New Zealand	√		√	√	in progress
Norway	√		√	√	
Portugal	√		limited	in progress	√
Thailand	√				
United Kingdom	√	√	√	√	√
California (US)	√		√	√	

Source: (IEA, Global EV Outlook 2022, 2022)

4.1.4 R&D funding

EU funding

The main source of support for R&I investments in smart EV charging at EU level is the Horizon Europe Framework Programme. The call "Clean and competitive solutions for all transport modes" of Horizon Europe has many actions related with smart EV charging, such as the "System approach to achieve optimized Smart EV Charging and V2G flexibility in mass-deployment conditions[5]" (2ZERO, HORIZON-CL5-2021-D5-01-03, 25M€), the "Nextgen vehicles: Innovative zero emission BEV architectures for regional medium freight haulage[6]" (2ZERO, HORIZON-CL5-2021-D5-01-01, 45M€), the "Modular multi-powertrain zero-emission systems for HDV (BEV and FCEV) for efficient and economic operation[7]" (2ZERO, HORIZON-CL5-2022-D5-01-08, 58M€), etc. In addition, according to the ETIP SNET R&I Implementation Plan[8] for 2021-2024, Smart EV charging, as a sub-research topic of the Flexibility Enablers and System Flexibility research area (RI) , will receive 24M€ (out of the 183M€ for the whole RI).

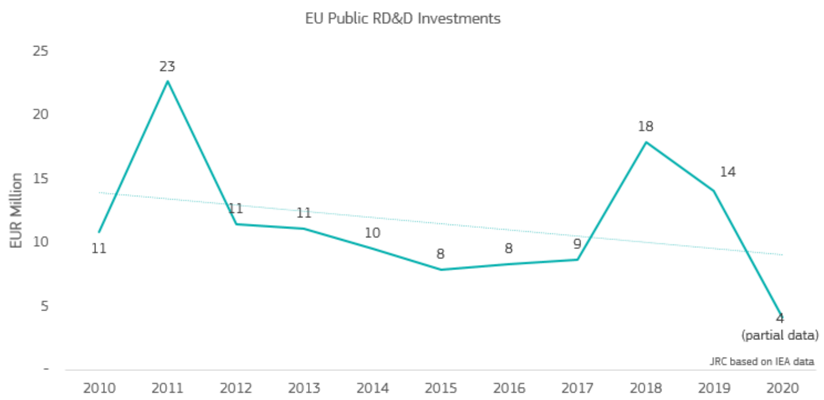
As far as the currently ongoing, EU-funded projects related with Smart EV charging, some of these are eCharge4Drivers[9], Green Charge[10], ASSURED[11], with a total EU contribution surpassing 40M€.

EU

The summary results for EV charging infrastructure, after a peak in 2018 show a decrease in EU Public R&D investments (**Figure *19***). The leading country in EU-27 for the period 2017 -2019 is France with total public investments of approximately 27M€. The total amount for EU Member States for the same period is approximately 4127M€[12].

[5] https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/horizon-cl5-2021-d5-01-03
[6] https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/horizon-cl5-2021-d5-01-01
[7] https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/horizon-cl5-2022-d5-01-08
[8] ETIP SNET, R&I Implementation Plan 2021-2024, 2020
[9] https://cordis.europa.eu/project/id/875131
[10] https://www.greencharge2020.eu/
[11] https://assured-project.eu/key-innovations/interoperable-high-power-charging-systems
[12] Some countries keep their data confidential or do not report to this level of detail.

Figure 19 EU Public R&D Investments

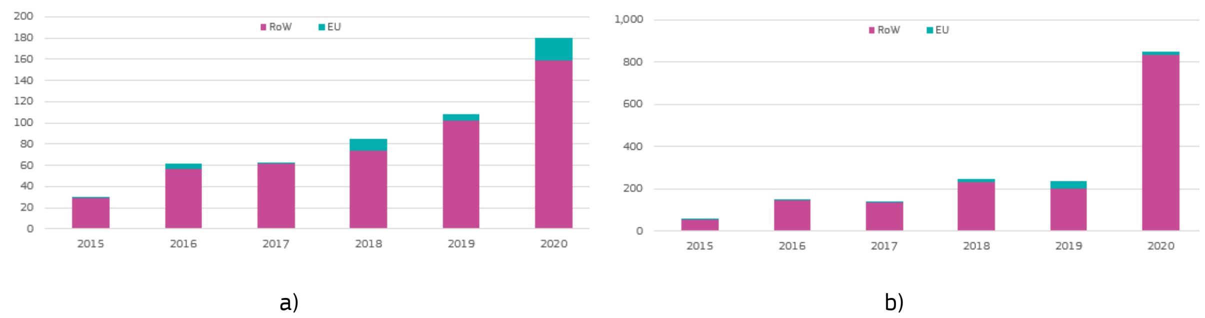


Source: JRC, commissioned by DG GROW -European climate-neutral industry competitiveness scoreboard (CIndECS)

EU and the rest of world

Figure 20 shows the early (one the left) and later (on the right) stage investment for EU and Rest of the World (RoW). For both early and later stages, one may notice that there is a remarkable increase in 2020. The total capital invested by EU from 2015 to 2020 for early stage investments reached almost 40M€ compared to the 480 invested by RoW. As far as the later stage investments are concerned, EU spent around 77 M€ from 2015 to 2020, compared to 1600 M€ of the RoW.

Figure 20 Early (Fig. 22a) and later (Fig. 22b) stage investment by region [EUR Million]



Source: JRC, commissioned by DG GROW -European climate-neutral industry competitiveness scoreboard (CIndECS)

4.2 Value Chains

4.2.1 Main Value Chain Streams

The value chain of smart EV charging can be grouped in the following three main streams:

Energy suppliers: The first stream includes everything from producing and transmitting energy from source to vehicle, to monitoring energy provider and recipient information and offering an easy-to-understand, easy-to-integrate payment system.

Charging infrastructure providers: The second stream comprises everything from building and operating charging stations to sales and maintenance and from creating home, public, and workplace charging infrastructure programs and managing the power supply and grid effects.

E-mobility service providers: The third stream contains everything from battery management and roaming environments to charging infrastructure and vehicle services to ensure flawless product performance, compliance with global standards, customer safety and satisfaction.

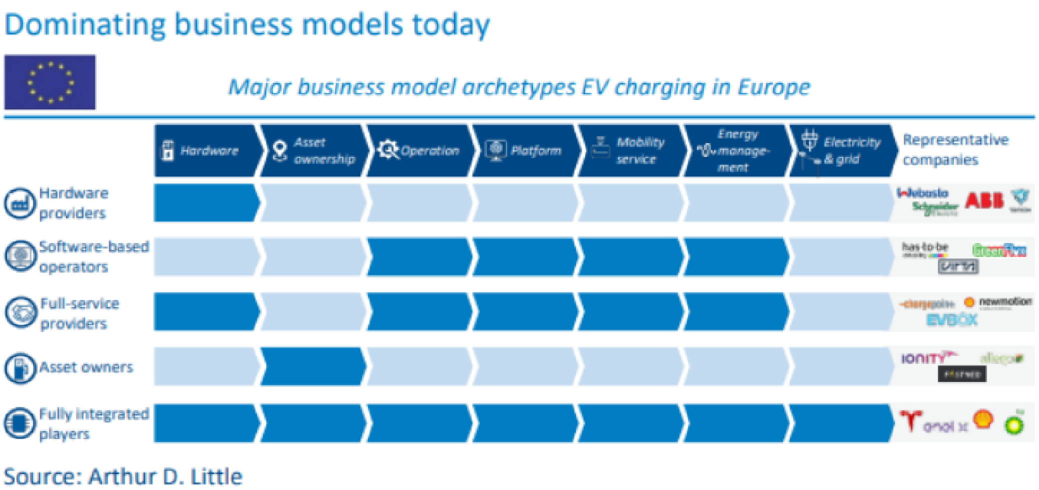
The three key insights gained with regards to the supply chain of EV charging infrastructure (Insights, 2020) (i) supply chain of manufacturers is mainly local and/or regional, in particular for EU based vendors, (ii) the basic electronic parts e.g., PCBs are purchased in Asia, and (iii) the value chain is not fully mature yet as vendors develop, design, and manufacture mainly in-house, with some contract manufacturing.

In 2020, Guidehouse conducted a series of interviews (Insights, 2020) with a number of leading smart EV charging vendors (Driivz, GreenFlux, The Mobility House, etc.) to provide a supply chain overview and identify potential barriers in the chain. The supply chain of EV charging platform vendors is highly integrated. Across the interviews, the firms stressed that design, development, and testing occurs in-house. Due to the level of integration, there are limited risks to be noted in the supply chain. One risk mentioned was capacity challenges. For capacity reasons, certain steps are outsourced, although the capabilities exist in-house as well. Such a close collaboration with partners is visible in other parts of the supply chain as well. A noteworthy detail is that a general dependence on US-based cloud hosting offers is visible in the sector. Amazon Web Services (AWS), Microsoft with its Azure platform, and the Oracle Cloud Infrastructure were all mentioned as being part of the offered EV charging platforms. However, such a dependence is not seen as a key risk, as switching from one supplier to another does not seem to relate to large transaction costs.

4.2.2 EU and Global Main Players in Smart EV Charging

Key players operating in the smart EV charging market include ABB (Sweden-Switzerland), Bosch Automotive Service Solutions Inc.(Germany), Schneider Electric (France), GreenFlux and Alfen N.V. (Netherlands), Virta (Finland), Driivz and Tesla (USA), etc. Key players operating in the global smart EV charger market are expanding their presence by engaging in merger & acquisition activities or by establishing new facilities. For instance, in January 2021, Alfen N.V. collaborated with Bee Charging Solutions as its supplier in Sweden to provide smart charging points for electric vehicles. This partnership focuses on providing home and public charging solutions. The figure below illustrates the dominating business models in the market and the main players.

