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Progress on competitiveness of clean energy technologies
8 & 9 - Smart Grids and Renewable Fuels

{COM(2021) 950 final} - {COM(2021) 952 final}

SMART GRIDS (DISTRIBUTION AUTOMATION, SMART METERING, HOME ENERGY MANAGEMENT SYSTEMS AND SMART EV CHARGING)

INTRODUCTION

Smart grids can be described as upgraded electricity networks to which two-way digital communication between supplier and consumer, intelligent metering and monitoring systems have been added[578]. Smart grids co-ordinate the needs and capabilities of electricity generators, grid operators, end-users and electricity market stakeholders to operate all parts of the system as efficiently as possible, minimising costs and environmental impacts while maximising system reliability, resilience and stability[579].

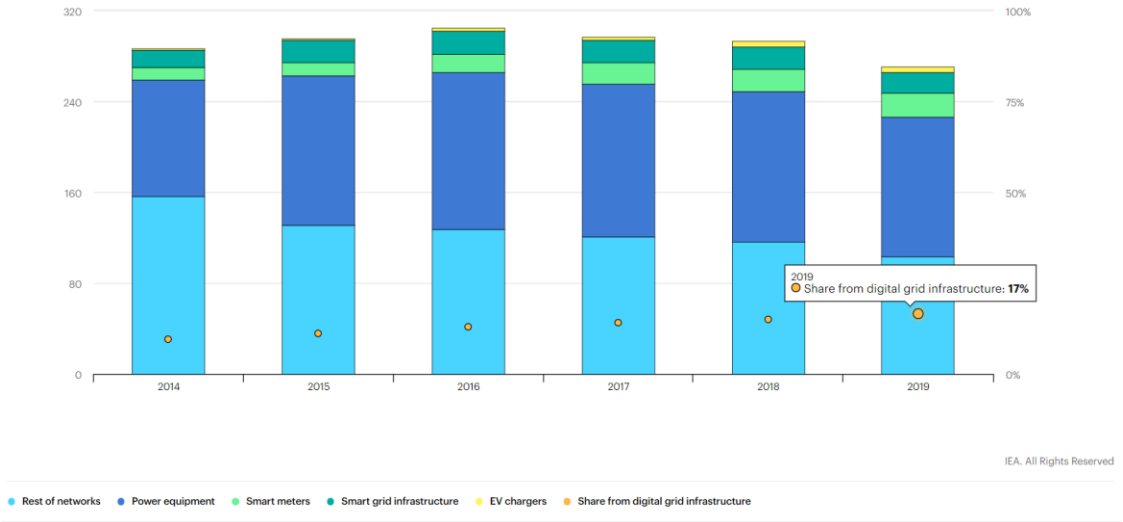
Fundamental in the smart grids, digital technologies (like smart meters and sensors, the Internet of Things, big data and artificial intelligence) support the transformation of the power sector in several ways, including better monitoring of assets and their performance, more refined operations and control closer to real time; the integration of distributed implementation of new market designs; and the emergence of new business models.

Digitalisation goes hand in hand with decentralisation and decarbonisation that involve local generation, storage and new loads integrated locally. In this context, aside from offering a range of useful energy services, distributed generation and enabling technologies have become sources of valuable data. Detailed, and sometimes real-time information on local generation/consumption patterns, load profiles, the performance of components in electricity systems and failures can enable better planning and system operation by grid operators. This also allows for a better forecasting of electricity production and consumption of distributed sources and, consequently, the electricity system can be operated with a higher share of variable renewable energy (VRE). By reducing supply and demand uncertainty, the related risks are reduced as well, without increasing the operation costs[580].

The digitalisation that started in the power transmission much earlier, due to the criticality of the latter, it is by now gaining strength in the power generation, distribution and end-use domains, too. In the recent years, while the size of global annual investment in power infrastructure declined (from USD 304 billion to USD 271 billion between 2016 and 2019[581]), the share of smart grid investments kept on growing (from 13% to 17% in the same period)[582] (Figure 1).

[578] Smart Grids: from innovation to deployment, COM(2011) 202 final.
[579] International Energy Agency (IEA), 'Technology Roadmap- Smart grids'April 2011, pp. 50.
[580] International Renewable Energy Agency (IRENA), Innovation landscape for a renewable-powered future: Solutions to integrate variable renewables, Abu Dhabi, 2019, pp. 32.
[581] Conversion rate: 1 USD = 0.84 EUR
[582] International Energy Agency (IEA), Tracking Energy integration 2020- Smart Grids: Investment in smart grids by technology area (2014-2019), Paris, June 2020.

