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CLEAN ENERGY TECHNOLOGY OBSERVATORY

# Smart grids in the European Union

*STATUS REPORT ON TECHNOLOGY DEVELOPMENT, TRENDS, VALUE CHAINS & MARKETS*

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# Contents

## Abstract

This document provides an overview of the latest technological and market trends on the topic of Smart Grids in the European Union. Given the broad scope of the topic and the comprehensive approach followed in the last year report, the analysis has focused instead on two specific enabling technologies which have exhibited significant developments in the last year: High Voltage Direct-Current (HVDC) connections and Smart Metering Infrastructure. The choice of analysing HVDC recognizes the fundamental role that the network infrastructure will play in the smooth integration of new renewable sources and in the support to an efficient operation of a decarbonized grid, whereas the focus on Smart Metering Infrastructure is meant to highlight its relevance in the upgrade of the energy grid, with numerous smart meter rollout plans worldwide. For each of these two topics, the current status is reported in terms of technology developments and trends, value chain analysis and global competitiveness.

## Foreword on the Clean Energy Technology Observatory

The European Commission set up the Clean Energy Technology Observatory (CETO) in 2022 to help address the complexity and multi-faced character of the transition to a climate-neutral society in Europe. The EU's ambitious energy and climate policies create a necessity to tackle the related challenges in a comprehensive manner, recognizing the important role for advanced technologies and innovation in the process.

CETO is a joint initiative of the European Commission Joint Research Centre (JRC), who run the observatory, and Directorate Generals Research and Innovation (R&I) and Energy (ENER) on the policy side. Its overall objectives are to:

- monitor the EU research and innovation activities on clean energy technologies needed for the delivery of the European Green Deal
- assess the competitiveness of the EU clean energy sector and its positioning in the global energy market
- build on existing Commission studies, relevant information & knowledge in Commission services and agencies, and the Low Carbon Energy Observatory (2015-2020)
- publish reports on the Strategic Energy Technology Plan (SET-Plan) SETIS online platform

CETO provides a repository of techno- and socio-economic data on the most relevant technologies and their integration in the energy system. It targets in particular the status and outlook for innovative solutions as well as the sustainable market uptake of both mature and inventive technologies. The project serves as primary source of data for the Commission's annual progress reports on competitiveness of clean energy technologies. It also supports the implementation of and development of EU research and innovation policy.

The observatory produces a series of annual reports addressing the following themes:

- Clean Energy Technology Status, Value Chains and Market: covering advanced biofuels, batteries, bioenergy, carbon capture utilisation and storage, concentrated solar power and heat, geothermal heat and power, heat pumps, hydropower & pumped hydropower storage, novel electricity and heat storage technologies, ocean energy, photovoltaics, renewable fuels of non-biological origin (other), renewable hydrogen, solar fuels (direct) and wind (offshore and onshore).
- Clean Energy Technology System Integration: building-related technologies, digital infrastructure for smart energy system, industrial and district heat & cold management, standalone systems, transmission and distribution technologies, smart cities and innovative energy carriers and supply for transport.
- Foresight Analysis for Future Clean Energy Technologies using Weak Signal Analysis
- Clean Energy Outlooks: Analysis and Critical Review
- System Modelling for Clean Energy Technology Scenarios
- Overall Strategic Analysis of Clean Energy Technology Sector

More details are available on the CETO web pages

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## Executive Summary


This report aims to provide an updated overview of the latest trends and developments in the Smart Grid sector. Given the very broad scope of the subject and considering the comprehensive approach followed in the 2022 report (European Commission, 2022), this document focuses instead on two specific topics that exhibited very significant developments in the last year: High-Voltage Direct-Current (HVDC) technology and Smart Metering Infrastructure.

**High-Voltage Direct-Current (HVDC) systems**

HVDC systems are establishing themselves as a fundamental enabling technology for the decarbonisation of the energy system. Thanks to their increased capacity and lower losses over long distances with respect to their AC equivalents, they can efficiently strengthen the interconnectivity of the energy system by linking distant power networks with different frequencies and facilitating the interconnection of large offshore wind plants. The analysis has shown the following:

- HVDC is already a mature and well-established technology with several systems already proven in operational environments. However, there are still significant margins for new technological developments and improvements, particularly in regard to DC/DC breakers and use of Cross-linked Polyethylene (XLPE) cables at very high voltage levels (525 kV and above).
- The worldwide installed HVDC capacity has tripled from 2010, reaching a total length of 100000 km and a total capacity of 350 GW at the end of 2021. As of 2022, the HVDC capacity in Europe amounts to around 43 GW, with additional 63 GW coming from 51 new projects (mostly in the planning and permitting stage.
- From a patenting perspective, the most active companies in this field are Chinese (State Grid Corporation of China and China Southern Power Grid). European companies such as Alstom (France) and ABB (Sweden-Switzerland) exhibit smaller patenting volumes but higher geographical reach and application diversity.
- The EU is providing substantial funding to HVDC-related research activities, with 6 funding calls and a total budget of 1300 M€ in the Horizon Europe program.
- HVDC transmission projects are generally supplied separately in their main components, i.e. point-to-point lines and converter stations. Currently, procurement lead times for cables usually range between two and four years while the typical lead time for HVDC converter stations is between two and three years. However, lead times appear to be increasing in the last period, mostly due to an increasing worldwide demand and extra-European countries that are able to place bulk orders at competitive prices and with more relaxed standards. One possible solution could be a simplification and uniform implementation in the Member states of the EU tendering law.
- In terms of supply chains, the main European manufacturers of transformers are considered leading global players. The same is true for the European cable manufacturers, who are expected to satisfy the forecast demand over the next ten years. The only relevant concern is associated with high-power semiconductors (a key component of converter valves), whose production is concentrated in Taiwan.
- Estimations on the value of the global HVDC market at 2021 range between 9.48 and 16.96 Bn $. The future outlook appears quite positive, with Compound Annual Growth Rate (CAGR) over the next 10 years estimated between 7.1% and 10.6%.

**Advanced Metering Infrastructure**

Smart meters and in general Advanced Metering Infrastructure play a key role to the digitalization of the energy grid. They have numerous advantages to offer at multiple actors, from the DSO/ energy provider to the end-consumers.

The advantages that advanced metering infrastructure offer are summarised as follows both from an energy provider perspective and end-consumer perspective:

- Grid monitoring and better grid management (outages, faults in the network);
- Enable initiaves like smart cities, increase usage of renewable energy sources;
- Empower consumers to control their consumptions;
- Enable energy saving in a comprehensive and effective way;
- Enable the participation in smart energy programs, like demand side flexibility program.
- Furthermore, associated to EVs (notably @Home/@work charging), they allow two-way energy and data flows (V2G), significantly contributing to peak-shaving, therefore improving the overall economic competitiveness of a region *(see China and South Korea recently legislative initiatives to generalise V2G plus links with AFIR, EPBD, Sustainable Transport Forum initiative).*

Advance metering infrastructure has attracted the interest of stakeholders in the energy chain at global level, with massive rollout-plans ongoing or scheduled around the globe. Due to the technology's importance, it is considered fundamental to monitor the technology readiness level, the value chain and the global market status. For this reason, the Clean energy Technology Observatory offers monitoring of the Advanced Metering Infrastructure technology. For the current release, we provide an update and a comparison with last year's report, showing the latest improvements in the field together with the overall picture. The related theme of charging infrastructure for EVs has not been considered in this document, as it is already extensively analysed in the latest CINDECS report (Kuokkanen, et al., 2023).

# 1 Introduction

## 1.1 Scope and context

This document addresses the Clean Energy Technology Observatory Sub-Task A.2 and aims to provide an updated overview of the latest developments and trends in the Smart Grid sector. The report released last year (European Commission, 2022) analysed five distinct topics: Transmission Network Innovation, Grid-Scale Storage Services, Electric Vehicle Smart Charging, Advanced Metering Infrastructure and Home Energy Management Systems. Differently from the extensive scope considered in (European Commission, 2022), the present report focuses in detail on two specific sectors (High-Voltage Direct-Current Technologies and Smart Metering Infrastructure) that exhibited very significant developments in the last year. In regard to these two topics, the report presents their most relevant technological statuses and trends, analises the key features and most timely issues of their value chains and assesses the market position and global competiteveness of EU companies.

### 1.1.1 High-Voltage Direct-Current (HVDC) Technologies

The choice of this first topic recognizes the fundamental role that the network infrastructure will play in the smooth integration of new renewable sources and in the support to an efficient operation of a decarbonized grid. The analysis follows up on the general Transmission Innovation overview provided in (European Commission, 2022) by focusing on the specific topic of High-Voltage DC Transmission. The scope of the study includes the main physical assets of HVDC systems, i.e. transformers, HVDC converters, DC circuit breakers and cables. The study does not consider other emerging technologies in the transmission sectors, such as Flexible Alternating Currents Transmission Systems (FACTS), which will be the subject of future analyses.