Figure 21: Dominating business models in the market and major players

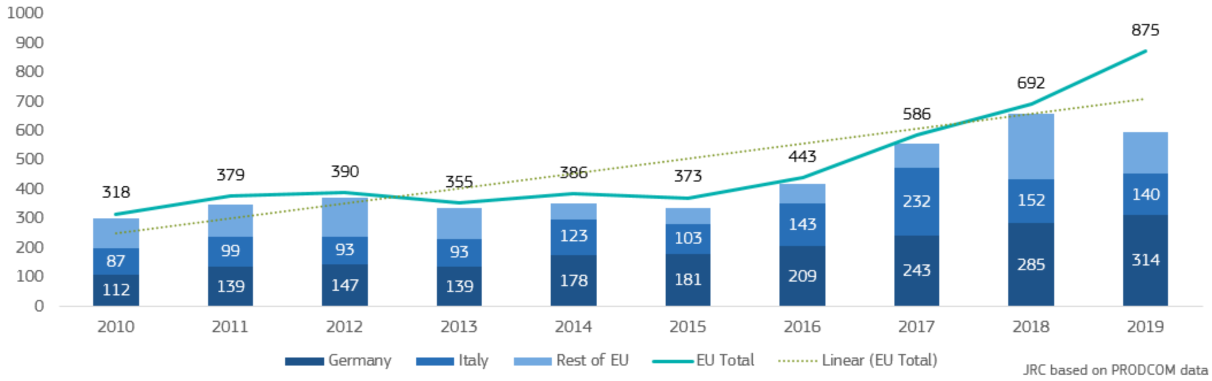


Source: (Alexander Krug, 2021)

4.2.3 Community Production

The total production value on the electric vehicle charging infrastructure value chain in the EU27 reached 875 M€ in 2019, showing a continuous increase from 2015. Germany and Italy together account for more than 50% of the total community production, as illustrated in Figure 22.

Figure 22: Total production value in the EU27 and top producer countries [EUR Million],



Source: (JRC - Joint Research Centre)

4.3 Markets, Trade and Resources

4.3.1 Global Market Analysis

Sale and demand for electric vehicles have been increasing across the globe for the last couple of years. Electric mobility has become a mass production market from a niche product. For the first time in the world, in 2017, the market share of electric mobility surpassed 1% share of total automobiles. The outlook for 2020 global EV sales was quite unpredictable at the beginning of the year amid COVID-19. However, as time showed, the year 2020 turned out to be surprisingly positive despite the pandemic and its effects. The global EV sales grew by 43% from 2019 and the global electric car industry market share rose to a record 4,6% in 2020 (Irle, 2021). In 2021, it is estimated that over 16.5 million electric cars were on road. According to a study (Research, 2021) from Transparency Market Research, in 2020, the global smart EV charging market was valued at US$ 1.52 Bn. It is estimated to expand at a compound annual growth rate (CAGR) of 32.42% from 2021 to 2031. Surge in adoption of electric vehicles among consumers, rise in trend of vehicle electrification in the automobile industry as well as government regulations on emissions, and increased fuel efficiency are prominent factors driving the demand for smart EV chargers, unlike other electric vehicles chargers. Based on end-use, the smart EV chargering market has been divided into residential charging unit and commercial charging station. In terms of revenue, the residential charging unit segment accounted for a major share of the global smart EV charger market in 2020. Residential charging unit offers convenience and universal compatibility of home charging stations; constant use and charging reduce its capacity to hold power.

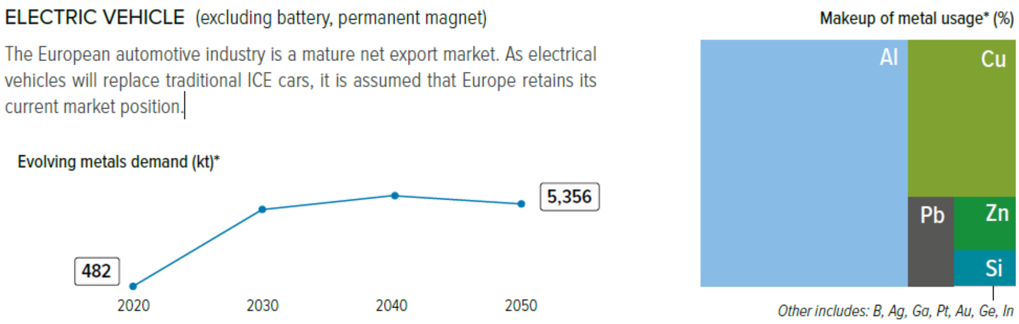
According to the same study, the global smart EV charging market has been segregated into North America, Europe, Asia Pacific, Middle East & Africa, and Latin America. Asia Pacific accounts for a key share of the global smart EV charger market due to the high rate of adoption of electric mobility in countries such as China, Japan, India, and South Korea. Followed to Asia Pacific, Europe hold major share of the global smart EV charging market, in terms of revenue, in 2020.

4.3.2 Resources

Metals will play a central role in successfully building Europe's clean technology value chains and meeting the EU's 2050 climate-neutrality goal. Increasing demand for EV charging stations will directly impact the requirements of raw materials, such as stainless steel, copper, aluminium, polycarbonates, elastomers, and thermoplastics polyurethanes used for critical manufacturing components of EV charging stations, such as enclosures, cables, connectors, cable insulation and jacketing, and flexible conduits. For the electronic circuits and boards, which are present in almost every component of a smart EV charging station, silicon and germanium are two crucial raw materials. Furthermore, as the main actors to implement smart EV charging are the electric vehicles, the availability of raw materials to keep up with a smooth EVs production is critical.

For electric vehicles (excluding battery and permanent magnets), the most important metals are aluminum, copper, lead and zinc. It is foreseen that Europe maintains its current market position regarding these metals (see **Figure 23**).

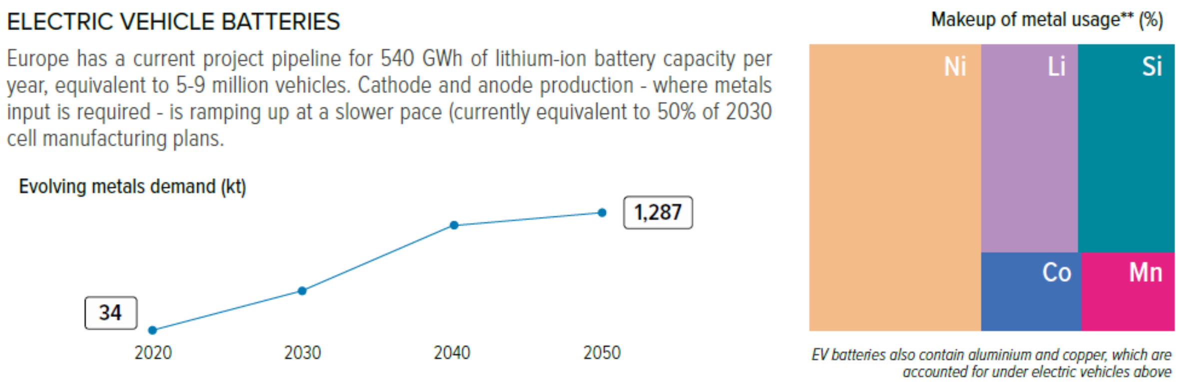
Figure 23: Electric vehicle (excluding battery, permanent magnet)



Source: (Leuven, 2022)

For EV batteries, nickel and lithium are the most required raw metals (Figure 24). Lithium in particular is very important, as it is needed to produce virtually all traction batteries currently used in EVs as well as consumer electronics. Despite expectations that lithium demand will rise from approximately 500,000 metric tons of lithium carbonate equivalent (LCE) in 2021 to some three million to four million metric tons in 2030, according to a McKinsey study, (McKinsey, 2022), the lithium industry will be able to provide enough product to supply the burgeoning lithium-ion battery industry.

Figure 24: Electric vehicle batteries



Source: (Leuven, 2022)

5 Advanced Metering Infrastructure

Advanced Metering Infrastructure (AMI) is an important part of the digital infrastructure for the smart energy system. AMI permits data exchange between the consumer (or prosumer) and the energy service provider, which enable the former one to be an active member of the smart grid, by adjusting consumptions to avoid energy peaks and facilitate the latter one in order to make the most out of the grid potential.

In this Section, we will examine the status of the Advanced Metering Infrastructure in Europe and beyond. The goal is to provide with an update of last year's effort to depict the situation with respect to AMI. This year, the purpose has been twofold: to confirm already existing information from last year's project and to identify new sources and include updated information. This latter objective means that information published in late 2021 or early 2022 needed to be identified and considered. In addition, for this year, we also include information about the rest of the systems comprising the AMI, whereas last year the interest was on smart meters. Our focus points are summarized as follows:

- Evidence based analysis
- Technology analysis
- Value-chain analysis
- Global market analysis

AMI systems comprise of different components, with smart meters being the core part of the system, whereas communication networks, data management systems, for processing of data received, are also fundamental for enabling complete AMI functionality (U.S. Department of Energy - Office of Electricity Delivery and Energy Reliability, 2016). There are three the main parts of AMI: smart meters; the communication networks that are responsible for massive data transmission to the control centre; a system to process data, like the Meter Data Management System (MDMS), which can include the Head End System.

Apart from the residential sector, AMI can be used in the industrial and commercial sector (Mordor Intelligence, 2021). In general, AMI systems can offer the following advantages to energy providers and the consumers:

- Reduced electricity bills, through better management of consumptions
- Better grid observability, thus better outage management
- Reduced costs for grid updates, due to better management of electricity peaks
- Better customer control through the usage of advanced customer infrastructure, i.e. smart applications, web portals.