Figure 1 Investment in smart grids by technology area, 2014-2019 (USD billlion)



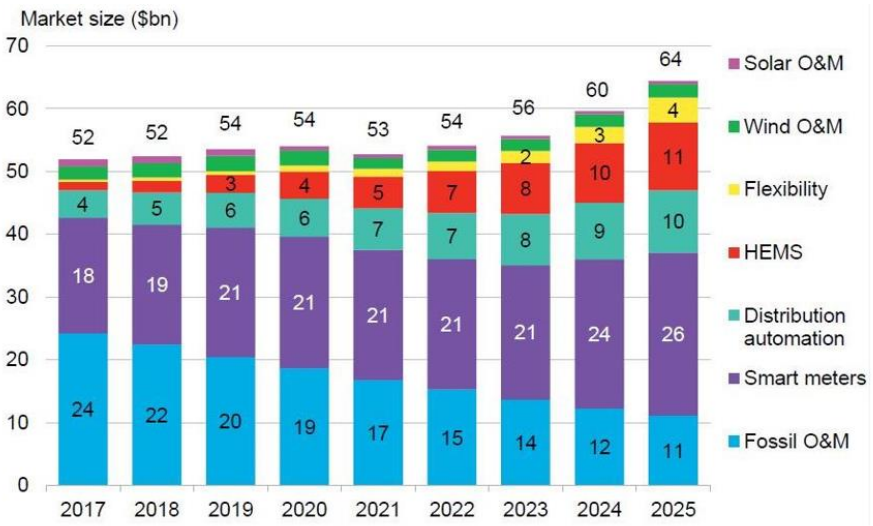
Source: IEA, Tracking Energy integration 2020- Smart Grids, Paris, June 2020

Similar growth is observed in patenting in enabling technology areas such as electricity storage and smart grids, which now have clear market value for the resilient operation of electricity networks with higher levels of variable renewable power", namely for enabling demand-side flexibility[583].

The take-up of smart grid technologies is expected to remain a robust trend during this decade and beyond, in close correlation with electrification and decentralisation: they will create market value by supporting higher levels of variable renewable power without compromising electricity network resilience. Consequently, it is widely anticipated that the market size for digital technologies will continue growing in all related segments, such as digital operation & maintenance (O&M) systems, Home Energy Management Systems (HEMS), distribution automation and smart meters (Figure 2).

[583] European Patent Office (EPO) and OECD/IEA, Statistics report: Patents and the energy transition - Global trends in clean energy technology innovation, April 2021, pp. 72

Figure 2 Market size for digital technologies in the energy sector (USD billion)



Source: Bloomberg New Energy Finance (BNEF), Market for Digitalisation in Energy Sector to Grow to USD 64 Billion by 2025, November 2017

Innovation, however, will remain key all along the smart grids value chain. While individual smart grid technologies (from information and communication technologies to smart energy appliances and devices) are relatively mature, their deployment at system level is both financially costly and technologically challenging. Demonstrating the benefits and security of a decentralised power system running on variable renewables is in the centre of innovation efforts[584]. The non-technological part of the challenge is also considerable: with access to (near) real-time end-users data, energy service providers (e.g. aggregators) will seek to increase their market share by offering innovative energy services for consumers (e.g. quality heating, cooling and vehicle charging) as well as for energy suppliers (flexibility services). As the digitalisation of energy progresses, so does its exposure to cyberattacks, and consequently cyber security will also top innovation and policy agendas[585].

In last year's Competitiveness report[586], the smart grid chapter provided an insight into technology (software) and market developments with regard to distributed energy resource management systems, virtual power plant and distributed energy resource analytics. This year, the report explores technology areas around the smart meters that allow a more efficient management of the grid and tapping potential flexibility sources. Namely, the take-up of distribution grid and substation automation, the rollout of smart meters, HEMS and smart charging of electric vehicles (EVs).

[584] See for instance the objectives of the 'Green Powered Future Mission', *Mission Innovation*, June 2021: http://mission-innovation.net/missions/power/

[585] "Between 2018 and 2023 the EU cybersecurity market is expected to grow at a compound annual growth rate (CAGR) of 11.3% and its value is expected to exceed EUR 40 billion." Kochanski, M., Korczak, K., Skoczkowski, T., 'Technology innovation system analysis of electricity smart metering in the European Union', *Energie*s, 18 February 2020

[586] Progress Report on Competitiveness, COM(2020) 953 final and Accompanying document, SWD(2020) 953 final

27. DISTRIBUTION AUTOMATION

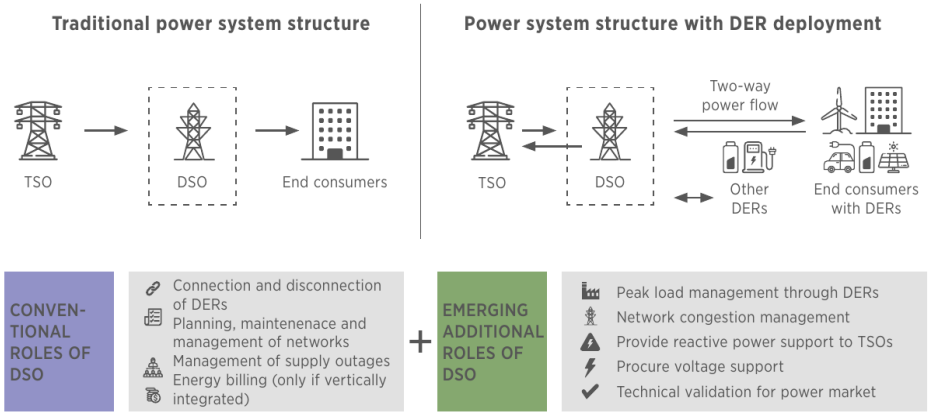
27.1. Technology Analysis

27.1.1. Introduction and technology maturity

Automation is a family of technologies, including sensors, processors, information and communication networks, and switches, through which a network operator can collect, automate, analyse, and optimise data to improve its operational efficiency. Automation can improve the speed, cost, and accuracy of several key distribution system processes, including fault detection, feeder switching, and outage management; voltage monitoring and control; reactive power management; preventative equipment maintenance for critical substation and feeder line equipment; and grid integration of DER[587]. As an example, by means of distribution automation, after a fault occurs, sections of the network can be restored remotely within a few minutes, instead of several hours as is the case with manual restoration. Early identification of changes in the operation of equipment through digital sensors also improves the operational efficiency and productivity of assets, allowing maintenance to take place before the problem worsens, becomes more expensive to resolve and results in unplanned outages.