### 1.1.2 Smart Metering Infrastructure

The choice of this topic intends to address main advancements in the Advanced Metering Infrastructure field together with providing the overall picture, not only at European level, but at global level. Indeed, advance metering infrastrure and in particular, smart meters, play a key role for the upgrade of the energy grid, with numerous smart meter rollout plans worldwide. The scope of this study is to give an update with respect to last year’s status for smart meters, and in particular for their technology readiness level, the value chains and the global market picture.

## 1.2 Methodology and Data Sources

The report has been written following the CETO methodology that addresses three principal aspects:

a) Technology maturity status, development and trends

b) Value chain analysis

c) Global markets and EU positioning

The main sources utilised for the study include:

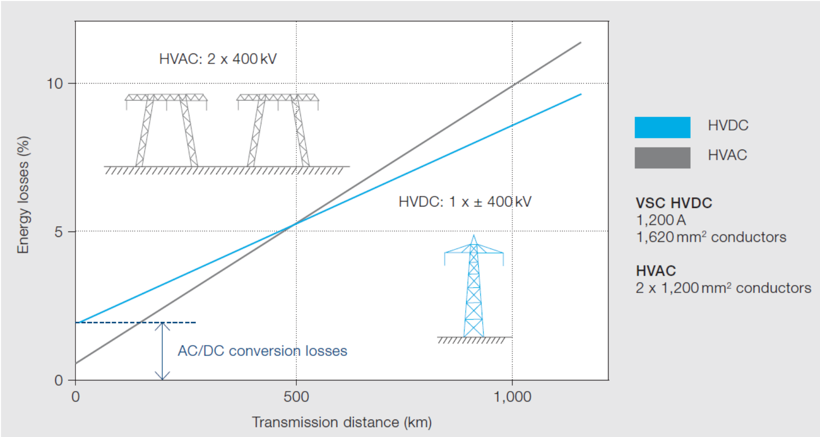
- Technical reports by public institutions and private entities
- Scientific review papers on technology state-of the-art
- ENTSO-E energy scenarios
- CORDIS database for Horizon 2020 and Horizon Europe research projects

Additional information, both in the form of qualitative assessments and quantitative data, has been obtained through contacts with external stakeholders, including TSO entities (Elia, ENTSO-E), individual manufacturers (Hitachi, General Electric) and industry associations (T&D Europe, Europacable).

# 2 High-Voltage Direct-Current (HVDC) Technology

High-Voltage Direct Current (HVDC) systems are playing an increasingly significant role in supporting the decarbonisation of the energy system. Thanks to their increased capacity and lower losses over long distances (see **Figure *1***) with respect to their AC equivalents, they can strengthen efficiently the interconnectivity of the energy system by linking distant power networks with different frequencies and significantly facilitating the interconnection of large offshore wind plants.

**Figure 1.** Comparison of energy losses in AC and DC overhead lines.

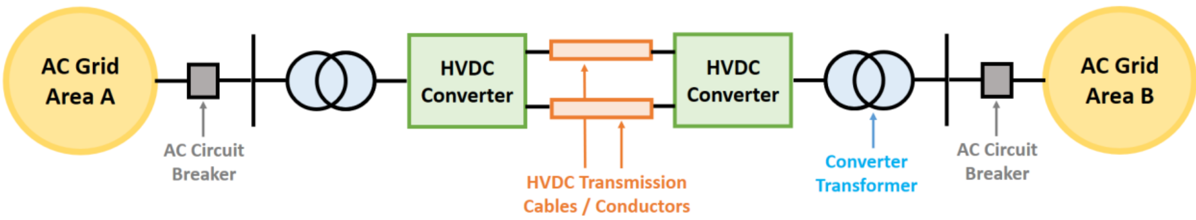



*Source: (ABB, 2014)*

In its basic structure (see **Figure 2**), a HVDC system includes:

- Circuit breakers on the AC side (considerably cheaper than DC breakers)
- HVDC converters, including AC/DC and DC/AC converters and equipment for reactive power support and filtering. The AC/DC and DC/AC converters can generally use two different topologies: Line Commutated Converters (LCC), a well-established technology relying on thyristors, and Voltage Source Converters (VSC), which are more recent and provide greater controllability
- HVDC conductors, which can either be onshore (overhead or underground) or offshore (mainly submarine cables)

**Figure 2**. Generic HVDC transmission project layout.



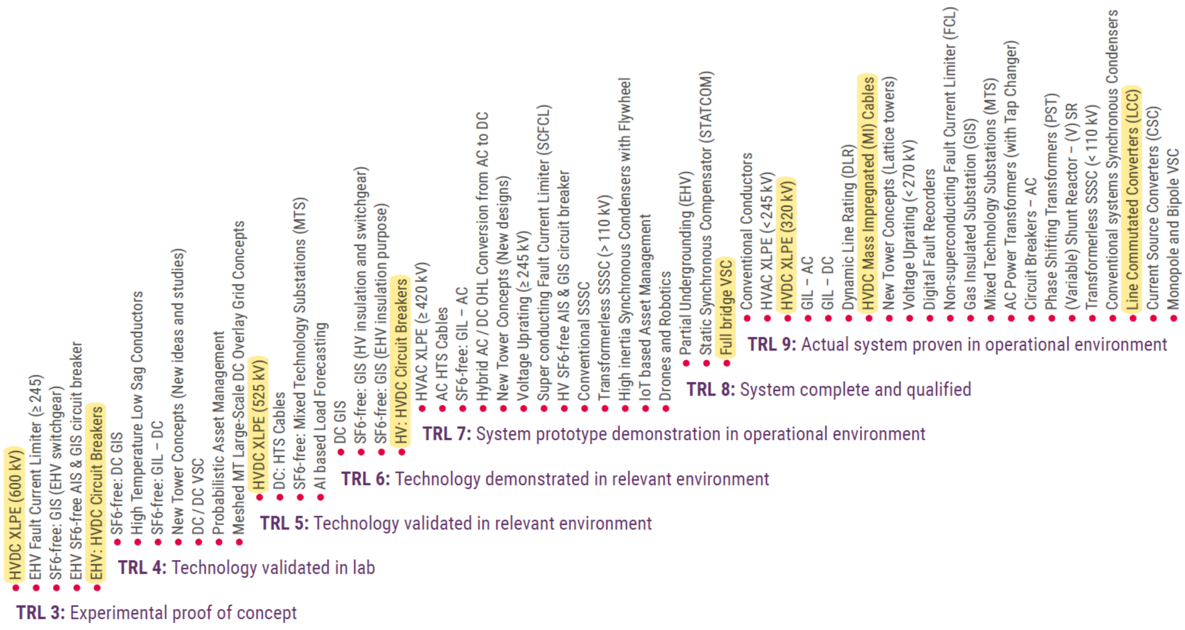

*Source: JRC re-elaboration of figure in (Alassi, Bañales, Ellabban, Adam, & MacIver, 2019)*

## 2.1 Technology development and trends

### 2.1.1 Technology Readiness levels

HVDC transmission has nowadays reached a significant level of maturity. As indicated in the latest technology factsheets by ENTSO-E (ENTSO-E, 2021), the bulk of the HVDC-related technologies have already been proven in the operational environment of actual system (TRL 9).

**Figure 3.** Technology Readiness Level (TRL) of primary energy transmission technologies (HVDC components highlighted in yellow).




*Source: (ENTSO-E, 2021)*

For example, Line Commutated Converters (LCC) are a well-established technology that has been used in HVDC systems since the 1970s and nowadays can operate on lines up to a length of 2000 km. Voltage Source Converters (VSC) have been developed more recently but they are being utilised in most of the new HVDC projects as they allow rapid control of active and reactive power. These converters generally achieve a TRL of 8-9, with the exception of DC/DC converter which are currently only being validated in lab (TRL 4).