5.1 Technology Development and Trends

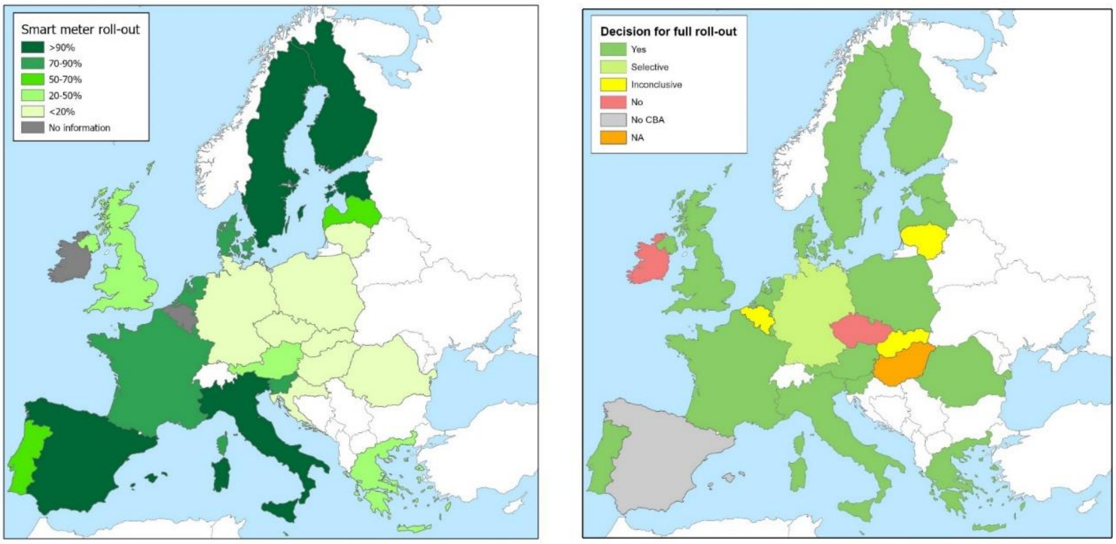
5.1.1 Technology readiness level

In this Section we analyse the smart meter roll-out status in Europe, services offered and technologies used for AMI. All of the above factors, clarify the situation around smart meters and the maturity level the technology reached in Europe. Indeed, with the status of smart meters roll-out it is obvious how mature the technology is in Europe, thus it is revealed the technology maturity level.

First of all, the legislation, the "Clean Energy for all Europeans" shapes the smart meter roll-out for the countries in Europe. According to it, 80% of consumers should have been equipped with a smart meter until the year 2020. Given this information, it is worth noticing the actual state of smart meter roll-out in Europe. A published paper in 2022 (Vitiello, Andreadou, Ardelean, & Fulli, 2022) sheds light to the situation. In order to proceed with a smart meter roll-out or not, the several countries first perform a Cost-Benefit Analysis. In the following Figure we show the extent at which the European countries have proceeded with their smart meter roll out. For reasons of completeness, we also give the situation with respect to the decision on smart meter roll-outs based on the CBAs performed.

As it can be seen from the figures, the objective of smart meters covering 80% of the electricity consumers is not within reach. It is stated that the target reached by 2020 has been as low as 43% - circa 123 million smart meters.

Figure 25: Smart meter roll-out status in Europe and information on national smart meter roll-out decision.



Source: (Vitiello, Andreadou, Ardelean, & Fulli, 2022).

Only 5 countries have reached a smart meter roll-out of more than 90%, namely: Italy, Sweden, Finland, Estonia and Spain. However, there are countries that have reached more than 70% (and below 90%) regarding their smart meter roll-out, namely: Malta, Slovenia, the Netherlands, Luxembourg, France, Denmark. On the other hand, Latvia and Portugal are at a good stage, having reached 50%-70% of their smart meter roll-out. Austria, Greece and the UK have reported to have reached between 20%-50% of their national smart meter roll-out. It should be noted here, specifically for Greece that the progress is mainly in the industrial sector, whereas little has been done in the residential sector, where the tender for a massive smart meters roll-out needs to be published again in 2022; thus, no wide-scale roll-out has taken place yet. It is noteworthy that for many countries the smart meter roll-out has hardly initiated. Such countries are: Croatia, Hungary, Ireland, Poland, Romania, Belgium, Czech Republic, Germany, Lithuania, Slovakia. For Germany, the green light for installing smart meters was only given early 2020, thus the procedure is still at an early stage (Mordor Intelligence, 2021). Particularly for Ireland, the CBA turned negative after an initial positive one back at 2014. On the contrary, Latvia and Portugal passed from a negative CBA to a positive one.

Another interesting fact to mention is that the differences in the CBAs outcomes are mainly due to the models used for these CBAs calculation (World Bank Group, 2018). In countries like Sweden, Finland, Italy, Netherlands, Estonia, Austria a traditional cost-recovery and justification model has been used, whereas in countries like Germany, Belgium, Portugal, Poland, Cyprus it has been not easy to balance the costs with benefits, also due to the fact that few incentives were given to the respective DSOs for this scope.

Given the fact that smart meters are being installed widely all over the world, it is obvious that they become a key-actor for the smart grid. Thus, it is important to summarize the functionalities and services offered in different countries. A recently published report from ACER in late 2021, (ACER, 2021) sheds light to this situation.

The most common functionalities of smart meters are summarized as follows:

- Billing services in accordance to actual consumption data
- Data communication should respect cyber security aspects
- In-house display
- Historical consumption and real-time consumption data available to consumers

In addition, it is stated in the same report, that:

- 17 countries offer detailed information via a meter interface about consumption data, like day and time the consumption took place. Such countries are: Austria, Belgium, Cyprus, Germany, Denmark, Spain, France, Ireland, Italy, Luxembourg, Latvia, Malta, Netherlands, Portugal, Romania, Slovenia and Norway.
- 17 countries offer information on cumulative consumption data, i.e. for the last 3 years. Such countries are: Austria, Cyprus, Germany, Denmark, Finland, France, Great Britain, Italy, Latvia, Luxembourg, Lithuania, Malta, Netherlands, Norway, Portugal, Sweden, Slovenia.
- 6 countries offer information on the impact on the environment caused by electricity consumption.

From the customer perspective, through smart meters, customers can benefit from price incentives / different price contracts and adjust their consumptions according to such incentives. In particular:

- Consumers in 14 countries can have time-of-use contracts, where price differs according to the time of electricity consumption. These countries are: Austria, Germany, Denmark, Estonia, Finland, France, Great Britain, Italy, Latvia, Lithuania, Malta, Portugal, Romania, Slovenia.
- Consumers in 11 countries can benefit from real-time or hourly energy pricing. These countries are: Austria, Belgium, Germany, Denmark, Estonia, Finland, Great Britain, Latvia, Netherlands, Norway, Sweden.
- Consumers in 6 countries can have access to remote control products. These countries are: Austria, Germany, Finland, France, Norway, Sweden.
- Consumers in 5 countries can have access to critical peak pricing products. These countries are: Denmark, France, Latvia, Norway, Slovenia.

It is worth noticing that dynamic tariff contracts are offered also by countries where the smart meter roll-out has not been completed yet. Such an example is Germany, where it is mandatory for suppliers with more than 200,000 customers to offer dynamic tariff contracts. In most countries with such contracts, information is offered to consumers about the usage of electricity products and different tariffs, i.e. Austria, Belgium, Spain, Finland, Great Britain, Lithuania, Latvia.

At this point, we examine the different technologies that can be supported by smart meters. When the implementation of smart meters started and at the beginning of the roll-outs, two popular technologies for data transmission was Narrow-Band Power Line Communications (NB-PLC) and RF-Mesh. Later on, other technologies have become popular, like the Broadband PLC and Low-Power-Wide-Area Networks (LPWAN), which guarantees long-range and low-power. An example is the LoRaWAN technology, which enables real-time data transmission and better management of the network (Mordor Intelligence, 2021). Typically, the smart meter has a communication module on which various technologies can be implemented, like Power Line Communications, RF-mesh, Wi-Fi, RS485 (World Bank Group, 2018).

It is worth mentioning at this point, that whereas in many countries the deployment of first generation smart meters takes place (AMI 1.0), there are certain utilities that have proceeded with the deployment of second generation smart meters (AMI 2.0). The difference from a technological point of view lies in the fact that AMI 2.0 can support more business use cases (Capgemini), (ESMIG, n.d.). The following figure shows the business use cases that can be supported by AMI 1.0 and AMI 2.0 respectively.

Figure 26: Business Use Cases that can be supported by different AMI technologies.

Source: (Capgemini)

Similarly to the European case, also outside Europe, the technologies used by smart meters vary a lot. Table 6 shows the potential technologies for smart meters (U.S. Department of Energy - Office of Electricity Delivery and Energy Reliability, 2016). It is stated that choosing the most suitable technology can depend on various parameters, like the bandwidth, latency, the available budget to invest and cybersecurity issues.

Table 6: Technologies for smart meters.

Wired	**Wireless**
Fiber optic cable	Radio Frequency (RF) – mesh network
Power Line Communications (PLC)	RF – point to multipoint
Telephone dial-up modem	RF - cellular
Digital subscriber line (DSL)	

Source: (U.S. Department of Energy - Office of Electricity Delivery and Energy Reliability, 2016).

HES (or MDAS) and MDMS

Regarding the infrastructure for receiving and processing data from smart meters, which also comprise the AMI, typically, these are the Head-End System or Meter Data Acquisition System and the Meter Data Management System. The HES (or MDAS) is first in the hierarchy, in the sense that data is forwarded from the HES to the MDMS as a final step of transmission. In general, the MDMS allows storage of smart meter data and can export the data to other systems and services. Both for the HES/ MDAS and the MDMS there are several options with respect to the possible manufacturers and the final choice is up to the energy provider and its needs.

Apart from the technological systems that comprise the AMI, it is important to have business applications that make the most out of the whole system. In fact, business applications are the last element that complete the AMI system. A list of business processes/ applications is shown below, (ESMIG, n.d.):

- **Management of Meter Lifecycle** – related to the installation of meters, reporting of their operation, replacement, etc.
- **Processing of Discrete Meter Readings** – related to uploading of meter readings, scheduling, processing of meter data, verification and correction of data.
- **Time Series Data Handling** – related to elaborating further on the smart meter data, processing of time series data as well as uploading such time series data and its verification and management.
- **Energy Settlement and Regulatory Compliance** - related to scheduling and planning of energy settlement and its execution.
- **Metering Analytics** - related to the analysis of meter readings and in general time series analytics.

5.1.2 R&I&D funding

At this point, we examine specifically the costs and investments that have been made in the area for AMI implementation not only in Europe but also at global level. It is noted here that the extent of investments, especially at global level can be seen also by the smart meters penetration level.

In Europe, it is estimated that investments of 35 million euros have been made only for smart meter installations by the year 2020, whereas 3.08 billion euros have been invested in general for smart grid projects, for a total of 407 projects (Vasiljevska, Gangale, Covrig, & Mengolini, 2021). Specifically for projects, there is a variety of projects that involve AMI; in the latter report, there have been analysed 7 projects categories:

1. *smart network management,*
2. *demand side management,*
3. *integration of distributed generation and storage,*
4. *renewable energy sources,*
5. *smart city,*
6. *e-mobility and*
7. *other*

For these categories, advanced metering infrastructure is fundamental, especially for demand side management, smart city and smart network management. It should be noticed that the demand side management projects have been the prevailing category since 2007 and until 2020, revealing the importance of AMI for the successful deployment of these projects. If we consider only the three above categories, where smart meters are fundamental for their realization, it is noticed that there are at least 250 out of the 407 projects realized in Europe. This means that smart meters and AMI in general play a key role for the majority of the smart grid projects realized the last years. For these 250 projects, investments of 1.825 billion euros have been made, which reveals the extent of smart meters penetration and importance in the smart grid.