With access to the flexibility coming from MV and LV grids, DSOs could better optimise the use of the whole distribution network and minimise the need for future grid reinforcements procuring flexibility services like peak load management through distributed energy resources (DERs), network congestion management and voltage support from the assets already connected to their distribution network (Figure 3).

Figure 3 DSOs role changes in the emerging decarbonising scenarios



Source: International Renewable Energy Agency (IRENA), Innovation landscape brief: Future role of distribution system operators, Abu Dhabi, 2019

In a study of 2019[588], 68% of the almost 2 000 energy industry professionals recognised that automation and digital workflow are among those technologies which are most impacting the transmission and distribution industry. Despite this clear drive towards digitalisation, research reveals that only some half

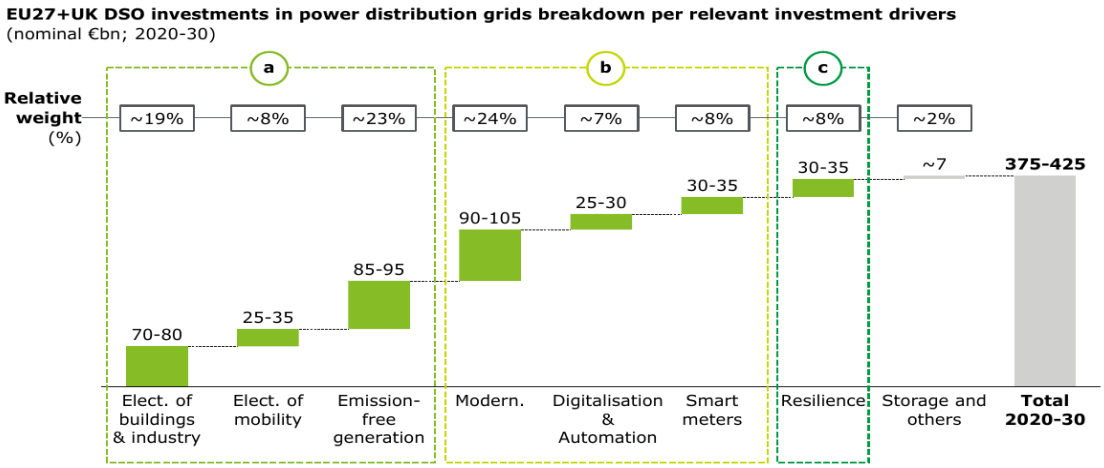
[587] National Electrical Manufacturers Association (NEMA), 'Distribution Automation', https://www.nema.org/directory/products/view/distribution-automation

[588] DNV GL, Digitalization and the future of energy : beyond the hype - how to create value by combining digital technology, people and business strategy, Arnhem, January 2019, pp.28

(52%) of Distribution Network Operators (DNOs) have digitalisation as a core part of their publicly stated strategy.

It has been estimated that for the EU and UK between EUR 25 billion and EUR 30 billion are needed in digitalisation and automation (Figure 4) until 2030, which corresponds to 7% of the total needed investment for this period[589].

Figure 4 Estimated investments in distribution grids until 2030



Source: Eurelectric, 'Connecting the dots: Distribution grid investment to power the energy transition'. January, 2021

Many technologies are already available today and allow for immediate large-scale deployment. However, data point to the fact that while this type of asset control is well-spread at the HV - MV substations, it is not common at MV level: over three-quarters of the DSOs taking part to the DSO Observatory[590] exercise had less than 7.5% of their MV substations remotely controllable.

27.1.2. Public Research and Innovation (R&I) funding

To better implement and connect among them different technologies in different locational scenarios, several projects, for a total of around EUR 200-400 million, each including more than one demonstrator, have been carried out at the EU level in the framework of the Horizon 2020 funding programme[591] (due to the fact that often, investment figures are aggregated into larger families of technologies, for instance, Transmission and Distribution, Power Grids … the provided figure is to be considered as order of magnitude)

A non-exhaustive list of projects includes UPGRID, Flex4GRID, FLEXICIECY, GOFLEX, INTEGRID or InterFLEX[592].

589 Connecting the dots: Distribution grid investment to power the energy transition - Eurelectric – Powering People

590 Prettico, G., Marinopoulos, A., Vitiello, S., 'Distribution System Operator Observatory 2020: An in-depth look on distribution grids in Europe', EUR 30561 EN, P*ublications Office of the European Union*, Luxembourg, 2021, ISBN 978-92-76-28430-7, doi:10.2760/311966, JRC123249

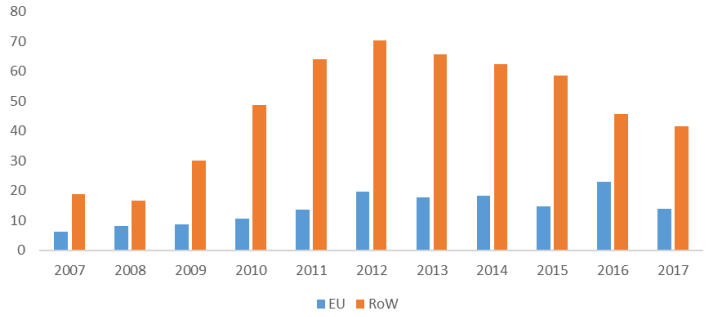
591 European Commission, 'Cordis: EU research results', https://cordis.europa.eu

592 Projects - Bridge (h2020-bridge.eu)

27.1.3. Patenting trends

For the 2007-2017 30% of the high-value inventions were submitted by applicants headquarters in the EU (Figure 5. Japan and the US lead the rank of host countries, with Germany in third and France and Italy also in the top 10).