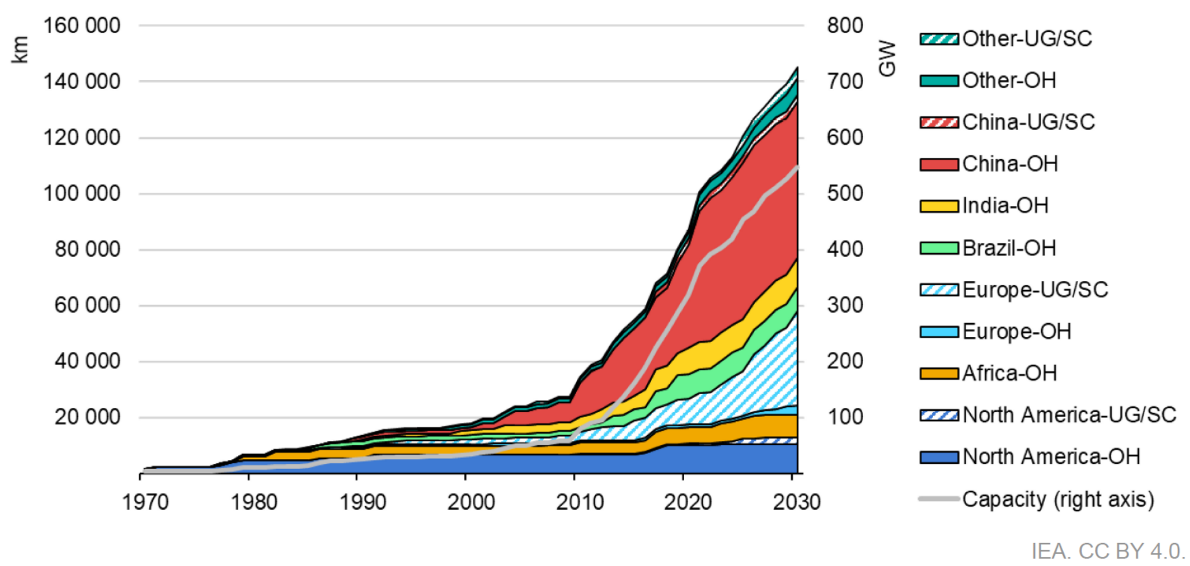
In terms of conductors, Mass Impregnated (MI) cables represent a very consolidated and traditional technology for HVDC system, used for both on-shore underground connections and off-shore applications. Recently, Cross-linked Polyethylene (XLPE) cables, i.e. conductors with extruded insulation, are seeing an increased diffusion as they can operate at a wide range of temperatures and are particularly resistant to corrosion and vibrations. XLPE cables operating at 320kV are a very mature technology (TRL 9) while their application at 525kV is still being validated (TRL 5) and their use at 600 kV is at an experimental stage (TRL 3).

Finally, in terms of switching components, the HVDC circuit breakers are less mature then their AC counterparts, mostly due to the challenge of breaking direct current in absence of zero-current crossings. At the moment, High-Voltage DC breakers are being demonstrated in relevant environments (TRL6) while Extra-High-Voltage (345kV and above) DC breakers are still at an experimental stage (TRL 3).

### 2.1.2 Installed capacity and production

According to the latest data provided in (IEA, 2023) and shown in ***Figure 4***, by the end of 2021 the total length of HVDC lines has reached 100 000 km and a total transmission capacity of more than 350 GW. HVDC lines have almost tripled since 2010, although they still represent only 2% of the total transmission infrastructure. In 2021, the largest capacity additions have been made in China, which introduced 50% of the new HVDC lines while Europe contributed by 10%.

**Figure 4.** Global HVDC transmission lines by country/region and line type.




Notes: UG = underground cable; SC = subsea cable; OH = overhead transmission line; km = kilometre; GW = gigawatt. Data are for year-end. "Capacity" refers to global HVDC transmission capacity, but excludes the capacity of HVDC back-to-back systems, which are used to link two AC networks. Data for 2023-2030 are based on announced projects.

Sources: IEA research; RTE International (2022).

*Source: (IEA, 2023)*

As of 2022, the HVDC transmission capacity installed in Europe amounts to around 43 GW (Power Technology Research, 2022). Germany leads this metric with 11.25 GW of installed HVDC capacity, which mostly consists of interconnection of offshore power plants in the North Sea region. The second country in terms of installed capacity is the UK, with 6.4 GW of installed HVDC links, including several cross-border interconnections with France, the Netherlands and Norway. Other countries with substantial HVDC capacity are Italy, with 3.7 GW of internal links and connections with France and Montenegro and Denmark, with 2 GW that are mostly subsea connections with Sweden, Norway and Germany. For future investments, (ENTSO-E, 2022) envisages 51 projects that entail new or expanded DC transmission lines, with 3 projects already under construction, 31 in the evaluation or planning stage and 17 in the permitting stage. The additional aggregate capacity of these projects amounts to about 63 GW. A detailed projection on the potential demand for High-Voltage (HV) and Extra High-Voltage (EHV) cables over the next ten years, estimated by Europacable on the basis of the ENTSO-E's TYNDP 2022 and the different National Development Plans is shown in Table 1.

***Table 1.*** Projected European demand of HV and EHV cables by 2032.

| Cables (km) | HV & EHV AC land | HV & EHV DC land | HV & EHV AC subsea | HV & EHV DC subsea | Total |
|---|---|---|---|---|---|
| ENTSO-E's TYNDP 2022 | 804 | 9,670 | 2,478 | 38,752 | 51,764 |
| ENTSO-E's TYNDP 2022 & European National Development Plans | 4,116 | 14,054 | 11,295 | 58,292 | 87,757 |

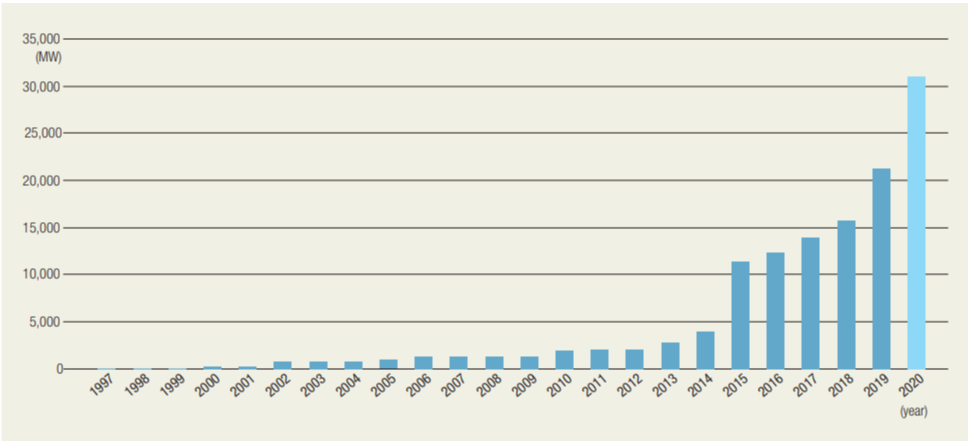
*Source: Europacable elaboration of TYNDP 2022 and European National Development Plans.*

It is estimated that, in the next ten years, the total length of new land cables installed in Europe for HVDC projects will be approximately between 10,000 and 14,000 km, a quantity significantly higher than for new AC assets. New subsea installations will be even more substantial, with an estimate of new DC subsea cables approximately between 39,000 and 58,000 km.

The European Union supports this substantial deployment of HVDC infrastructure through its Projects of Common Interest (PCIs), i.e., key cross-border infrastructure projects that bring significant positive impact on energy market integration and energy security in at least two EU countries (European Commission, 2021). Such projects benefit from an accelerated permit-granting process, improved regulatory treatment, and the possibility to apply for financial support under the Connecting Europe Facility (CEF) for Energy (total budget of €5.84 billion for the period 2021-2027). The latest PCI list (European Commission, 2021) includes 14 different projects that entail the development of new HVDC lines. Nine of these projects envisage an HVDC connection between different countries, for a total 10.9 GW of new transmission capacity, over a total connection length of at least 3300 km. Four other projects entail the strengthening of national grid infrastructures with additional HVDC links, for an additional 12 GW capacity and more than 2200 km of lines. Finally, HVDC interconnectors will also be used in the North Sea Wind Power Hub, with the objective of connecting 12 GW of future offshore wind parks to Denmark, the Netherlands and Germany (European Commission, 2021).

In terms of technology, investments have been gradually shifting from LCC to VSC transformers, with the latter constituting the 72% of new investments between 2010 and 2020, compared to only 44% in the previous ten years. As shown in **Figure *5***, new VSC projects have significantly increased since 2015 and have reached about 30GW of cumulative new capacity in 2020.

**Figure 5.** Cumulative new capacity of VSC HVDC lines.

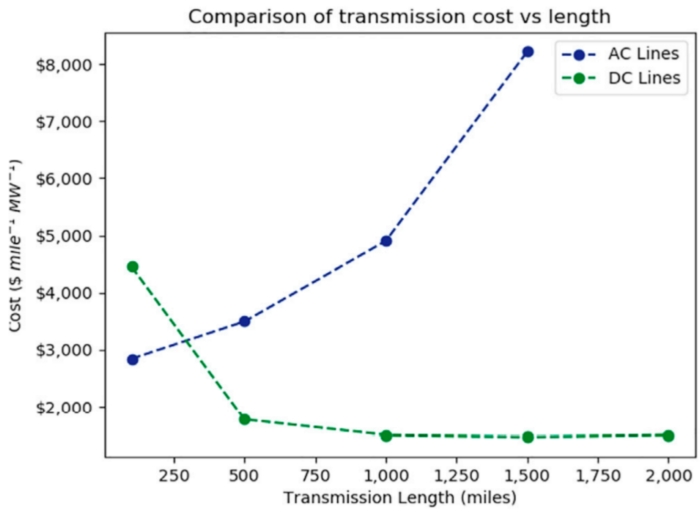



*Source: (Nishioka, Alvarez, & Omori, 2020)*

### 2.1.3 Technology costs

Some of the latest data on the cost of the HVDC transmission infrastructure are provided in (De Santis, James, Houchins, Saur, & Lyubovsky, 2021), which indicates a capital cost of 933.34 $/km-MW for a transmission project of 1610 km (1000 miles). Such cost is given by the sum of four main components, each with a different impact on the total: the biggest cost factors are materials (57%) and substations (26%) while the impact of labor (11%) and Right-of-way (6%). The same authors also provide a comparison between the costs of AC and DC high-voltage line over different connection lengths, as shown in **Figure *6***. It can be seen that cost parity is achieved at around 300 miles (483 km). Over longer distances, the additional costs of the transformer substations required for the HVDC connections are compensated by the increased efficiency and lower losses provided by the direct current link.