In the USA, one of the main funding sources for smart grid projects has been the Smart Grid Investment Grant Program (SGIG). AMI deployment has accounted so far for approximately $4.439 billion (U.S. Department of Energy - Office of Electricity Delivery and Energy Reliability, 2016).

With respect to other countries, investments in Brazil, account for $709.30 million of investments for AMI installation projects until 2018 (World Bank Group, 2018).

In general, at worldwide level, it has been estimated that the AMI market came up to $10.47 billion in 2020 and it has been forecasted that this value will climb up to $22.98 billion by 2026, (Mordor Intelligence, 2021), meaning that the investments are planned to be more than doubled in the following years. All of the above reveal the importance of the smart meters at worldwide level with very high investments and a significant perspective for further growth for the future. It can also be concluded that Europe is one of the leaders in the AMI domain, with major investments and projects running.

5.2 Value Chains

In this Section, we give information about the value chains: we present the functionalities smart meters should have, according to the "Clean energy for all Europeans" and the target set by different countries to reach the smart meter roll-out; we also give an analysis of socio-economic issues, like on which use cases smart meters can be used; we finally present the potential vendors of smart meters, including European or non-European vendors.

5.2.1 Value Creation

In Europe, many countries are proceeding with their national smart meter roll-outs, whereas others have already completed it. It is noticeable, that the situation varies a lot among different countries. The newly adopted legislation, the "Clean Energy for all Europeans" shapes the smart meter roll-out for the countries, which have not completed it. (Vitiello, Andreadou, Ardelean, & Fulli, 2022). Table 7 shows the summary of main provisions on smart meter data related functionalities, which had been introduced by the Clean Energy Package.

Table 7: Summary of main provisions on SM data related functionalities introduced by the Clean Energy Package.

Smart Metering Data-Related Functionalities According to the New Directive
Smart meters send information about consumption to end-users: historical consumption and near real-time consumption
Smart meters should be aligned with privacy, data protection and cybersecurity law rules
Smart meters should send information about the electricity generated by prosumers and inserted into the grid
Smart meters data are owned by the consumers and can be transmitted to third actors
Smart meters' functionalities regarding consumption readings should become known when they are installed or a priori.
The predefined resolution for time, set by the electricity market, should be followed regarding consumption and/or generation smart meter measurements

Source: (Vitiello, Andreadou, Ardelean, & Fulli, 2022).

In this Section, we examine the penetration of smart meters for the future, according to recorded estimations. In Europe, it is stated that some consumers will not be equipped with smart meters by 2024 (ACER, 2021). Table 8 shows the expected year, when the target of 80% regarding smart metering roll-out will be reached.

Table 8: Target year at which 80% of electricity smart meters will be installed

Austria	In 2020	**Latvia**	Before 2024
Belgium	After 2024	**Lithuania**	Before 2024
Bulgaria	No info	**Luxembourg**	in 2020
Croatia	No positive roll-out decision	**Malta**	No info
Cyprus	No info	**Netherlands**	No national law stating this, despite positive roll-out
Czech R	After 2024	**Norway**	Before 2020
Denmark	In 2020	**Poland**	After 2024
Estonia	Before 2020	**Portugal**	No national law stating this, despite positive roll-out
Finland	Before 2020	**Romania**	After 2024
France	In 2020	**Slovakia**	No positive roll-out decision
Germany	After 2024	**Slovenia**	in 2020
Greece	No national law stating this, despite positive roll-out	**Spain**	Before 2020
Hungary	No national law stating this, despite positive roll-out	**Sweden**	Before 2020
Ireland	In 2024	**United Kingdom**	In 2024
Italy	Before 2020		

Source: (ACER, 2021).

It is noticed, that the target year for many countries has been shifted from 2020 to the future. The covid pandemic has contributed to delays in implementing the smart meters and thus shifting the target year. On the other hand, there are countries, like Greece, Hungary, Malta, Portugal that have not declared a new target year, although they have a positive CBA outcome bonding them for a smart meter roll-out (Vitiello, Andreadou, Ardelean, & Fulli, 2022).

5.2.2 Socio economic analysis

In this Section, we present the characteristics of smart meters that can result in specific benefits to consumers. We also present cost-related issues.

According to the new Directive, the characteristics of the smart meters and the characteristics of the smart metering data-related functionalities are given as follows:

Table 9: Summary of main provisions on SM systems introduced by the Clean Energy Package.

Characteristics of SM According to the New Directive
Smart meters should be coupled with energy management systems
Part of smart meters costs should be attributed to consumers
A revision of a negative roll-out decision and the relevant CBA should be performed at least every 4 years.
Already existing smart meters should be replaced within 12 years from the moment the Directive enters into force

Source: (Vitiello, Andreadou, Ardelean, & Fulli, 2022).

According to (ESMIG, n.d.), there are various use cases that can be realised by the deployment of smart meters, from which the end customers can benefit. The following figure gives a list of such use cases that can attribute benefits to the future society.

Figure 27: Use Cases that can be realised by smart meters

Use Case	Description	Relevant for Retailer	Relevant for TSO/DSO
Billing (Meter to cash)	Provisioning of metered data or billing determinants to the billing system, invoicing and payment	X	X
Energy Settlement	Determination and aggregation of energy data according to certain market rules and transfer of the results to other participants (ex-post)		X
Market Communication	Exchange of master and transactional data between market participants in deregulated markets	X	X
Energy Portfolio Management	Calculation of complete demanded energy consumption vs. available capacity (short – mid – long-term); transfer of delta to trading hubs	X	
Sales Quotation Process	Creation and administration of sales quotations based on projected energy consumption	X	
Analytics	Analysis of energy data such as the identification of customer segments and consumption patterns, forecast of peak demands, etc.	X	X
Schedule Management	Calculation of demanded energy consumption based of certain rules; transfer of data to other market participants (ex-ante)	X	
Customer Insights	Provides consumers the ability to visualize their energy consumption as part of a portal or app	X	
Product Design	Development of new energy products based on consumption data	X	
Billing Simulation	Simulate future bills for sales and other processes	X	

Source: (ESMIG, n.d.)

5.2.3 Role of EU companies

Regarding the key smart meter vendors, these are listed as follows (list not exhaustive) (Allied Market Research, 2021). The list comes in accordance with last year's report, where the main smart meters vendors had been firstly identified.

Table 10: Key smart meter vendors.

Vendors			
Itron	Siemens AG	Mueller Systems LLC	General Electric
IBM Corporation	Tieto Corporation	Trilliant Inc.	Elster Group GMBH
Landis + Gyr	Aclara Technologies LLC	Schneider Electric SE	Secure
Sensus Solutions	Cisco Systems Inc.	Honeywell International In	

Source: (Allied Market Research, 2021).

It should be noticed that the major part of the smart meters vendors presented above, are multinational companies with offices all over the world. Such examples are: Itron; IBM; Landis+Gyr; Siemens; Aclara; Cisco Systems Inc; Trilliant; Schneider Electric; Honeywell International; General Electric; Elster Group GMBH; Secure. It should be mentioned that Landis+Gyr has its headquarters in Europe, as well as Schneider Electric and the Elster Group. In addition, Sesnus Solutions and Tieto Corporation are European companies. It can be concluded that European companies play an important role in the market with leading companies in the field and also multinational companies with offices and businesses in Europe.

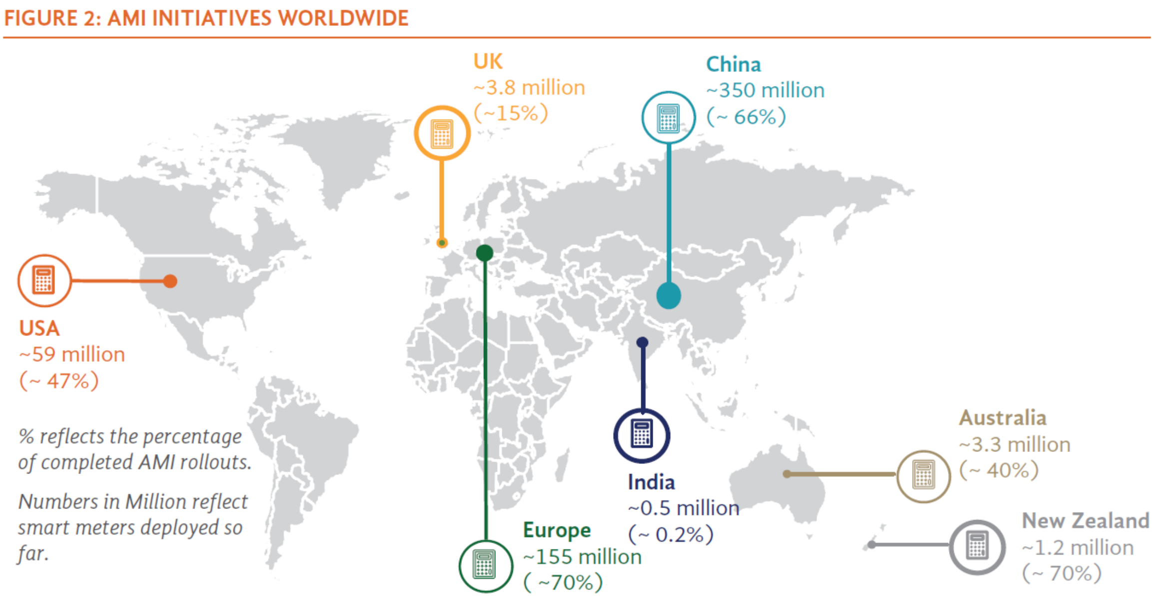
5.3 Markets, Trade and Resources

5.3.1 Global Market Analysis

In this Section, we present the global market and value chain analysis, including the smart meter roll-out status outside Europe. It should be mentioned that there are great differences in the world with respect to the extent of smart meters penetration, as it is expected. This Section helps the reader have a fair comparison of the European situation with the one at worldwide level.