Figure 5 High-value inventions in Grid Energy Management systems

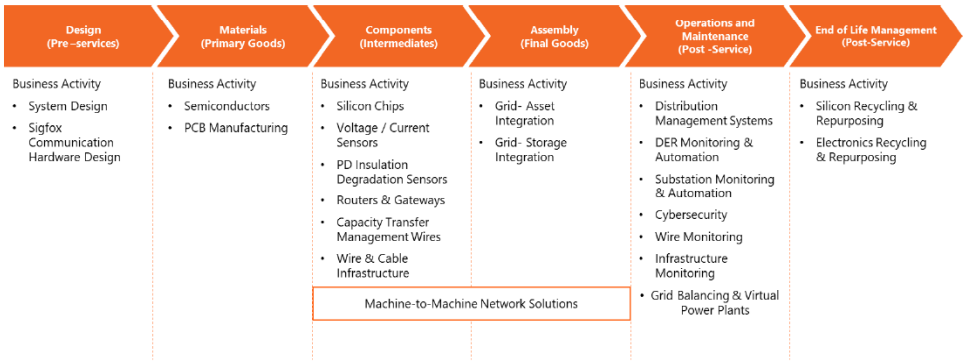


Source: JRC, commissioned by DG GROW -European climate-neutral industry competitiveness scoreboard (CIndECS) (Draft, 2021)

27.2. Value chain analysis

Due to the technology aggregation reason stated above, value chain data cover the full transmission and distribution level considering the automation as a combined item (with Substation Monitoring) under the Operation and Maintenance segment (Figure 6).

Figure 6 Grid Energy Management System value chain structure



Source: Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, 'Climate neutral market opportunities and EU competitiveness Final Report', Written by ICF and Cleantech Group, December 2020

The scope of the Grid Energy Management System value chain[593] covers digital-integrated systems to manage, coordinate, monitor and control utility-connected grids for the efficient transmission and distribution of electricity. The analysis includes hardware and software operating on transmission and distribution networks, communication hardware, distributed energy resource management devices as well

[593] Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, 'Climate neutral market opportunities and EU competitiveness Final Report', Written by ICF and Cleantech Group, December 2020

as power and Volt/VAR control systems. However, this value chain does not include smart meters, inverters, other on-building energy systems (e.g. plug loads), demand response or grid edge technologies.

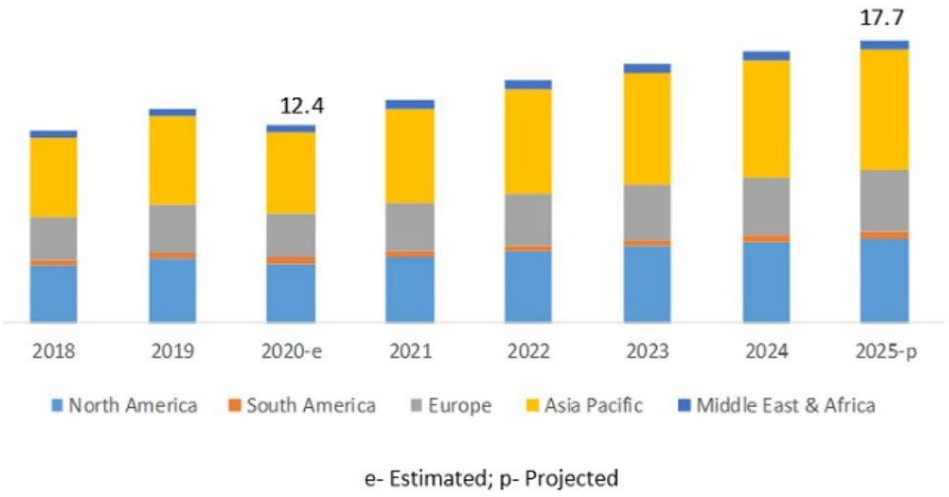
Over the 2015-2019 period, 27% of the total value of global private venture capital investments in early-stage companies active in the Grid Energy Management Systems value chain was in EU companies. When assessing the number of investments, this percentage grows to 43%, suggesting that the average size of investments was higher outside of the EU. The value chain saw over 150 investments during that period for a total of EUR 477 million, showing a very active market in terms of innovation and appetite from venture capital investors. In the EU, Germany (EUR 19 million) stands out in terms of total size of investments in early stage companies over the studied period but remains behind the US that benefited from close to 50% of these early stage investments (i.e. EUR 235 million during 2015-2019). China and Israel also performed very well in terms of early stage investments attracting respectively EUR 66 million and EUR 27 million.