**Figure 6.** Comparison of transmission costs vs distance for AC and DC technologies.

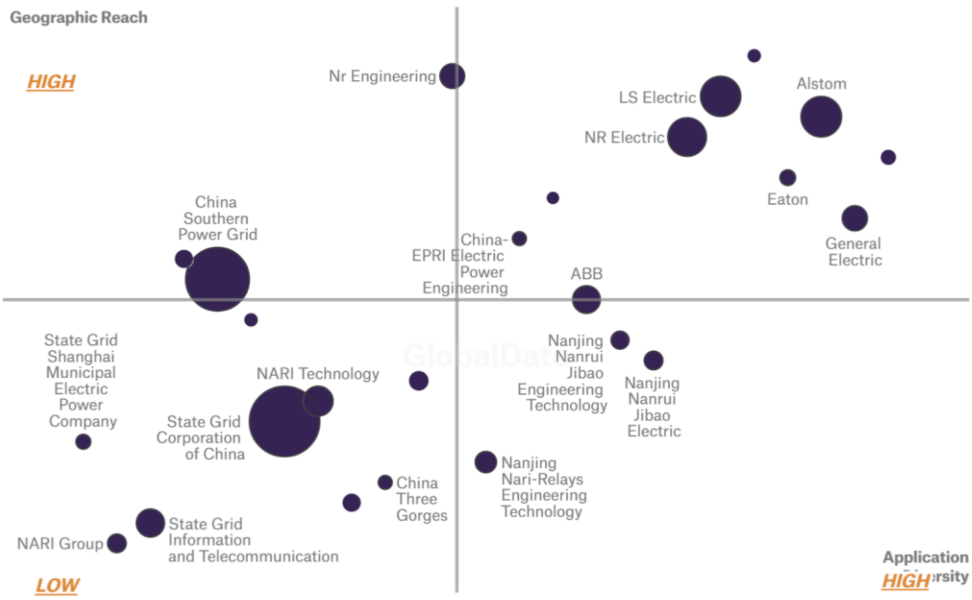



*Source: (De Santis, James, Houchins, Saur, & Lyubovsky, 2021)*

### 2.1.4 Patenting trends

A summary of the patenting activities by key players in the HVDC sector is shown in **Figure 7**. It can be seen that the most active companies in this field are by far State Grid Corporation of China and China Southern Power Grid. Other relevant companies with smaller patenting volumes but higher geographical reach and application diversity include: LS Electric (Korea), Alstom (France), NR Electric (China) and ABB (Sweden-Switzerland).

**Figure 7.** Analysis of patenting activities for HVDC sector. Bubble size represents patent volumes between 2010 and 2021.




*Source: (Power Technology, 2023)*

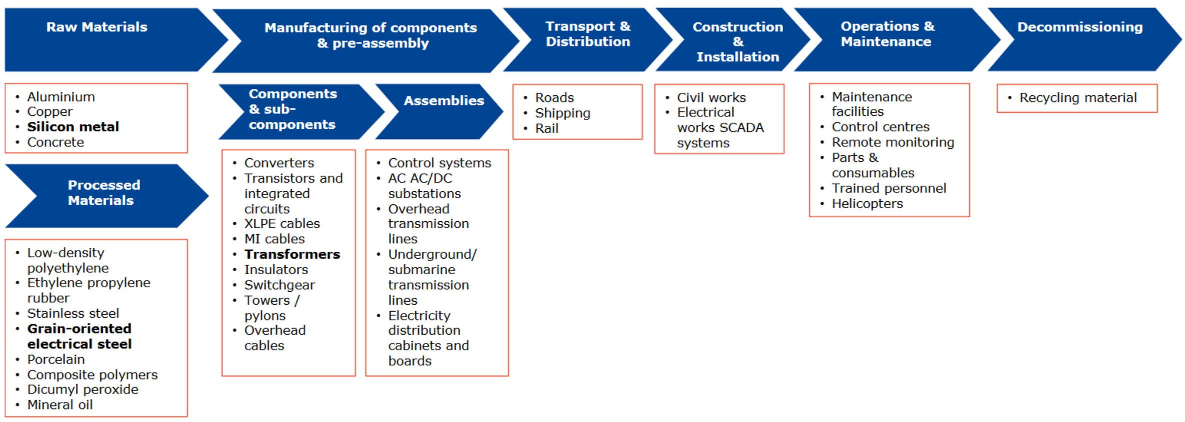
### 2.1.5 Public funding and impact of EU-supported research

The fundamental role of HVDC 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). In particular, its Flagship Initiative 1 "Develop an optimized European power grid" underlines how HVDC can provide fundamental support to enhance network controllability and flexibility. The HVDC technologies have been widely investigated in the context of the Horizon 2020 program, with a total of 14 funding calls on the topic and a total budget of 849 M€. The research activities on HVDC are being further supported by the Horizon Europe program, with additional 6 funding calls (5 closed and 1 forthcoming), for a total budget of 1300 M€. The EU funding support not only fosters technological research but it also enables large-scale partnerships between different stakeholders, pooling their expertise and skills to define new market solutions and establishing the future frameworks and paradigms of the HVDC technology. One example in such sense is the project "Enabling interoperability of multi-vendor HVDC grids" (InterOPERA), which has been funded by the European Union with 50 M€ (with additional 19 M€ from project partners). The project brings together European TSOs, manufacturers, sector associations and universities to define mutual compatibility and interoperability standards for HVDC, thus facilitating facilitate the design and deployment of scalable, multi-vendor, multi-terminal HVDC systems (WindEurope, 2023).

## 2.2 Value Chain Analysis

A general representation of the supply chain for electricity network technologies is provided in **Figure *8***.

**Figure 8.** The supply chain of electricity network technologies.

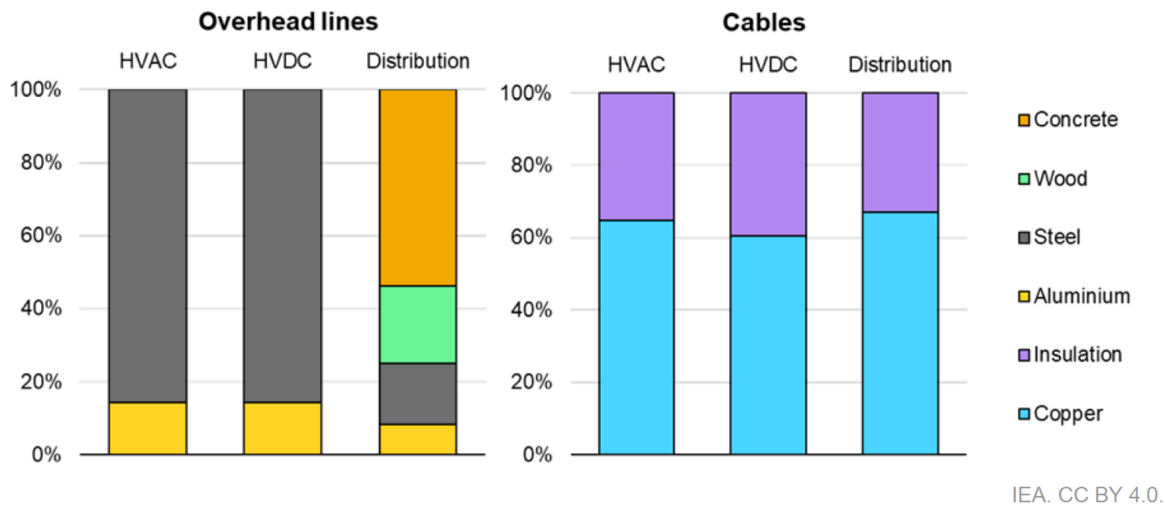


*Note: vulnerable elements found highlighted in bold.*

*Source: (Triconomics and Artelis, 2021)*

The raw materials needed for the construction of HVDC overhead lines and cables are generally similar in composition to the ones required for HVAC, as shown in **Figure *9***. As for their AC equivalent, HVDC lines requires mostly aluminium and steel, whereas underground cables are mostly made of copper and insulation. In a context of increasing material demand for the overall grid infrastructure (from 4 Mt/year in the 2012-2021 period to 5 Mt/year in 2022-2031 of copper and from 12 to 16 Mt/year in the same periods for aluminium), the HVDC lines exhibit lower requirements with respect to their AC counterparts. In fact, HVDC requires fewer lines (only one or two) compared to a three-phase AC system and HVDC systems are generally operated at higher voltage levels, meaning that the same amount of material ensures higher transmission capacity. As a result, an HVDC overhead lines requires on average 5kg/MW/km of aluminium, less than half of its HVAC counterparts (11kg/MW/km). The material savings are even more relevant in the case of underground cables, where the 29 kg/MW/km of copper requirements for HVDC are about 70% lower than in the HVAC case (101 kg/MW/km) (IEA, 2023).