There are around 1.2 billion smart meters deployed worldwide (World Bank Group, 2018). The region where smart meter roll-out is behind, is South Asia; however, the know-how developed by the smart meters installation globally, will be of help also for the regions where a lot needs to be done still. On the other hand, Europe, United States of America, Canada and Australia are considered as the early adopters of AMI. This comes in accordance with the findings of last year's project, where it was shown that specific regions are the early adopters, in other regions there have been announced important investments to be made, whereas in other parts of the world the installation of smart meters is mainly at a very early stage. The following figure shows the smart meter installation worldwide in rough terms.

Figure 28: Smart meter installations worldwide.



Source: (World Bank Group, 2018).

In the USA, the Smart Grid Investment Grant (SGIG) has been one of the main funding sources for projects in the smart grid area including smart metering infrastructure implementation (U.S. Department of Energy - Office of Electricity Delivery and Energy Reliability, 2016). In the USA, there is an annual report on demand response and advanced metering infrastructure issued by the Federal Energy Regulatory Commission according to the Energy Policy Act of 2005 (EPAct 2005). The last update has been in December 2021, (Federal Energy Regulatory Commission) and its results are worth mentioning. According to it, between 2018 and 2019 there has been a 9% annual increase in the smart meters installations, resulting in a total of at least 94.8 million smart meters, standing for the 60.3% of all meters in the country. The report states that in some regions, this percentage is even greater, reaching numbers greater than 65% as penetration rates. In addition, it is stated, that another source, the Edison Foundation's Institute for Electric Innovation, gave a greater number, resulting in 99 million smart meters and a 63% of penetration rate.

In Canada, 7.5 million smart meters have been installed in the regions of Ontario and British Columbia of Canada (World Bank Group, 2018). The country is keen on energy policy aiming at contributing in climate neutrality issues, and already in 2010 it was announced the objective of 90% emissions-free in the electricity sector by the year 2020.

For Brazil, information obtained only for one energy provider (World Bank Group, 2018) states that 55,000 smart meters have already been installed. In overall, it is estimated that within the year 2022, 462,000 smart meters will have been installed in the country. As a second stage, 1 million smart meters will be scheduled to be installed (Mordor Intelligence, 2021).

In Australia, 680,000 smart meters have been installed only in the region of Victoria by one energy provider (World Bank Group, 2018).

In India, 51,500 smart meters have been installed, whereas data regards one energy provider with 3 million customers in Kolkata. A second energy provider in the area of New Delhi has installed 75,000 smart meters out of 1.6 million customers (World Bank Group, 2018). Specifically for India, it has been made public in 2020 that an investment will be made (presumably circa 14,604 USD) so as to install smart meters in the country (Mordor Intelligence, 2021).

In Saudi Arabia, it is foreseen to have been installed around 12 million smart meters by the year 2025 (Mordor Intelligence, 2021).

According to the same source, the same year (2025) it is predicted to have 650 million smart meters installed in China, whereas the equivalent first generation smart meters are estimated to have already been installed. The second generation smart meters are already being installed (expected to finish in 2025).

The equivalent estimation for Japan and South Korea is at 82 million and 22.5 million smart meters already installed (Mordor Intelligence, 2021).

Table 11: Some Vendors for the AMI system (list non-exhaustive).

MDAS / HES vendors	MDMS vendors
Itron	Oracle
Sensus, Big Cellular	Itron
Verizon	L&G
L&G	Siemens
Siemens	SAP

Source: (World Bank Group, 2018).

6 Home Energy Management Systems

6.1 Technology Development and Trends

The term home energy management system (HEMS) denotes a combination of hardware and software solutions aimed at efficiently managing the energy usage of a home. The hardware generally includes a series of sensors and actuators within the home that are all connected to a central hub. A software platform is used for monitoring and control purposes, managing also the exchange of data and communications. HEMS are considered a key technology in the decarbonisation of the electricity system and in the transition to a smart grid paradigm, as they allow to reduce energy consumption and enable flexibility and regulation capabilities on the consumer side.

The Home Energy Management (HEM) market has been undergoing significant change (Zafar, Bayhan, & Sanfilippo, 2020). Smart meters, as energy managers, home area networks (HANs), and smart appliances never materialized at scale. Instead, other technologies behind the meter have grown in importance. Smart meters still matter for HEM; the data flowing from these meters remains an important tool for utilities. But the number of other HEM information channels has grown in the past 5 years and that has altered the market's dynamics. These new data streams come from smart thermostats, smart plugs, smart lighting, as well as DERS such as solar PV, EVs, and other technologies.

More channels have meant not only an increase in the amount of energy management data but also data that is more nuanced. For instance, combining data from a smart meter, a smart thermostat, and a home's physical aspects means the insights and potential actions can be much more personal to a home and its occupants. Additionally, residential customers now also have options for efficiently managing their energy consumption without a smart meter.

As a result, utilities have had to change their thinking about how they play in the HEM space in order to engage consumers. Utilities now emphasize advanced analytics, personalization, and targeted engagement with energy users. These features have become mainstream elements of HEM solutions. Current HEM solutions range from direct-to-customer energy monitoring apps to white-label software platforms for utility customers that are then rolled out to end users. All solutions support basic energy monitoring functionality, alerts, and report features. More advanced platforms support personalization and disaggregation and help identify faulty equipment or similar appliance-level data.

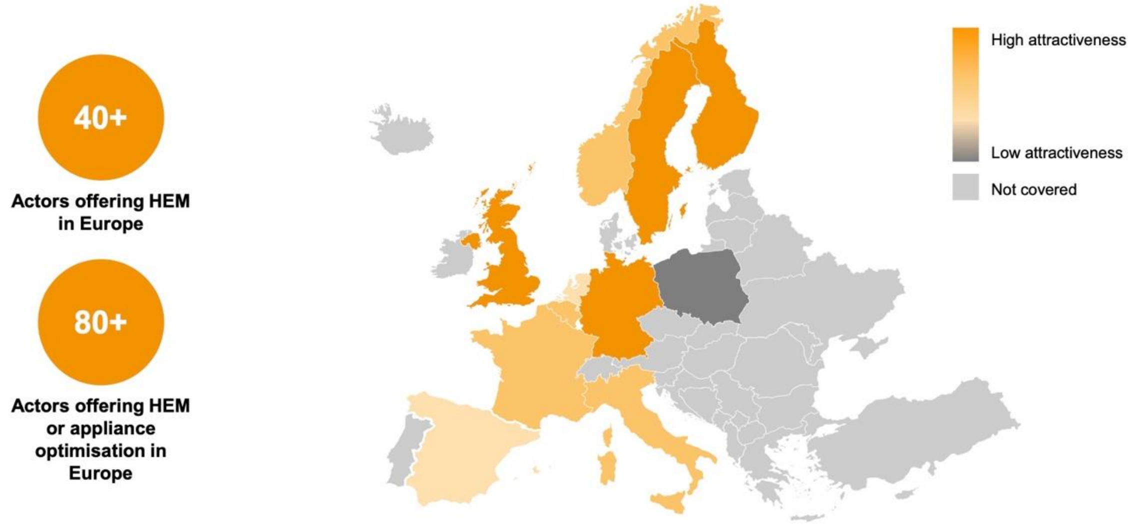
Large software companies such as Google, Apple, and Cisco now distribute HEMS products. This trend emphasizes the increasing role of software engineering for IoT devices. Google's Home, Apple's Siri, and Cisco's energy management service are examples of home energy management services. Cisco's energy management service can integrate products and services that control HEMSs.

The GE digital power meter is yet another device that is easily integrated with a Building Management System (BMS) using the Modbus protocol, and incorporates straightforwardly with the electrical distribution system. Traditional audiovisual vendors such as Control4, AMX, and Crestron also manufacture products for home energy management and control. Crestron and Control4 run products on proprietary protocols. However, they provide interfaces to some of the most popular open protocols.

6.2 Value Chains

Today, when we talk about HEM to organisations across Europe, it is at the centre of the innovation roadmaps, or already part of the day-to-day business. It is still much localised, with a majority of them focusing on one country, but some could quickly find the right recipe and become major players in multiple countries.

Figure 29: HEM actors in Europe

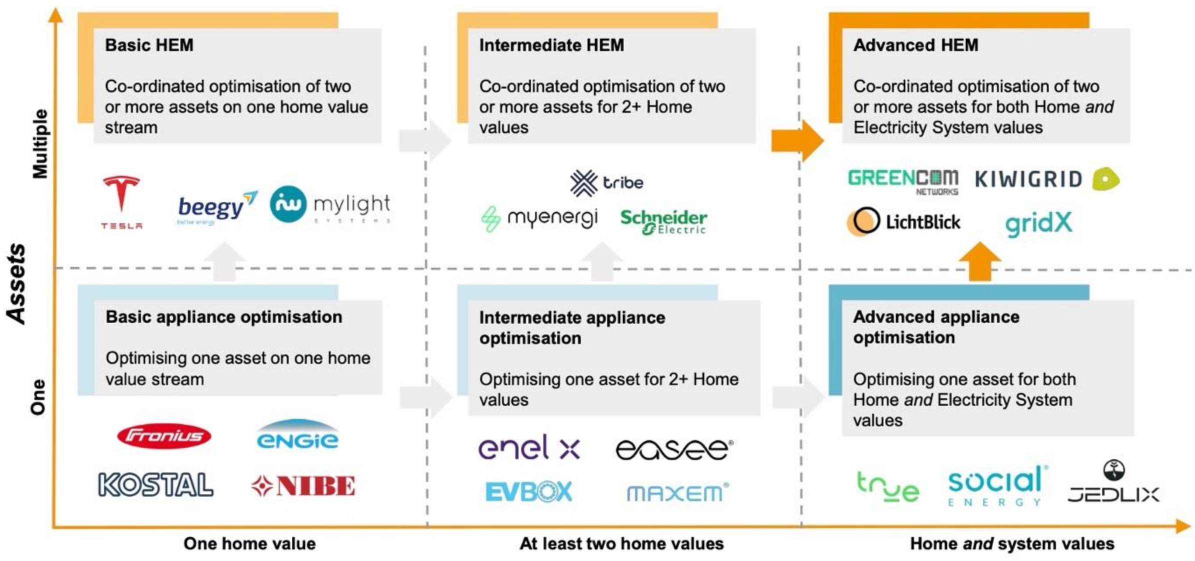


Source: (Delta-EE, 2022).