In terms of late-stage investments in innovative companies, the EU attracted 23% of the total value of global late stage investment tracked by the Cleantech Group. The volume (EUR 3.5 billion) and number of deal (167) of late-stage investments confirm the dynamism of this Venture Capital (VC) at global level. At the EU level, France (EUR 368 million), Germany (EUR 218 million) were the leaders, but were largely outperformed by the US (EUR 2 billion) and to a lesser extent China (EUR 398 million). Additionally, Israel attracted EUR 233 million in terms of late stage investments.

27.3. Global market analysis

The distribution automation market size is projected to reach USD 17.7 billion by 2025 from an estimated value of USD 12.4 billion in 2020, at a CAGR of 7.4 % during the forecast period[594]. The need for improved grid reliability and operating efficiency and increasing investments to upgrade aging grid infrastructure are the key growth drivers for this market (Figure 7).

Figure 7 Distribution automation market by region (USD billion)



Source: Distribution Automation Market - Global Forecast to 2025, Markets and Markets, 2020

[594] Markets and Markets, Distribution Automation Market by Component (Field Devices, Software, Services), Communication Technology (Wired (Fiber Optic, Ethernet, Powerline Carrier, IP), Wireless (RF Mesh, Cellular, Wimax)), Utility, Region - Global Forecast to 2025, 2020 https://www.marketsandmarkets.com/Market-Reports/distribution-automation-market-65029172.html.

The major players in the distribution automation market include ABB (Switzerland), Eaton (Ireland), GE (US), Schneider Electric (France), and Siemens (Germany).

27.4. Conclusions (Distribution)

In the EU, and in some other parts of the world (most notably in the US), substation automation has been a trend in recent years, coupled with utilities' efforts to expand the use of software platforms to monitor and control their assets, notably through digital twins. Correspondingly, some utilities and grid companies in EU (Iberdrola, Enel, Rte and e.On) and in the US (Exelon, Duke and Edison International) have started spending a greater part of their budget on software.[595]

Enel (IT) offers a prime example of how digitalisation can increase operational efficiency and improve quality of service for a grid owner or operator. The IEA reports that in just ten years, Enel reduced the System Average Interruption Duration Index (SAIDI, an indicator of grid quality) by 65%, and it is currently spending nearly one-third of its investment budget on digital technology. On the other side of the Atlantics, National Grid (US) partnered with Utilitidata and Sense to create a "digital twin" of the grid, mapping power flow, voltage and infrastructure from the substation to the home. American Electric Power also announced the digital twinning of their transmission infrastructure, developed in collaboration with Siemens.

Quantifying benefits remains difficult, however. Many regulatory regimes reward cost savings, whereas smartening the grid often produces other qualitative or softer benefits (e.g. enabling other technology or business models; reducing emissions; creating jobs) that cannot be easily rate-based. While some utilities have begun reporting direct financial savings, improvements in traditional reliability metrics remain the mainstays to evaluate costs and benefits of smartening the grid.

There are, however, big differences among EU Member States when grid modernisation levels are considered. Despite requirements in the Clean Energy Package to fully deploy smart grids, distribution system operators need stronger incentives to move from conventional grid expansion options to more alternative and sophisticated solutions based on ICT, artificial intelligence and automation.

Among the main barriers hindering the full deployments of smart grids, the uncertainty related to the missing universal standards, the lacking of mature markets and the return on investments not guaranteed are the most burning ones. The missing consumer awareness represents another barrier: the benefits of a smart grid can be achieved only if customers are fully aware of the smart grid concepts and they use all of its features. At present, privacy concerns and the risk of cyber-attacks does not help deploy smart grid solutions as paved. At the same time the scaling of solutions is often impeded by proprietary standards that lack of interoperability. Last but not least, the shortage of training and technical staff required for deploying and operating especially intragrid control applications is another important obstacle.

28. SMART METERS

28.1. Technology Analysis

28.1.1. Introduction and Technology maturity

Smart electricity metering system means an electronic system that is capable of measuring electricity fed into the grid or electricity consumed from the grid, providing more information than a conventional meter,

[595] IEA, Smart Grids, IEA, Paris, 2020 https://www.iea.org/reports/smart-grids

and that is capable of transmitting and receiving data for information, monitoring and control purposes, using a form of electronic communication[596].

Smart meters are well developed technologies. In 2012, the European Commission recommendations[597] defined ten minimum functionalities for smart meters (Table 1), which became guidelines for Member States, technology providers and utility companies during the first wave of deployment (the 2010s). Leading countries that mostly completed their rollout strategies by 2020 (e.g. Finland, Italy, Spain and Sweden) have been preparing, or are already undertaking, a second wave of smart meter deployment, with enhanced or new features.

A significant majority of smart meters installed in the EU use Power Line Communication (PLC) technology[598] that makes Europe one of the world leaders. PLC enables the use of existing power lines for telecommunications between smart meters and DSO interfaces. PLC comes especially "handy" where power lines and installations are below the ground and hence not well covered by wireless services (like most European cities).

Table 1 Minimum functionalities for smart meters in EC recommendations

Consumer	1. Provide readings directly to consumer and/or any 3rd party 2. Upgrade readings frequently enough to use energy saving schemes
Metering operator	3. Allow remote reading by the operator 4. Provide 2-way communication for maintenance and control 5. Allow frequent enough readings for network planning
Commercial aspects of supply	6. Support advanced tariff systems 7. Remote on/off control of the supply and/or flow or power limitation
Security & Data Protection	8. Provide secure data communications 9. Fraud prevention and detection
Distributed generation	10. Provide import/export and reactive metering

Source: ESMIG

Landys+Gyr observes increasing focus on grid edge intelligence and direct consumer benefits for second wave use cases, including “hyper-critical focus” on (consumer) data security, increasing value of prepayment (Pay-As-You-Go solutions) and common approach to single management solution for home-plus-EV metering and management (Figure 8)[599].