**Figure 9.** Typical material composition of overhead lines and cables by weight.




Notes: HVAC = high-voltage AC transmission; HVDC = high-voltage DC transmission. Materials in overhead lines include conductors, towers and poles.

*Source: (IEA, 2023)*

HVDC transmission projects are generally supplied separately in their main components, i.e. point-to-point lines and converter stations. In general, cable manufacturing is a lengthy process composed of several sequential operations. For this reason, procurement lead times usually range between two and four years. The typical lead time for HVDC converter stations is between two and three years (IEA, 2023).

From the analysis and stakeholders interview conducted in (Triconomics and Artelis, 2021), no major concern was raised regarding the vulnerability of the European supply chain, with the exception of raw and processed material such as high-power semiconductors, whose production is concentrated in Taiwan (U.S. Department of Energy, 2022). The main European manufacturers of transformers were considered leading global players and the European cable manufacturers were expected to satisfy the forecast demand over the next ten years. However, from recent conversations with a European TSO, it appears that the high supply levels of the previous years are quickly receding and there are increasing difficulties for a quick and cost-effective procurement of the necessary assets. For example, the delivery of HVDC converters by leading European manufactures for new orders placed in 2023 is expected by 2031-2032. The substantially higher lead times could be explained by a rapid increase of worldwide demand, with extra-European countries that are able to place bulk orders at competitive prices and with more relaxed standards. Some of the potential actions to tackle this issue are proposed in (ENTSO-E, 2023), where a simplification and uniform implementation in the Member states of the EU tendering law are recommended. In terms of available expertise within the European job market, discussions with several stakeholders operating in this sector have not highlighted any significant skill shortage or mismatch in the workforce.

## 2.3 EU Market Position and Global Competeveness

### 2.3.1 Global & EU market leaders

In terms of cables, the main European companies include NKT in Denmark, Nexans in France, Südkabel in Germany and Prysmian in Italy. Outside Europe, the most relevant companies are Sumitomo in Japan, General Cable in the United States, NBO and ZTT in China and LS Cable in Korea (IEA, 2023). The most updated information regarding the European manufacturing capacity in this sector that has been retrieved refers to 2018 data (Europacable, 2019) and is summarised in **Table *2***:

**Table 2.** Annual HVDC cables manufacturing capacity by European companies.

| Annual Production Capacity (km) | Land only | Land & Submarine |
|---|---|---|
| **320 kV HVDC** | 6,090 | 6,980 |
| **320 kV and 525 kV HVDC** | 5,550 | 6,440 |

*Source: (Europacable, 2019)*

Europacable, contacted during the preparation of this report, has stated that updated manufacturing data are not being released for later years, as the market framework has become too complex to provide accurate aggregate estimations.

In terms of HVDC converters, the leading producers are Hitachi Energy (formerly ABB – Japanese, but still Europe-based), followed by Siemens (Germany) and General Electric (United States), Mitsubishi Electric (Japan), NR Electric and C-EPRI Electric Power Engineering (China) and Bharat Heavy Electricals Limited (India) (IEA, 2023).

### 2.3.2 Market value

There are some relevant differences in the evaluations and estimates on the value of the global HVDC market. For example, Transparency Market Research evaluated the global HVDC market at 16.96 Bn $ in 2021 (Transparency Market Research, 2022), with the Asia Pacific region accounting for the 51.29% of the total market, followed by Europe (21.9%) and North America (17.7%). The Compound Annual Growth Rate (CAGR) for the next ten years was estimated to be equal to 7.1%, with the HVDC market reaching a total value of 33.54 Bn $ by 2031. More conservative estimates are provided in (Power Technology Research, 2022), which evaluates the global HVDC market at 9.48 Bn $ in 2021 and estimates a CAGR of 10.6% in the next 10 years, reaching an aggregate market value of 28.51 Bn $ by 2032. It was not possible to retrieve disaggregated information regarding the market shares of the different companies (both at European and worldwide level) as these figures seem to be confidential and are not shared publicly.

## 3. Advanced Metering Infrastructure

Advanced Metering Infrastructure is a key element of the distribution grid enabling customer empowerment, by offering knowledge of their actual consumptions, whereas on the other hand it enables participation in various smart grid programs like demand side flexibility programs. Due to its numerous benefits to all relevant stakeholders, i.e. energy providers, DSOs, consumers, aggregators, etc, monitoring the status of Advanced Metering Infrastructure has become an annual periodic exercise, as part of the CETO project.

The key role of smart meters is recognised at global level, with a lot of investments in the field of updating conventional meters worldwide. The main drivers of the smart meters industry are summarised as follows (Allied Market), (MordorIntelligence, 2022), (MENAFN, 2022), (Markets):

- Advancement in communication network infrastructure and digital electricity infrastructure, i.e. the development of artificial intelligence and machine learning technologies and their incorporation into smart meters.
- Several policies at national level supporting smart meters installations.
- Policies for climate neutrality, which highlight the necessity for grid monitoring through Advanced Metering Infrastructure.
- Enabling monitoring of the distribution system in real-time, thus tracking of outages and reducing system failures.
- Increase in initiatives for smart cities; increase in the usage of renewable energy resources, which is facilitated through smart meters' usage; growth in the adoption of electric vehicles.
- The advances in the Home Energy Management system or Building Energy Management system markets, which are usually linked to the Advanced Metering Infrastructure systems.
- The advancements in the energy smart appliances market, which are linked to smart meters.
- The fact that smart metres enable consumer empowerment through visualization of energy consumptions, thus increasing awareness and facilitating electricity savings and bills' reduction.
- Enabling energy efficiency.
- Enabling the connection of other smart grid components, like rooftop solar systems, wind turbines, to the rest of the grid, facilitating visualization of consumptions.
- On the other hand, the main obstacles are listed as follows:
- Installation costs that need to be borne by consumers.
- Low investments in technological development of the infrastructure.
- Issues related to security of smart meters data.
- Necessity of stable connections between smart meters and the grid.
- Sophisticated systems to collect accurately smart meter data.

The main advantages of the smart meter deployment are summarised as follows (MENAFN, 2022), (MordorIntelligence, 2022):

- Smart meters enable energy efficiency. It is reminded that global electricity generation in 2021 was estimated at 28,466 Terawatt-hours in 2021, with the global installed electricity capacity at 7.1 terawatts. It is estimated that electricity generation will more than double by 2050, resulting in 14.7 terawatts.
- Smart meters are key to digitalization of the energy grid.
- Smart meters enable the usage of renewable energy sources, like solar power.
- Smart meters enable the connection with Home Energy Management System (HEMS) or Building energy Management System (BEMS), and thus the visualisation of electric consumptions in homes/ buildings.
- They empower consumers and enable them to participate in the market by adjusting consumptions after receiving market signals.

## 3.1 Technology development and trends

In this Section, we give an update of the smart meter rollout status in Europe with respect to last year's data. For this year, the main source for updating our data, has been the newest release of the DSO Observatory 2022 (released in Autumn 2022), (Meletiou, Vasiljevska, Prettico, & Vitiello, 2022). The DSO Observatory collects data from European DSOs with a dedicated section about smart meter rollout status. This data has been further elaborated to obtain information at country level (where feasible). Another source of information has been the report published in 2022 by the European Union Agency for the Cooperation of Energy Regulators (ACER). The report is entitled "Annual Report on the Results of Monitoring the Internal Electricity and Natural Gas Markets in 2021 - Energy Retail and Consumer Protection Volume", published in October 2022, which includes a section about the status of smart meter rollout. Although the report has been published in autumn 2022, it refers to data from 2021, which, at some extent, have been taken into consideration for last year's report.
To extract the update for the status for smart meter rollout for this year's release, the following strategy has been followed: all possible sources of information have been considered (Prettico, et al., 2022), (Vitiello, Andreadou, Ardelean, & Fulli, 2022), (ACER, 2022), (Meletiou, Vasiljevska, Prettico, & Vitiello, 2022); the most accurate and updated numbers have been used to depict the status for the smart meter rollout.

In general, there is a positive trend with respect to smart meter installations in European Countries overall, as revealed by the DSO Observatory. Almost all interrogated DSOs have already started to implement a smart meter rollout program (95%), while only 3 DSOs have declared not to have introduce a smart meter rollout program. It is also interesting to notice that out of 56 interrogated DSOs, only 18 have replied to have equipped with smart meters less than 20% of their total customers, whereas on the other hand, 30 DSOs have declared to have equipped with smart meters more than 70% of their customers (25 out of these 30 have completed their rollout), (Meletiou, Vasiljevska, Prettico, & Vitiello, 2022).