Europe is a region with a variety of aspects and the potential to drive up the demand for the home energy management systems in the region due to the significant production of smart meters in respective countries. The government of the UK has increased its focus on rolling out initiatives with the goal of reducing the emission of greenhouse gases by rapidly installing smart meters across the country. Moreover, Germany is also focused on following a resembling strategy as of the above-mentioned countries. Therefore, these factors are expected to boost the growth and demand for home energy management solutions in the regional market during the forecast period.

The German market dominated the Europe Home Energy Management Market by Country in 2020, and is expected to continue to be a dominant market till 2027; thereby, achieving a market value of $458.9 million by 2027. The UK market is anticipated to grow at a CAGR of 17.7% during (2021-2027). Additionally, The France market is expected to showcase a CAGR of 20.3% from (2021 - 2027).

Figure 30: Main types of HEM.

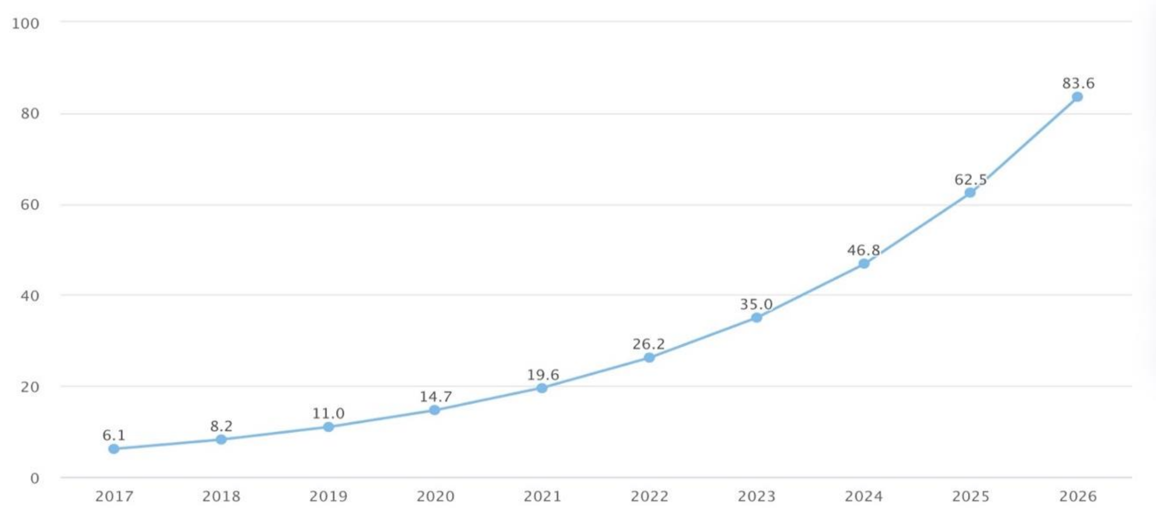


Source: (Global Market Insights, 2017).

Based on Product Type, the market is segmented into Lighting Controls, Programmable Communicating Thermostats, Advanced Central Controllers, Intelligent HVAC Controllers, and Self-Monitoring Systems and Services. Based on Technology, the market is segmented into Ethernet, Z-Wave, ZigBee, Wi-Fi, and Other technologies. Based on Offering, the market is segmented into Software, Services, and Hardware. Based on countries, the market is segmented into Germany, UK, France, Russia, Spain, Italy, and Rest of Europe (Research and Markets, 2021).

The estimated number of smart homes (single occupant homes and households in multi-unit dwellings) throughout the years in Europe is shown in **Figure 31**.

Figure 31: Smart homes in Europe (millions)



Source: (Statista, 2022)

6.3 Markets, Trade and Resources

The global home energy management systems market reached a value of US$ 2.1 Billion in 2021. Looking forward, IMARC Group expects the market to reach US$ 6 Billion by 2027, exhibiting a CAGR of 16.5% during 2022-2027 (IMARCgroup, 2022).

Key players in this competitiveness landscape are Honeywell International, Inc., Google Nest Vivint, Inc., General Electric Company, Ecobee, Inc., Alarm.Com, Comcast Cable (Xfinity), Panasonic Corporation, Ecofactor, Inc. and Energyhub, Inc. It is imprtant to notice that none of these companies is European.; most of them are based in North America and one of them in Japan.

Figure 32: Global Home Energy Management Systems Market 2021-2025.

Source: (Business Wire, 2020).

6.3.1 Market Projections

Home Energy Management System Market size would expand over 2021-2027 driven by the growing need for sustainable energy and increased consumption of energy for household purposes including cooking, heating, and more. Additionally, rising feasibility of battery and small-scale power storage is also to catalyze the industry progression through the coming years. The HEMS market is also slated to record massive gains owing to its positive attributes including monitoring the usage of electricity, effective use of solar energy, and management of backup with the help of battery storage. The growth in home energy management system market is also expected to come from increasing investments in the smart grid infrastructure worldwide. Various governments and energy conglomerates have been working towards revamping the existing smart grid infrastructure to effectively serve the mounting energy demand by the country's citizens. For instance, the European Investment Bank (EIB) and Iberdrola inked a 550 million euro green loan deal to support the development of smart grids in Spain. Increased prominence of home energy management technology worldwide would further augment the business space by 2027 end. However, high deployment cost of these systems would potentially obstruct the market growth over the analysis time frame. HEMS market is gaining potential from device monitoring and control applications. These systems need to be able to control and monitor diverse devices and appliances in a home. Device information can be available to the user through either a web interface or tablet/phone application. In order to better monitor and control devices, HEMS is required to offer seamless communication among different smart devices and sensors through ZigBee, Wi-Fi, and Z-Wave, and more. ZigBee powered home energy management system market is projected to expand through 2027, as these modules are generally used to monitor the energy consumption of home appliances and lights. ZigBee is a low-cost, wireless, and low-power mesh networking standard. Its low cost enables the technology to be expansively used in wireless control and monitoring applications, while the low power usage allows increased life with smaller batteries. North America and Asia Pacific are touted to emerge as lucrative regional hubs for the home energy management system industry. North America HEMS market would grow through 2027 owing to the rising technological advancements and increased adoption of wireless technologies like Z-Wave, Wi-Fi, and ZigBee for energy management. Besides, the mounting demand for Home Area Network devices has further strengthened the regional business space. APAC home energy management system market would observe significant gains throughout the forecast time frame, on grounds of the rising inclination among consumers to control and manage their electricity consumption. Some of the prominent players operating in the global home energy management system industry are Cisco Systems, Panasonic Corporation, General Electric, Hitachi Ltd., Honeywell International, Inc., and Johnson Controls International, amongst others. These players are engaged in various industrial strategies like collaborations, partnerships, and product launches, letting them gain a significant position in the global market space.

COVID-19 impact on HEMS market forecast

The COVID-19 pandemic outbreak has negatively impacted the power industry globally (Global Market Insights, 2022). Given the current scenario, various device producers across diverse regions were prompted to shut down their manufacturing facilities and services as countries followed restrictions put forth by the governments to deal with the pandemic. Moreover, the decline in business activities has further affected home energy management system.

7 Conclusions

Within the broad scope of smart grid technologies that are shaping the evolution of the electricity system, the present report has analysed five distinct topics that have been selected for their relevance and timely importance: Transmission network innovation, Grid-Scale storage services, Electric Vehicle smart charging, Advanced metering infrastructure and Home energy management systems. Each topic has been analysed in detail in the previous sections and the main conclusions regarding the development, value chains, markets and sustainability of each technology are summarized next.

Transmission network innovation

Substantial expansion and capacity upgrades of the transmission infrastructure are required to integrate the large amounts of renewable production needed to decarbonise the European economy. Failing to proper invest into grid reinforcements might result in grid congestions which can be resolved via expensive and CO2-emission intensive re-dispatching measures. However, from a different perspective, overinvesting into network capacity can jeopardise the integration of new flexibility providers which have start to emerge at the distribution grid level. Some main insights have emerged on the transmission network investments needs and on the expected actions for the future:

- According to the latest study on the power sector by the consultancy, Monitor Deloitte, 70% of the planned Renewable Energy Sources (RES) in the decade 2020 – 2030 will be connected to distribution electricity networks. As a result, important levels of investment are foreseen to modernize and smarten distribution grids as well. Remarkably, in the latest DSO Observatory 2020 exercise, 77% of the participants in the survey declared that they are preparing a multiyear network development plan.
- From a planning perspective, the long-term DSOs investments plans combined with the TYNDP will help policy makers, national regulators and stakeholders in the power sector assess how to guide investments towards a more efficient system integration strategy in T&D sectors.
- Notably, non-wire investments, aimed at more efficient monitoring and control of grids, should be prioritized given the increasing demand for metals like aluminium and copper required for electric cars and batteries manufacturing.

Grid-scale storage services

Storage assets constitute a fundamental resource for a smooth and cost-efficient decarbonisation of the electricity system. The following points have been highlighted in our analysis:

- Bulk storage can provide a wide range of network services:
    - At an operational level, storage can participate in capacity schemes and contribute to system adequacy by providing additional energy during peak demand;
    - It can support the frequency and voltage regulation of the system;
    - It can be utilized to remove or prevent congestion in the system.
- On investment and market trends:
    - It is expected that, in the next 10 years, the growth of new grid storage assets will be exponential all over the world, reaching a cumulative 160GW of power by 2026 and 360 GW by 2030;
    - This trend is led by the US and China, while the EU is lagging in terms of investments and new storage capacity.
    - This is largely related to stronger grid in the EU and the selected market-based approach. The latter normally delivers results more cost efficiently in the long term.
- The substantial increase in storage penetration follows a significant reduction in the cost of the technology. The reduction of batteries cost by 2030 is expected to be in the order of -40%, while the

overall costs of storage grid assets are estimated to decrease by about -30% in the same period. It is necessary to take actions that remove the existing regulatory barriers, i.e.:

    - A redefinition and adjustment of the ancillary services in order to account for specific technical features of storage, such as its limited energy capacity;

- The subject of grid-scale services provision by storage assets has been widely investigated in the context of the H2020 programme, where 36 different research projects have analysed in some form the topic of electricity network solutions that envisage a significant participation of storage technologies, with a total funding of 357.5 M€
- In the Horizon Europe programme, the role of storage in the provision of grid-scale services is considered in the wider context of the "Climate, Energy and Mobility" cluster and in particular in its destination "Sustainable, Secure and Competitive Energy Supply". In the 2021-2022 work programme of the cluster, 6 different topics include in their scope the role of storage in supporting system operation, for an overall total budget of 147 M€.