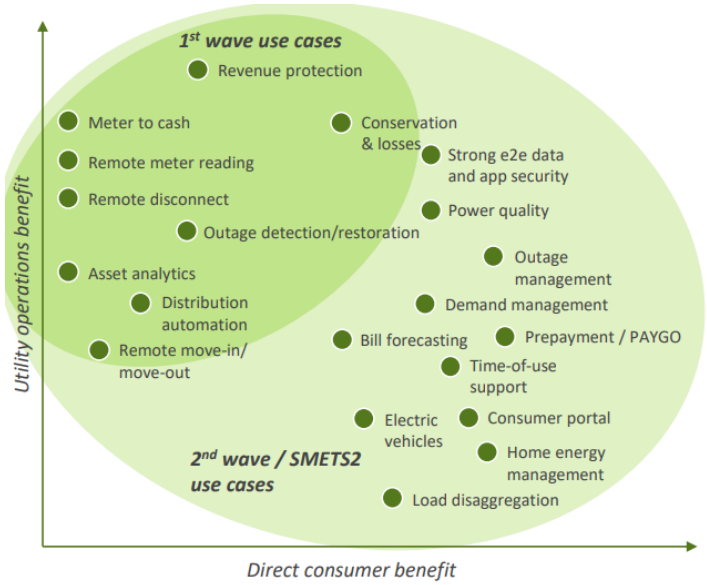
[596] DIRECTIVE (EU) 2019/944 on common rules for the internal market for electricity.

[597] COMMISSION RECOMMENDATION of 9 March 2012 on preparations for the roll-out of smart metering systems (2012/148/EU)

[598] Horizon 2020 Project INTEGRIDY, D2.5: Smart Grid Deployment, Infrastructures & Industrial Policy applicable to the inteGRIDy pilot cases, inteGRIDy hyperlink

[599] Landis+Gyr, Capital Markets Day: EMEA, January 2019: https://www.landisgyr.com/webfoo/wp-content/uploads/2019/01/4.-CMD-EMEA.pdf

Figure 8 Grid edge use cases driven by retail market innovation



Source Landis+Gyr, Capital Markets Day: EMEA, January 2019

28.1.2. Capacity installed

The 2009 Electricity Directive envisaged an 80% rollout rate of smart meters in Member States by 2020, in which the cost-benefit assessment provided a positive outcome. However, this goal was not achieved. While by the end of the last decade three quarters of EU Member States adopted specific legal provisions for the rollout of smart metering systems[600], in 2018 44% of all electricity meters were "smart" in the EU+UK (the global – worldwide – penetration rate was 14% (2019), 70% in China and also 70% in the US, with 98 million smart meters installed).[601] There were, however, big disparities between individual Member States as shown in Table 2.

The rollout of smart meters will continue during the next decade, pulled by the favourable policy environment and the digitalisation trend in the energy sector. ESMIG, the association of European smart energy solution providers, estimates that the penetration rate in EU + Norway, Switzerland and UK will grow from 45% in 2019 to 69% by 2025 based on available figures and expected shipments (Table 3).

[600] Benchmarking smart metering deployment in the EU-28, Study produced by Tractebel Impact for the European Commission, DG Energy (2019)

[601] IRENA, Innovation landscape brief: Energy as a Service, International Renewable Energy Agency, Abu Dhabi, 2020

Table 2 Rollout of smart meters in EU, Norway, Switzerland and UK

Country	Share (%) of smart meters in all electricity meters (early 2020)	Country	Share (%) of smart meters in all electricity meters (early 2020)
Austria	36	Latvia	75
Belgium	9	Lithuania	6
Bulgaria	41	Luxembourg	96
Croatia	15	Malta	89
Cyprus	40	Netherlands	86
Czech Republic	3	*Norway*	99
Denmark	99	Poland	12
Estonia	100	Portugal	41
Finland	98	Romania	14
France	78	Slovakia	16
Germany	2	Slovenia	78
Greece	8	Spain	99
Hungary	2	Sweden	100
Ireland	11	*Switzerland*	13
Italy	99	*United Kingdom*	38

Source: Berg Insight Report, June 2020, www.berginsight.com

Table 3 Electricity smart meter penetration rate, 2019–2025 (EU+CH, NO, UK)

Million units	2019	2020	2021	2022	2023	2024	2025
Smart meters, installed base	135.5	149.6	167.8	182.9	194.4	205.0	214.4
Penetration rate	45 %	49 %	55 %	60 %	63 %	66 %	69 %

Source: Berg Insight Report, June 2020, www.berginsight.com

28.1.3. Public R&I funding

Between 2012 and 2017, a total of 416 public procurements for energy meters were announced at the EU level, mainly by utilities. In this sense government procurement can be regarded as a direct investment that is actively used at the EU level for smart meter development and deployment[602].