It should be noticed here, that the smart meter rollout is the result of a positive Cost-Benefit- Analysis (CBA) performed by the Member States. This explains why the situation varies among Member States, as the equivalent CBAs either did not turn positive at the same time moment, or were not positive at all. According to the most recent data, 21 Member States have decided to go for a smart meter rollout, meaning a positive CBA. However, there are 2 Member States that have still not completed a CBA or have not communicated its results, namely:

- Bulgaria;
- Hungary.

On the other hand, there are 4 Member States with negative or inconclusive CBAs, namely:

- Belgium;
- Czech Republic;
- Germany;
- Slovakia.

Despite the negative CBA, in Germany, a law came into force, thanks to which DSOs can proceed to smart meter rollouts immediately (2023), while it has been announced that smart meter rollout will be obligatory from 2025 and onwards aiming at full smart meter rollout by 2030.
Among the Member States that have proceeded with a smart meter rollout, the pioneer group, meaning countries that have reached almost 100% smart meter rollout, consists of:

- Denmark;
- Estonia;
- Finland;
- Italy;
- Spain;
- Sweden.

There are other Member States, where the CBA has been positive, the national smart meter rollout is still in progress, but there are DSOs who have already completed their smart meter rollout. Such countries are listed as follows:

- Austria;
- France;

- Netherlands;
- Portugal.

In particular for Portugal, although smart meter rollout started rather late, in 2019, the country has made significant progress and is expected to reach full coverage by 2025.

With respect to countries that have not progressed with their smart meter rollout, and as of 2022 data, Germany is still behind with the smart meter rollout. Three out of four DSOs that took part in the JRC's survey, replied that their smart meter rollout is beneath 10% coverage. On the other hand, one DSO reported coverage of 40%. Data regarding Belgium state that one DSO has achieved coverage of less than 5% for smart meters, (Meletiou, Vasiljevska, Prettico, & Vitiello, 2022).

The following table shows the smart meter rollout status in different countries. Information about Norway and UK is also included, as from (ACER, 2022).

**Table 3.** Smart meter rollout status in Europe *(ACER, 2022), (Meletiou, Vasiljevska, Prettico, & Vitiello, 2022).*

| **Country** | **Smart meter penetration** | **Change with respect to CETO 2022 (if any)** | **Target year, when 80% of consumers will be equipped with smart meters** |
|---|---:|---:|---:|
| Austria | 47% | **Increase by 18** percentage points | 2024 |
| Belgium | Less than 10% | No data in 2022 | No statement for this |
| Bulgaria | Less than 10% | No data in 2022 | Not positive CBA |
| Cyprus | 0% | No data in 2022 | after 2024 |
| Croatia | Less than 20% | - | Not positive CBA |
| Czech R | Pilot projects only | - | No statement for this |
| Denmark | 100% | **Increase by 10-20** percentage points | 2020 |
| Estonia | 100% | - | 2017 |
| Finland | 100% | - | 2017 |
| France | 92% | **Increase by 2-12** percentage points | 2020 |
| Germany | 14% | - | No statement for this |
| Greece* | 4% | - | No statement for this |
| Hungary | 8% | **Increase by 7** percentage points | No statement for this |
| Ireland | 38% | No data in 2022 | 500,000 SMs by 2024 |
| Italy | 100% | - | 2017 |
| Latvia | 90% | **Increase by 40** percentage points | 2022 |
| Lithuania | 88% | **Increase by 80** percentage points | No statement for this |
| Luxemburg | 98% | **Increase by 8-18** percentage points | 2019 |
| Malta | 93% | **Increase by 3-13** percentage points | Beyond 2024 |
| Netherlands | 88% | **Increase by 3** percentage points | No statement for this |
| Norway | 100% | No data in 2022 | 2018 |
| Poland | 15% | **Increase by 7** percentage points | after 2024 |
| Portugal | 52% | - | 2025 |

| | | | |
|---|---|---|---|
| Romania | 18% | **Increase by 4-6** percentage points | after 2024 |
| Slovakia | Less than 20% | - | 2020 |
| Slovenia | 90% | **Increase by 5-10** percentage points | 2020 |
| Spain | 100% | **Increase by 7** percentage points | 2017 |
| Sweden | 100% | - | 2019 |
| UK | 49% | No data in 2022 | 2024 |

*Source: JRC analysis 2023.*

* Industrial smart meters have not been considered.

It is clear that there has been progress with respect to the 2022 data:

- In 13 countries there has been an increase in the percentage of smart meter penetration, whereas in 5 out of these 13 countries there has been an increase of more than 10 percentage points;
- It is noteworthy the examples of Latvia and Lithuania that seem to have actually proceeded with their smart meter rollouts within this last year of observation;
- We also have some data obtained for 3 countries, for which there were no data declared in the previous observatory;
- In 9 countries, the situation has remained stable.

## 3.2 Value chain analysis

In this Section, we give information about the value chains: we present the functionalities of smart meters and the programs offered to customers. First of all, we give information about the data usage of smart meters from a DSO perspective, meaning the way data is used by DSOs in Europe and the scope of smart meter usage. On the other hand, we present the programs offered by smart meters from a customer perspective. Thus, the reader can comprehend the smart meters' value chain: the final products that smart meters offer and the business models that smart meters work for.

As we have seen before, smart meters can be used for multiple functionalities and they can offer different programs to consumers. We have made a categorization of these functionalities and programs offered:

- With respect to smart meters usage by DSOs;
- With respect to smart meters usage and programs offered to customers.

**DSO perspective,** (Meletiou, Vasiljevska, Prettico, & Vitiello, 2022):
The main functionalities used from a DSO perspective, are summarised as follows:

1) Usage for grid management tasks;
2) Usage for grid control tasks;
3) Usage for distribution planning tasks.

Meters used for grid management tasks, provide with data about critical nodes on the grid. Such meters collect data for outages and voltage quality. Therefore, they give information about managing assets of the grid. The particular use cases with respect to such smart meters are listed as follows:

- Network state analysis & topology assignment: synchronous distributed measurements are planned (34 DSOs);
- Outages/disturbances detection and prevention: as the name implies, prevention of outages is carried out (30 DSOs);
- State estimation: smart meter data contributing to forecasting tools for grid state estimation (18 DSOs);

- Costumer monitoring: creating consumption behaviours for customers (38 DSOs).

Overall, 41 out of 56 DSOs use smart meters for grid management tasks.

Meters used for grid control tasks are used in overall by 18 out of 56 DSOs. Grid control tasks can result in benefits, like the automation of LV/MV grid and/ or automation of customers' systems, including facilitating their participation in demand response programs.

Meters for distribution planning tasks are used overall by 29 out of 56 DSOs. Through smart meters, the distribution grid can be better planned, whereas investment decisions can be better made. Specifically, the applications from using smart meter data are summarised as follows:

- Grid Planning based on real data: such data is used for forecasting customer loads and evaluating system constraints. Real smart meter data regarding the voltage rise and drop can be also made, in order to achieve a better modelling of LV grids (27 DSOs use such data).
- Re-design distribution facilities: in order to manage the complex smart grid, which comprises of voltage controllers and demand response schemes, what is needed are automated management systems and verification systems, particularly for smart devices at consumer premises. For such devices at consumer premises, smart meters can offer a monitoring module of the whole system (11 DSOs use such data).
- Grid asset planning: smart meters can offer valuable data about grid asset planning, namely for reducing the costs for installation, commissioning and operation of grid assets (16 DSOs use such data).

Table 4 summarises this information at country level. It is considered for each country that: if a DSO from one country entails a specific functionality, then this functionality is offered by the country. Since the information has been based on voluntarily participation of European DSOs to a dedicated survey, it is highlighted that:

- For the countries that are not present in the list, it means that we don't have enough information for these countries.
- When a box is not filled in with yes, it does not mean that the respective country does not offer the equivalent functionality, but that we do not have enough information for this country.

So, the list is indicative but not exhaustive.

**Table 4.** Smart meter functionalities in different countries.

| **Country** | **Usage for grid management tasks** | | | | **Distribution planning tasks** | | | **Usage for grid control tasks** | |
|---|---|---|---|---|---|---|---|---|---|
| | Network state analysis | Outages detection/ prevention | State estimation | Customer monitoring | Grid Planning | Re-design distribution facilities | Grid asset planning | Automation of LV/MV grid operation | Automation of customers' systems |
| Austria | | | Yes | Yes | Yes | | | Yes | |
| Belgium | | | Yes | | | | | | |
| Bulgaria | | | | Yes | Yes | | | | Yes |
| Croatia | Yes | | | Yes | | | | | |
| Denmark | Yes | | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Estonia | | | | Yes | | | | | |
| Finland | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| France | Yes | Yes | Yes | Yes | | | | Yes | Yes |
| Italy | | | | Yes | Yes | | | | Yes |
| Lithuania | Yes | | | Yes | Yes | | Yes | | |
| Luxemburg | Yes | Yes | | Yes | Yes | | | | |
| Netherlands | Yes | Yes | | | Yes | Yes | Yes | | |
| Poland | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Portugal | Yes | Yes | | Yes | Yes | Yes | Yes | Yes | |
| Romania | Yes | Yes | | Yes | Yes | | | Yes | |
| Slovakia | Yes | Yes | | Yes | Yes | Yes | Yes | Yes | Yes |
| Spain | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | |
| Sweden | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |

*Source: (Meletiou, Vasiljevska, Prettico, & Vitiello, 2022)*

* It is reminded that UK and Norway have not been considered for this analysis.