Electric vehicles smart charging

The EV Smart Charging market is becoming more and more mature since its initial infrastructure rollouts in the early 2010. Forecasts sees this market as one of the fastest expanding. The main points that have come out can be summarized as follows:

- The number of projects, pilots, and demonstrations have grown alongside development of the larger EV market, whereas there is increased focus lately on residential applications.
- There is the need to develop common standards to guarantee the interoperability of charging networks and perform V2G operations.
- It is predicted that the impact of electro mobility and EV charging infrastructure on the electricity grid will be in the medium and long term. However, existing grids in major EV markets should be able to handle the added demand by 2030.
- Smart EV charging can alleviate the need for grid upgrades and can mitigate the undesirable impact caused by the increasing EVs penetration on electricity grids.
- From a technological point of view, the technology to support smart EV charging (including its most important types such as V1G, V2G, V2X) is already available and has been tested through many pilot projects.
- Countries such as China, Japan and India, Asia Pacific lead the smart EV charging market, with Europe holding a major share of the global smart EV charging market, in terms of revenue.

Advanced metering infrastructure

With respect to the AMI, a special focus has been put on smart meters' development. We have provided a detailed evidence-based analysis for both Europe and beyond. The main insights for this technology can be summarised as follows:

- In Europe, the smart meter roll-out status varies a lot among Member States, whereas the new legislation, the "Clean Energy Package" forms the regulations for smart meters installations.
- In terms of technologies, NB-PLC has been used widely especially at early stages of smart meter deployment, whereas LPWAN has also emerged. There are numerous key vendors not only for smart meters, but also for the other AMI parts, like the HES and the MDMS.
- At global level, there are 1.2 billion smart meters installed; USA, Canada, EU and Australia are considered early adopters; there is an important boom in smart meters installations in Asian countries

like China, Japan, South Korea; South Asia is considered the area with larger investments predicted for the future in the sector.

- There is a large number of investments worldwide not only performed until now but also planned for the future.

Home energy management systems

Home energy management systems are going to play an important role in the next few years in Europe as they will help Europe's electrification and decarbonisation targets. Already the European directives, like Energy Efficiency Directive (Directive 2012/27/EU) and the Energy Performance in Buildings are putting an emphasis in the technologies of energy management to support the active participation of end users in the optimization of their energy consumption. The following points have emerged from this analysis:

- As flexibility markets mature across Europe, the participation of consumers in Demand Response program will boost the specific market.
- Countries like Germany and France are leaders in Europe. The German market has dominated and is expected to dominate the Europe Home Energy Management Market by Country until 2027, achieving a market value of $458.9 million by 2027. The French market is expected to showcase a CAGR of 20.3% (2021 - 2027).
- Globally, some of the prominent players operating in the home energy management system industry are Cisco Systems, Panasonic Corporation, General Electric, Hitachi Ltd., Honeywell International, Inc., and Johnson Controls International, amongst others. In addition, software companies such as Google, Apple, and Cisco penetrate the market.
- The lack of standardization and the lack of an interoperability index which will indicate which technologies are able to interoperate are still pending issues.

References

ACER. (2021). *Annual Report on the Results of Monitoring the Internal Electricity and Natural Gas Markets in 2020 - Energy Retail Markets and Consumer Protecion Volume.* Retrieved from ACER: https://www.acer.europa.eu/electricity/market-monitoring-report

Alexander Krug, T. K. (2021). *Cutter, an Arthur D. Little Community*. Retrieved from The Future of Electric Vehicle Charging: https://www.cutter.com/article/future-electric-vehicle-charging?page=3

Allied Market Research. (2021). *Advanced Metering Infrastructure (AMI) Market by Product Type (Smart Metering Devices, Solutions, and Services) and End User (Residential, Commercials, and Industrial): Global Opportunity Analysis and Industry Forecast, 2021–2030.* Retrieved from Allied Market Research: https://www.alliedmarketresearch.com/ami-metering-market-A12092

Allied Market Research. (2021). *Home Energy Management Market By Offering (Hardware, Software, and Services), Product Type (Lighting Controls, Self-Monitoring Systems and Services, Programmable Communicating Thermostats, Advanced Central Controllers, and Intelligent HVAC Controllers) an.* Retrieved from Allied Market Research: https://www.alliedmarketresearch.com/home-energy-management-market?msclkid=54413b15b02f11ec99fb7254904178f5

Bhattacharyya, S., Van Cuijk, T., & Fonteijn, R. (2019). Integrating Smart Storage and Aggregators for Network Congestion Management & Voltage Support in a Pilot Project in Eindhoven. *25th Cired International Conference on Electricity Distribution*.

BloombergNEF. (2021, November 15). *Global Energy Storage Market Set to Hit One Terawatt-Hour by 2030.* Retrieved from BloombergNEF: https://about.bnef.com/blog/global-energy-storage-market-set-to-hit-one-terawatt-hour-by-2030/#_ftn1

Business Wire. (2020). *New Home Energy Management Systems Market Research 2021-2025 | Post-Pandemic Market Analysis for the New Normal.* Retrieved from Business Wire: https://www.businesswire.com/news/home/20201229005302/en/New-Home-Energy-Management-Systems-Market-Research-2021-2025-Post-Pandemic-Market-Analysis-for-the-New-Normal-Technavio

Cameron, M. (2022). *Battery storage could capture a third of new pan-European frequency response market*. Retrieved from Energy Storage News: https://www.energy-storage.news/battery-storage-could-capture-a-third-of-new-pan-european-frequency-response-market/

Capgemini. (n.d.). *Capgemini.* Retrieved from Next-Gen AMI: https://www.capgemini.com/ch-en/wp-content/uploads/sites/43/2020/09/AMI-Brochure_Final-1.pdf

CEI, C. E. (2022, 03). *Reference technical rules for the connection of active and passive.* Retrieved from Comitato Elettrotecnico Italiano: https://www.ceinorme.it/doc/norme/18308.pdf

Chami, E., & Naim. (2020, November 9). *Europe's energy storage transformation.* Retrieved from Energy Storage News: https://www.energy-storage.news/europes-energy-storage-transformation/

Delta-EE. (2022). *Home Energy Management Service.* Retrieved from Delta-EE: https://www.delta-ee.com/research-services/home-energy-management/

Derrick, T. a. (2022). Retrieved from Manufacturers: https://www.powerandcables.com/manufacturers

Dudley, G. (2020). *Energy storage market & policy developments in China.*

ECOS. (2020). *Electric vehicle smart charging: the key to a sustainable grid.* Environmental Coalition on Standards.

EIA. (2021). *Battery storage in the United States: an update on market trends.*

Eirgrid. (2022). *System Services Contract.* Retrieved from Eirgrid website: https://www.eirgridgroup.com/site-files/library/EirGrid/WFPS-OR-Test-Report-template.docx

El Chami, N. (2020). *Europe's energy storage transformation*. Retrieved from Energy Storage News: https://www.energy-storage.news/europes-energy-storage-transformation/

Elaad. (2020). *Smart Charging Guide.* Elaad nl.

Energy Storage North America. (2018). *SCE Distribution Energy Storage Integration (DESI) Pilot 1.* Retrieved from Energy Storage North America: https://www.esnaexpo.com/portfolio/sce-distribution-energy-storage-integration-desi-pilot-1/

Energy Transition Expertise Centre. (2022). *Study on Energy Storage.*

ENTSO-E. (2021). *European Electricity Transmission Grids and the Energy Transition: why remuneration frameworks need to evolve.*

ENTSO-E. (2021). *RDI Implementation Report 2021-2025 - Project concepts for delivering the ENTSO-E Roadmap 2020-2030.* ENTSO-E.

ENTSO-E. (2022). *TYNDP 2022 Projects Sheets.* Retrieved from ENTSO-E: https://tyndp2022-project-platform.azurewebsites.net/projectsheets

ESMIG. (n.d.). *ESMIG Interoperability Demo*. Retrieved from ESMIG Interoperability Demo: https://www.esmig.eu/

European Commission. (2019). *Report on the Implementation of the Strategic Action Plan on Batteries: Building a Strategic Battery Value Chain in Europe.*

European Commission. (2020). *Powering a climate-neutral economy: An EU Strategy for Energy System Integration.*

European Commission. (2020). *Study on energy storage – Contribution to the security of the electricity supply in Europe.*

European Commission. (2021). *Strategic Energy Technology Plan - Implementation plan - Action 4: Increase the resilience and security of the energy.* Retrieved from European Commission: https://setis.ec.europa.eu/system/files/2022-02/SET%20Plan%20ENERGY%20SYSTEMS%20Implementation%20plan.pdf

European Parliament. (2019). Directive on common rules for the internal market for electricity . *Official Journal of the European Union* .

Federal Energy Regulatory Commission. (n.d.). *2021 Assessment of Demand Response and Advanced Metering.* Retrieved from Federal Energy Regulatory Commission: https://www.ferc.gov/media/2021-assessment-demand-response-and-advanced-metering

Fluence. (2018). *Energy Storage Used in Place of Traditional Infrastructure on the Distribution Grid.* Retrieved from Fluence Energy: https://fluenceenergy.com/wp-content/uploads/2019/04/Project-Spotlight_APS-Punkin-Center_Fluence_PS-006-01-EN.pdf

Forsyth, O. (2022, December). *As frequency regulation markets across Europe saturate, new installations will be driven by new market opportunities and battery energy storage adding new sources of revenues*. Retrieved from IHS Markit Energy Storage Database: https://ihsmarkit.com/research-analysis/as-frequency-regulation-markets-across-europe-saturate-new-ins.html

FSR, F. S. (2022, February 1). *Distributed resources and flexibility.* Retrieved from https://fsr.eui.eu/distributed-resources-and-flexibility/#_ftnref5

Global Market Insights. (2017). *EMS Market Size -Energy Management System (EMS) market outlook: Depleting non-renewable energy resources to boost the industry demand, Trends & Forecast- 2024.* Retrieved from Global Market Insights: https://gminsights.wordpress.com/tag/ems-market-size/

Global Market Insights. (2022). *Home Energy Management System Market Size, COVID-19 Impact Analysis, Regional Outlook, Application Potential, Price Trends, Competitive Market Share & Forecast, 2022 – 2028.* Retrieved from Global Market Insights: https://www.gminsights.com/industry-analysis/home-energy-management-system-market

Global Transmission Report. (2022). *Germany's Network Expansion Plans: BNetzA confirms NEP*. Retrieved from Global Transmission Report: https://www.globaltransmission.info/archive.php?id=44508

GreenFlux. (2021). Retrieved from GreenFlux EV Smart Charging whitepaper: https://www.greenflux.com/whitepaper/

Grids, E. D. (2019). *Making electric vehicles integral parts of the power system, White paper.*

Grids, E. D. (2020). *Position paper on Electric Vehicles Charging.* European Distribution System Operators for Smart Grids.