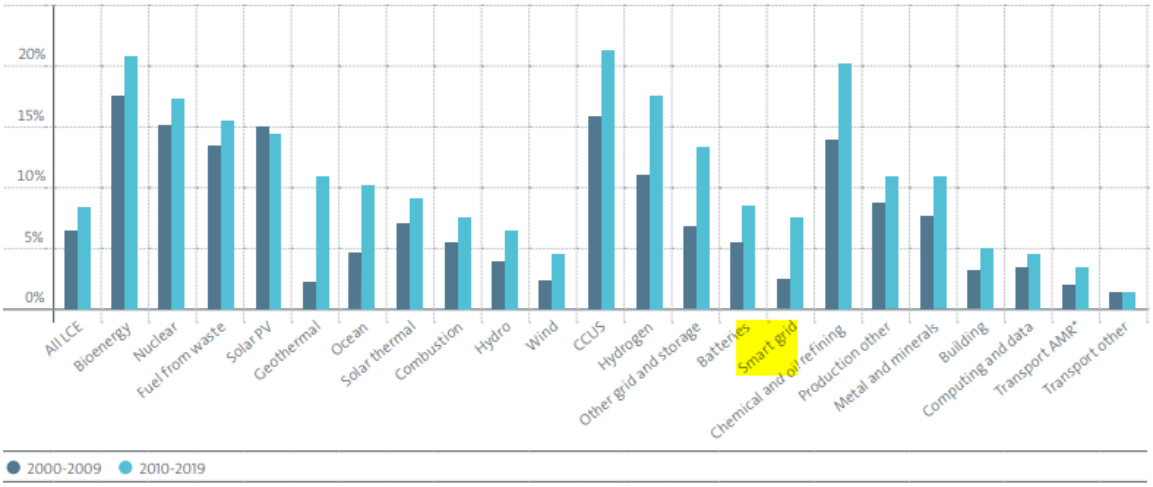
28.1.4. Patenting trends (smart grids)

The recent joint EPO-IEA report[603] demonstrates an increasing patenting activity for technologies enabling the integration of clean energy resources, including smart grids. For example, the share of smart grids international patent families (IPFs) in all low-carbon energy technology IPFs almost tripled between the beginning of the 2000s and the end 2010s (Figure 9).

[602] Kochanski, M., Korczak, K., Skoczkowski, T., 'Technology innovation system analysis of electricity smart metering in the European Union', *Energies*, 18 February 2020

[603] European Patent Office (EPO) and OECD/IEA, Statistics report: Patents and the energy transition - Global trends in clean energy technology innovation', April 2021, pp. 72

Figure 9 Share of IPFs in low-carbon energy technology fields, 2000-2019



Source: European Patent Office (EPO) and OECD/IEA, Statistics report: Patents and the energy transition - Global trends in clean energy technology innovation, April 2021

For smart grid technologies, the EPO-IEA report identified three top clusters. They are largely dominated by the region of Tokyo, Japan, which alone generated nearly twice the total of smart grid IPFs than in the other two top clusters (Seoul, R. of Korea, and Beijing, P.R. of China) between 2010 and 2018.

Patenting trends also unveil different specialisation strategies. Some companies show strong specialisation in technologies related to EV in their respective IPF portfolios. Toyota, for instance, has a strong patenting contribution in EV, hydrogen, batteries and smart grids, although it also generated a significant share of IPFs in other low-carbon emission technologies (LCE) for road transportation. Other high-ranking automotive companies show similar profiles. Companies such as Samsung, LG and Panasonic specialise in batteries and are likewise active in EV and smart grid technologies, as well as solar and other end-use technologies (building, industrial production, ICT), with possible spill-over effects.

General Electric and Siemens show a different profile, specialising in all LCE energy supply technologies, especially efficient combustion and wind power, as well as in smart grids and other grid and storage technologies. Japanese companies Hitachi and Toshiba have a comparable profile, with patenting activities in these fields, as well as in EV and batteries. Nearly all top applicants are significantly active in the full spectrum of enabling technologies, with a stronger focus on batteries, hydrogen and smart grids.

28.2. Value chain analysis

28.2.1. Turnover

The penetration of smart meters has been steadily growing in the EU for a decade now. In 2019 (hence before the global breakout of the COVID19 pandemic), a forecast by Landis+Gyr saw the number of installed smart meters reaching 211 million unit in 2023 in the EU, corresponding to an 11% Compound Annual Growth Rate (CAGR) between 2018 and 2023. This sharp growth in units installed would have led

the EMEA market value (including Europe, as well as the smaller markets of Africa and the Middle East) to grow in the 2017-2021 period from USD 1.4 billion USD to USD 2.2 billion.[604]

The impacts of the pandemic were such that, in 2020, some shipments and installations have been delayed or postponed. However, this should be a temporal impact. ESMIG expects that the lost volumes will be recuperated during 2021–2022, underpinned by the post-COVID-19 acceleration of ongoing projects as well as the completion of major first-wave rollouts in countries such as France and the Netherlands along with second-wave deployments in Italy and Sweden. This should lead to a peak in annual smart meter shipments in 2021-2022 (with approximately 26 million units shipped in 2022) (Table 4 Electricity smart meter shipments, 2019–2025 (EU+CH, NO, UK)).