**Customer perspective,** (ACER, 2022):
The main programs offered to customers are summarised as follows:

- Historical consumption data, where customers have access to;
- Information about environmental impact;
- Electricity programs offered based on flexible tariffs.

Here, we describe the information that can be available for consumers through their smart meters, along with information about tariff programs offered via smart meters. Table 5 shows the historical consumption to which the consumers can have access together with information about products entailing flexible tariffs offered in different countries and enabled through smart meters. Such programs improve consumer empowerment, as they enable them to adapt electricity consumptions and take advantage of dynamic tariffs. For the programs to take place, the customers need to respond to price signals. It is foreseen that fixed price contracts will not be offered from 2023 and onwards, whereas it is stated in the Directive for the Internal market for Electricity that Member States must ensure that consumers equipped with smart meters should be able to have access to dynamic price contracts at least from one supplier (with over 200,000 clients). The characteristics of such contracts should be made clear to consumers, (ACER, 2022).

**Table 5.** Data, to which consumers have access and programs related to different tariff contract opportunities for consumers.

| Country | Cumulative data for 3 years or up to the beginning of contract | Near real-time data offered through the internet for time of use | Information about environmental impact through reference to the equivalent sources | Energy price differentiation according to intra-day/ weekdays/ weekend | Hourly or real-time energy pricing | Consumption remote control | Critical peak pricing |
|---|---|---|---|---|---|---|---|
| Austria | Yes | Yes | Yes | Yes | Yes | Yes | No |
| Belgium | Yes | Yes | No | Yes | No | No | No |
| Bulgaria | No | No | No | No | No | No | No |
| Cyprus | Yes | Yes | Yes | Yes | No | No | No |
| Croatia | No | No | No | No | No | No | No |
| Czech R | No | No | No | No | No | No | No |
| Denmark | Yes | Yes | No | Yes | Yes | No | Yes |
| Estonia | Yes | Yes | No | No | Yes | No | No |
| Finland | No | No | Yes | No | Yes | No | No |
| France | Yes | Yes | No | Yes | Yes | Yes | Yes |
| Germany | Yes | Yes | No | Yes | Yes | Yes | No |
| Greece | No | No | No | No | No | No | No |
| Hungary | No | No | No | No | No | No | No |
| Ireland | No | No | No | No | No | No | No |
| Italy | Yes | Yes | No | Yes | No | No | No |
| Latvia | No | Yes | No | Yes | Yes | No | Yes |
| Lithuania | Yes | Yes | No | Yes | No | No | No |
| Luxemburg | No | Yes | No | No | No | No | No |
| Malta | Yes | Yes | Yes | No | No | No | No |
| Netherlands | Yes | Yes | No | Yes | Yes | No | No |
| Norway | Yes | Yes | No | No | Yes | Yes | Yes |
| Poland | No | No | No | Yes | No | No | No |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Portugal | Yes | Yes | Yes | Yes | No | No | No |
| Romania | Yes | No | No | Yes | No | No | No |
| Slovakia | Yes | Yes | No | Yes | Yes | No | No |
| Slovenia | Yes | Yes | Yes | Yes | No | No | Yes |
| Spain | Yes | Yes | No | Yes | Yes | No | No |
| Sweden | Yes | Yes | No | No | Yes | Yes | No |
| UK | No | Yes | No | Yes | Yes | No | No |

*Source: (ACER, 2022).*

## 3.3 Global competiveness

In 2020, the Advanced Metering Infrastructure market has been evaluated to $19.4 billion, whereas it is forecasted to reach **$36.3 billion by 2028 worldwide**, (MENAFN, 2022).

The drivers of the smart meter market are summarized as follows, (MENAFN, 2022), (Markets):

- Growing adoption of Renewable Energy Sources;
- Policies favourable of smart meter rollouts together with policies to reduce carbon footprint worldwide;
- Advanced grid reliability thanks to smart meters;
- The necessity for analysing data of the electric power industry.

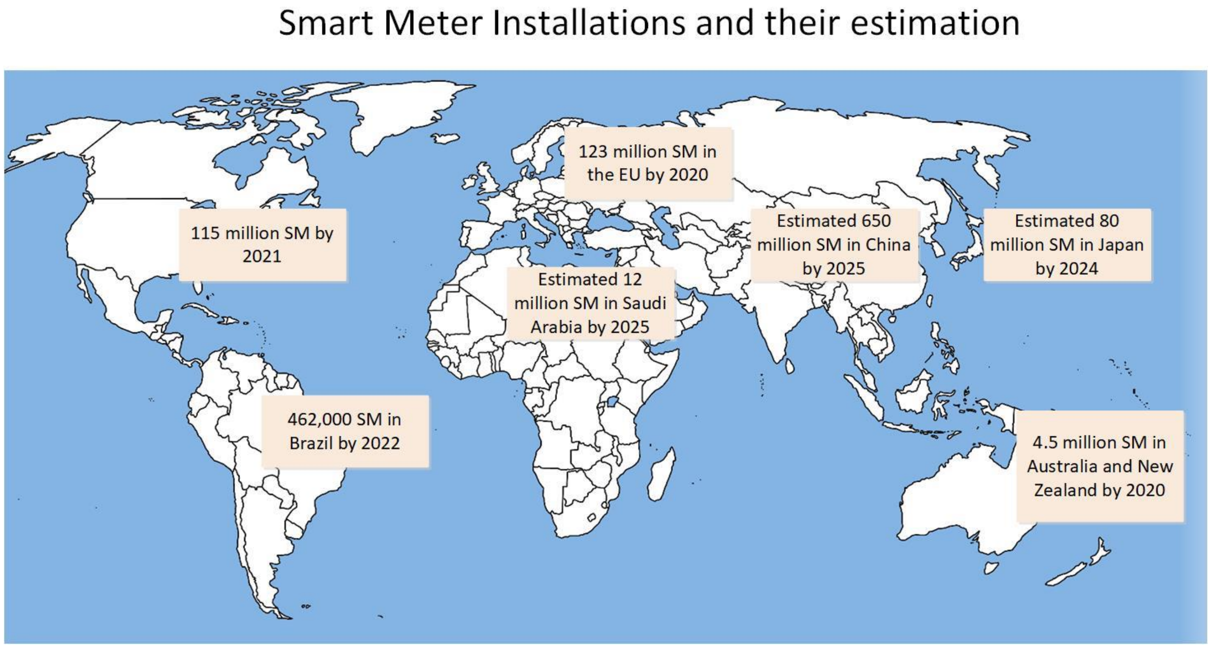
On the other hand, the main obstacles are summarized as follows:

- High investments needed in the field for smart meter rollout;
- Concerns for data privacy issues;

The fastest growing market is expected to be Asia Pacific, whereas various market actors are anticipated to have opportunities in the sector at least until 2028. On the other hand, Europe is expected to be the second market in the field. Europe, together with North America, have been the early adopters of smart meters, thanks to relative technological advancements and IT infrastructure. The overall market of Advanced Metering Infrastructure is expected to grow also in other regions, due to the fact that the major players are willing to expand their businesses, (MordorIntelligence, 2022).

The following figure shows the situation with respect to the smart meter installations, as this is depicted after collecting information from all relevant sources (ACER, 2022), (Allied Market), (MENAFN, 2022), (MordorIntelligence, 2022), (Meletiou, Vasiljevska, Prettico, & Vitiello, 2022), (Prettico, et al., 2022), (Strategic Intelligence). As the figure shows, there are many wide scale smart meter installations. The reference years are not the same for every region, since different information has been retrieved from different sources. Nevertheless, the figure is illustrative of the smart meter situation and give a clear picture at where the world stands with respect to this topic.

**Figure 10.** Smart meter installations worldwide.




*Source: JRC analysis 2023.*

Compared to the CETO report of 2022, we observe that we do not only have new data for European countries, as this is revealed in previous Subsection, but we also have updated information with respect to the rest of the world:

- Updated information has been obtained for USA, depicting that 115 million smart meters have been installed at least by 2021;

- Updated information has been obtained for Brazil, stating that 462,000 smart meters have been installed in the country by 2022.

**Asia Pacific Region:**

The region of Asia Pacific is dominating in the smart meter market at the moment, being the fastest and largest smart meter market. One reason is because there are numerous smart city projects that require smart meters' installations. In the region of Asia Pacific, investments for Advanced Metering Infrastructure are expected to facilitate the adoption of smart meters. Another factor acting as facilitator is the introduction of different tariffs according to the time-of-use of electricity by consumers, (MENAFN, 2022). In the region, there are also many initiatives for clean energy, improvement of grid operations and reliability, battery storage programs and microgrids, (MordorIntelligence, 2022).