IEA. (2020). *Innovation in Batteries and Electricity Storage.* Retrieved from IEA: https://www.iea.org/reports/innovation-in-batteries-and-electricity-storage

IEA. (2021, December 1). *How rapidly will the global electricity storage market grow by 2026?* Retrieved from IEA: https://www.iea.org/articles/how-rapidly-will-the-global-electricity-storage-market-grow-by-2026

IEA. (2022). *Global EV Outlook 2022.* IEA.

IEA. (2022). *World Energy Investment 2022.* Paris: IEA.

IMARCgroup. (2022). *Home Energy Management System Market Size and Share 2022-2027.* Retrieved from IMARCgroup: https://www.imarcgroup.com/home-energy-management-systems-market?msclkid=5440b237b02f11ecae445030f049ab37

Insights, G. (2020). *Asset Study on Digital Technologies and Use Cases in the Energy Sector.*

IRENA. (2017). *Electricity storage and renewables: costs and markets to 2030.*

IRENA. (2019). *Electric- Vehicle Smart Charging, Innovation Landscape Brief.* IRENA.

IRENA. (2019). *Innovation Landscape for a Renewable-Powered Future: Solutions to Integrate Variable Renewables.*

IRENA. (2019). *Innovation Outlook, Smart Charging for Electric Vehicles.* IRENA.

Irle, R. (2021). *EV-volumes.com.* Retrieved from Global EV Sales for 2021: https://www.ev-volumes.com/country/total-world-plug-in-vehicle-volumes/

JRC - Joint Research Centre, C. b. (n.d.). European climate-neutral industry competitiveness scoreboard (CIndECS).

Lazard. (2021, October). *Lazard's Levelized Cost of Storage Analysis - Version 7.0.* Retrieved from Lazard: https://www.lazard.com/media/451882/lazards-levelized-cost-of-storage-version-70-vf.pdf

Leuven, K. (2022). *Metals for Clean Energy: Pathways to solving Europe's raw material challenge.*

Liukai Chen, Z. W. (2018). Study on the Effects of EV Charging to Global Load Characteristics via Charging Aggregators. *Energy Procedia, Vol 145*, 175-180.

Marnell, O., Obi, M., & Bass, R. (2019). Transmission-Scale Battery Energy Storage Systems:. *Energies*.

McKenzie, e. (2016). Electrified transportation as a power grid resource. *IEEE Transportation Electrification Conference and Expo.* Dearborn, Michigan.

McKinsey. (2022). *Lithium mining: How new production technologies could fuel the global EV revolution?*

McKinsey&Company. (2018). *The potential impact of electric vehicles on global energy systems, McKinsey Center for future mobility.*

Mordor Intelligence. (2021). *Sample Report on Global Advanced Metering Infrastructure Market (2021-2026).* Retrieved from Mordor Intelligence: https://www.mordorintelligence.com/industry-reports/advanced-metering-infrastructure-market

Next, K. (2022). *FCR, aFRR and mFRR: What is the Difference?* Retrieved from Next - The power of mant: https://www.next-kraftwerke.com/knowledge/afrr

NREL. (2022). *Storage Futures Study - Grid Operational Impacts of Widespread Storage Deployment.* Retrieved from NREL: https://www.nrel.gov/docs/fy22osti/80688.pdf

NREL, N. (2021). *Storage Technology Modeling Input Data Report.*

Orange & Rockland. (2021, April). *Orange & Rockland and Key Capture Energy Begins Operations at O&R's First Energy Storage Facility.* Retrieved from Orange & Rockland.

Research and Markets. (2021). *Europe Home Energy Management Market By Product Type, By Technology, By Offering, By Country, Opportunity Analysis and Industry Forecast, 2021 - 2027.* Retrieved from Research and Markets: https://www.researchandmarkets.com/reports/5522248/europe-home-energy-management-market-by-product

Research, T. M. (2021). *Smart EV Charger Market: 2021 – 2031.*

Rocky Mountain Institute, R. (2016). *Electric vehicles as distributed energy resources.* Basalt: Rocky Mountain Institute, RMI.

Shittekatte, T., & Meeus, L. (2021). *Capacity Remuneration Mechanism in the EU: today, tomorrow, and a further look ahead.* Florence School of Regulation.

SMB Smart Grid Strategic Group. (2010). *IEC Smart Grid Standardization Roadmap.*

SNET, E. (2022). *E-mobility deployment and impact on grids: Impact of EV and charging infrastructure on European T&D grids – Innovation needs.*

Statista. (2022). *Smart Home - Energy Management*. Retrieved from Statista: https://www.statista.com/outlook/dmo/smart-home/energy-management/europe#smart-homes

Stecca, M., Ramirez Elizondo, L., Batista Soeiro, T., Bauer, P., & Palensky, P. (2020). A Comprehensive Review of the Integration of Battery Energy Storage Systems Into Distribution Networks. *IEEE Open Journal of the Industrial Electronics Society*, 46-65.

Stein K, T. M. (2018). Characterization of a fast battery energy storage system for primay frequency response. *Energies*.

Strbac, G., Pudjianto, D., Aunedi, M., Djapic, P., Teng, F., Zhang, X., . . . Brandon, N. (2020). Role and Value of Flexibility in Facilitating Cost-Effective Energy System Decarbonization. *Progress in Energy*.

Taljegar D, M. (2017). *The impact of an electrification of road transportation on the electricity system.* Gothenburg: Chalmers University of Technology.

Terna. (2020). *Fast Reserve*. Retrieved from Terna website: https://www.terna.it/en/electric-system/pilot-projects-pursuant-arera-resolution-300-2017-reel/fast-reserve-pilot-project

U.S. Department of Energy - Office of Electricity Delivery and Energy Reliability. (2016). *Advanced Metering Infrastructure and Customer Systems, Results from the Smart Grid Investment Grant Program.* Retrieved from U.S. Department of Energy: https://www.energy.gov/sites/prod/files/2016/12/f34/AMI%20Summary%20Report_09-26-16.pdf

US Department of Energy. (2020). *2020 Grid Energy Storage Technology Cost and Performance Assessment.*

Vasiljevska, J., Gangale, F., Covrig, L., & Mengolini, A. (2021). Smart Grids and Beyond: An EU Research and Innovation Perspective. *Publications Office of the European Union*.

VDE. (2018, 10). *Technical Connection Rules for Medium-Voltage (VDE-AR-N 4110).* Retrieved from VDE: Technical Connection Rules for Medium-Voltage (VDE-AR-N 4110)

Vertgewall, C. M. (2021). Modelling Of Location And Time Dependent Charging Profiles Of Electric Vehicles Based On Historical User Behaviour. *The 26th International Conference and Exhibition on Electricity Distribution, CIRED 2021*, (p. 6).

Virta. (2020). *How to build a business from EV charging - EV charging business guide.* Virta.

Vitiello, S., Andreadou, N., Ardelean, M., & Fulli, G. (2022). Smart Metering Roll-Out in Europe: Where Do We Stand? Cost Benefit Analyses in the Clean Energy Package and Research Trends in the Green Deal. *Energies*.

Wood Mackenzie. (2020, November). *Europe losing global energy storage battle as US and China race ahead.* Retrieved from Wood Mackenzie.

Wood Mackenzie. (2022, April 11). *Europe's grid-scale energy storage capacity will expand 20-fold by 2031.* Retrieved from Wood Mackenzie: https://www.woodmac.com/news/opinion/europes-grid-scale-energy-storage-capacity-will-expand-20-fold-by-2031/

Wood Mackenzie. (2022, May 9). *Stellar growth for global energy storage.* Retrieved from Wood Mackenzie: https://www.woodmac.com/news/opinion/stellar-growth-for-global-energy-storage/

World Bank Group. (2018). *Survey of International Experience in Advanced Metering Infrastructure and its Implementation.* Retrieved from World Bank Group - Energy and Extractives Global Practice Group: https://openknowledge.worldbank.org/handle/10986/32468

WPD, W. P. (2015). *Project FALCON - Final Report.*

Zafar, U., Bayhan, S., & Sanfilippo, A. (2020). Home Energy Management System Concepts, Configurations and Technologies for the Smart Grid. *IEEE Accessa*.

List of abbreviations

AC: Alternating Current

AMI: Advanced metering infrastructure

CAPEX: Capital Expenditures

CEP: Clean Energy Package

DAM: Day-Ahead Market

DC: Direct Current

DER: Distributed Energy Resources

DMS: Distribution Management System

DSO: Distribution System Operator

EC: European Commission

ENTSO-E: European Network of Transmission System Operators for Electricity

EU: European Union

EV: Electric Vehicle

EVSC: Electric vehicles smart charging

GSSS: Grid scale storage services

GW: Giga-Watt

GWh: Giga-Watt-hour

H2020: Horizon 2020

HE: Horizon Europe

HEMS: Home energy management systems

HV: High Voltage

IEM: Internal Energy Market

kWh: Kilo-Watt-hour

kW: Kilo-Watt

LV: Low Voltage

MS: Member States

MV: Medium voltage

MWh: Mega-Watt-hour

MW: Mega-Watt

OPEX: Operational Expenditures

R&D: Research and Development

RES: Renewable Energy Sources

R&I&D: Research and Innovation and Development

SG: Smart Grids

TEP: Third Energy Package

TI: Transmission Innovation

TRL: Technology Readiness Level

TSO: Transmission System Operator

TYNDP: Ten years network development plan

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The European Commission's science and knowledge service

Joint Research Centre

JRC Mission

As the science and knowledge service of the European Commission, the Joint Research Centre's mission is to support EU policies with independent evidence throughout the whole policy cycle.

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