For 2022, it was Asia Pacific that held the largest share of the AMI market, (Allied Market). In 2020, the smart meter market in the region was estimated around $10.82 billion, (MENAFN, 2022). Specifically for countries in the region:

China:

On the other hand, China is already at its second-wave smart meter installations. Specifically for China, there are severe governmental mandates indicating to proceed for a smart meter rollout, which is a target to be soon achieved by the country. The strong presence of smart meter companies and manufacturers in the country, leave no margin for non-chinese competitors to thrive in the country, (MordorIntelligence, 2022).

Japan:

Japan is the fifth carbon emitter worldwide. In 2021, it was announced the target to reduce emissions by 46% by 2030. In addition, governmental policies support smart grid and smart metering initiatives with investments reaching $155 billion. It is expected to have installed 80 million smart meters by 2024 in the country, (MordorIntelligence, 2022).

South Korea:

South Korea is implementing its national rollout plan, (MordorIntelligence, 2022).

India:
Specifically for India, the government invested $2677.42 million for the energy grid, including smart meter investments, (MordorIntelligence, 2022).

**America region:**

North America has been one of the pioneers in smart meter deployment. For the coming years, installing second generation smart meters is expected to be the driver for the market in the region along with progress in data analytics technologies, (MordorIntelligence, 2022).

In North America, it is estimated to have 1.4 billion smart buildings and 700 million smart homes (United States and Canada), thus, it is expected to have an elevated number of smart meters, as well.
Specifically for smart meters, it has been estimated that in 2018 their penetration was around 60% among all electricity customers; this number is estimated to rise to more than 80% by 2024, (Strategic Intelligence).

Particularly for the United States, it is estimated that in the United States, 115 million smart meters have been installed by 2021. In the region of North America, it is evaluated that the market share of the United States is the dominant one, with this trend continuing in the future.

### 3.3.1 Smart Meter Market Leaders

There is a list of smart meter market leaders, justifying the smart meter initiatives undertaken globally. To give a picture of some of the smart meter leaders, we give the following list in alphabetical order (not exhaustive). As we can see, there is a strong presence of European manufacturers in the field (MordorIntelligence, 2022), (MENAFN, 2022), (Allied Market).

Along with listing the manufacturers, an attempt has been made to categorize them according to where they are based, in order to identify the Europe-based manufacturers. Although for some manufacturers their categorization was rather straightforward, for others it is hard to tell, as they hold activities all over the world, whereas for others information was not enough to conclude whether or not they have offices also within Europe. The following list gives an idea of the presence of European manufacturers in the field and it is indicative of the situation.

- ABB – Europe based
- Aclara – Europe based
- Aichi Tokei Denki Co., LTD – non Europe based
- Badger meter inc – Europe based
- EDMI Limited - non Europe based
- EMH Metering GmbH & Co KG – Europe based
- General Electric – non Europe based but with offices also in Europe
- Holley Technology Ltd – non Europe based
- Honeywell – Europe based
- Itron, Inc. – non Europe based but with offices also in Europe
- Jabil – non Europe based
- Kamstrup – Offices also in Europe
- Landis+gyr Group AG – Europe based
- Neptune Technology Group Inc – non Europe based
- Sagemcom SAS – Europe based
- Schneider Electric – Europe based
- Secure Meter Limited – non Europe based with offices also in Europe
- Sensus USA Inc. (XYLEM INC) – non Europe based
- Siemens – Europe based
- Shenzhen Kaifa technology Co., LTD – non Europe based
- Suntront tech co. LTD – non Europe based
- Wasion Group Limited – non Europe based
- Xemex – Europe based
- ZPA Smart Energy – Europe based

# 4. Conclusions

Within the broad scope of smart grid technologies that are shaping the evolution of the electricity system, the present report has analysed two distinct topics that have been selected for their relevance and timely importance. The analysis in Section 2 has extended the general study on Transmission Innovation presented in last year's CETO report (European Commission, 2022) by focusing on High-Voltage Direct-Current assets, which are widely considered one of the key enabling technologies for the energy transition. The analysis in Section 3 has instead focused on Advanced Metering Infrastructure, expanding and updating the analysis provided in (European Commission, 2022). The main conclusions regarding the key technology development needs and trends and future development options are summarized next:

**High-Voltage Direct-Current (HVDC) systems**

- HVDC is already a mature and well-established technology which nevertheless still exhibits significant margins for improvements in terms of efficiency and competiteveness. European funding in this sector appears to be adequate, with about 1300 M€ of research funds allocated over the next few years.
- Europe companies currently hold a leadership market position in the production of HVDC cables and a relevant market share in HVDC converters manifacturing. To preserve this strong role against an increasing competition from non-european companies, standardization of products might be advisable.
- The supply chain does not present big criticalities at the moment. However, lead times are increasing as a result of rising demand. A consistent and clear commitment on this technology choice and the introduction of joint procurement procedures for member states could ensure that the manifacturing capacity remains sufficient for the growing European demand.

**Smart Metering Infrastructure**

- There are more than 1.2 billion smart meters installed worldwide, with Europe, Australia and North America being the pioneers in the field and only in the EU more than 123 million smart meters installed.
- The AMI market is estimated at around 20 billion dollars worldwide.
- For the near future, Asia pacific will be the main players in the field with massive second generation smart meters being installed.
- The European companies play a significant role in the market with numerous companies present in the overall global picture.
- Smart meters can offer multiple functionalities to customers, like: cumulative data for up to 3 years; near real-time data; energy price differentiation; hourly time energy pricing; consumption remote control and critical peak pricing.
- Smart meters can offer multiple functionalities also for energy providers/ DSOs, like: grid management tasks (network state analysis, outages detection, state estimation, customer monitoring); usage for grid control tasks); distribution planning tasks (automation of LV/MV grid operation, automation of customers' systems), grid asset planning).

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## List of abbreviations and definitions

AC – Alternating Current

BEMS – Building Energy Management System

CAGR – Compund Annual Growth Rate

CBA – Cost-Benefit Analysis

CEF – Connecting Europe Facility

CETO – Clean Energy Technology Observatory

DC – Direct Current

DSO – Distribution System Operator

FACTS – Flexible Alternating Currents Transmission Systems

EHV – Extra High Voltage

EV – Electric Vehicle

HEMS – Home Energy Management System

HVDC – High Voltage Direct Current

LCC – Line Commutated Converters

LV – Low Voltage

MI – Mass Impregnated

MV – Medium Voltage

PCI – Project of Common Interest

SET-Plan – Strategic Energy Technology Plan

TSO – Transmission System Operator

TRL – Technology Readiness Level

V2G – Vehicle to Grid

VSC – Voltage Source Converters

## List of figures

## List of tables

## Annexes

## Annex 1 Summary Table of Data Sources for the CETO Indicators

| Theme | Indicator | Main data source |
|---|---|---|
| Technology maturity status, development and trends | Technology readiness level | (ENTSO-E, 2021)<br>(ACER, 2022)<br>(Meletiou, Vasiljevska, Prettico, & Vitiello, 2022)<br>(Vitiello, Andreadou, Ardelean, & Fulli, 2022)<br>(Prettico, et al., 2022) |
| | Installed capacity & energy production | (IEA, 2023)<br>(MENAFN, 2022)<br>(MordorIntelligence, 2022) |
| | Technology costs | (De Santis, James, Houchins, Saur, & Lyubovsky, 2021)<br>(Meletiou, Vasiljevska, Prettico, & Vitiello, 2022)<br>(MENAFN, 2022) |
| | Public and private RD&I funding | (Strategic Intelligence) |
| | Patenting trends | (Power Technology, 2023) |
| | Scientific publication trends | Horizon 2020 and Horizon Europe database |
| | Assessment of R&I project developments | |
| Value chain analysis | Turnover | (Triconomics and Artelis, 2021)<br>(ACER, 2022) |
| | Gross Value Added | (Transparency Market Research, 2022)<br>(Power Technology, 2023)<br>(Meletiou, Vasiljevska, Prettico, & Vitiello, 2022) |
| | Environmental and socio-economic sustainability | (Triconomics and Artelis, 2021)<br>(Meletiou, Vasiljevska, Prettico, & Vitiello, 2022)<br>(ACER, 2022) |
| | EU companies and roles | (IEA, 2023)<br>(MENAFN, 2022)<br>(MordorIntelligence, 2022) |
| | Employment | |

| | | |
|---|---|---|
| | Energy intensity and labour productivity | |
| | EU industrial production | |
| Global markets and EU positioning | Global market growth and relevant short-to-medium term projections | (IEA, 2023)<br>(ENTSO-E, 2022)<br>(MENAFN, 2022)<br>(Markets)<br>(MordorIntelligence, 2022)<br>(Allied Market) |
| | EU market share vs third countries share, including EU market leaders and global market leaders | (IEA, 2023)<br>(ENTSO-E, 2022)<br>(ACER, 2022)<br>(MordorIntelligence, 2022)<br>(Allied Market) |
| | EU trade (imports, exports) and trade balance | |
| | Resource efficiency and dependencies (in relation EU competiveness) | |

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