Table 4 Electricity smart meter shipments, 2019–2025 (EU+CH, NO, UK)

Million units	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	
Electricity meter shipments	25.5	23.0	30.5	25.5	20.2	17.3	12.7	
Of which smart meters		20.9	19.5	26.5	22.3	17.3	14.9	10.4

Source: Berg Insight Report, June 2020, www.berginsight.com

28.2.2. EU market leaders

Smart electricity meters are typically produced by electronic and/or software companies, or by manufacturers covering several segments of the metering market (electricity, gas and water). The major regional European players according to ESMIG are: ADD Group (Moldova), AEM (Romania), Apator (Poland), Energomera (Russia), Iskraemeco (Slovenia), Landis+Gyr (Switzerland), Sagemcom (France) and ZIV (Spain) in electricity metering and Kamstrup (Denmark) in electricity and heat metering. Significant international players active on the European smart electricity metering market include Aclara (Hubbell, US), EDMI (Osaki Electric, Japan), Itron (US), NES (US) and Sensus (US).

According to the above-sited Landis+Gyr report, in 2017, Sagemcom (France) and Landis+Gyr (Switzerland) had each a quarter of the smart meter market in the Europe, Middle East and Africa (EMEA) grand region, while Itron (US), ENEL/Endesa (Italy/Spain) and Iskraemeco (Slovenia) roughly shared another quarter, with the last quarter left to "others". In the same (EMEA) region, the services & metering software market was dominated by Landis+Gyr, Kamstrup (Denmark) and Sagemcom (France), while Capgemini (France), ELTEL (Sweden), Eriksson (Sweden), Honeywell (US), IBM (US), ZIV (Spain) and were the contenders.

28.3. Global market analysis

28.3.1. The global market for smart meters

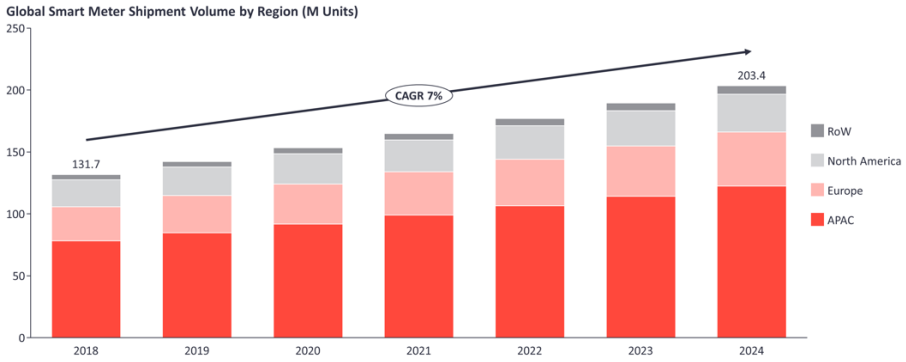
The global market for smart meters is growing, and will continue doing so in the near future. One market analysis estimates that global smart meter penetration (electricity, water and gas) has surpassed 14% in 2019, i.e., 14% of all meters are now smart meters[605]. The estimated installed base of smart meters (electricity, gas and water) is expected to surpass the 1 billion mark within the next 2 years. Just under 132

[604] Landis+Gyr, Capital Markets Day: EMEA, January 2019: https://www.landisgyr.com/webfoo/wp-content/uploads/2019/01/4.-CMD-EMEA.pdf

[605] Knud Lasse Lueth, "Smart meter market 2019: Global penetration reached 14% – North America, Europe ahead", *IOT Analytics*, 13 November, 2019; https://iot-analytics.com/smart-meter-market-2019-global-penetration-reached-14-percent/

million smart meters (electricity, gas and water) were shipped worldwide in 2018. This number is expected to grow 7% per year to exceed 200 million by 2024.

Figure 10 Global smart meter shipment volume by region (million units)



Source: IoT Analytics research blog, Smart Meter Market Report 2019-2024, 13 November 2019

ESMIG reports that the global market size, in 2019, was estimated at USD 21.3 billion and projected to grow to USD 38-39 billion in 2027; this sharp increase being due to projected market growth mainly in Asia.

There is a high level of fragmentation in the global smart meter market, due to a combination of different regional or country-level institutional support and regulatory frameworks and the varying needs of utilities in different areas of the world. The three main regions (North America, Europe, Asia Pacific) have vastly different characteristics and market dynamics.

The smart meter market in North America is fairly mature, with a penetration rate estimated at about 30-40% of total utility consumers of electricity, gas and water. Both the US and Canada were early adopters of smart meters. Today many of the tier 1 utility operators in the region have deployed a large-scale smart meter solution or are currently in the process of doing so.

Asia Pacific (APAC) currently represents the largest region in the global smart meter market (with focus on smart electricity meters), with an estimated 78.1 million smart meters shipped in the region in 2018. That number corresponds to almost 60% of the global shipments volume. The overall penetration of smart meters in the region remains lower than North America and Europe however, with less than 20% of utility customers equipped with smart meters. As in Europe, there are large differences among countries. **China** is the leading country in the APAC smart meter market. In 2011, the State Grid Corporation of China began the deployment of smart electricity meters in various areas of the country, installing a total of 476 million meters that represent more than half the worldwide installed base today. Japan and South Korea are two other hotspots in the region, with large scale deployments of smart energy meters currently ongoing. India is expected to roll out 250 million smart meters by 2025 according to latest figures[606]. Indonesia, Malaysia, Philippines, Singapore and Thailand are expected to become key markets after 2020.

In the rest of the world, the smart meter market is largely still at an early stage with some countries such as Mexico, Brasil, Egypt, Nigeria, or South Africa planning for large deployments.

[606] https://www.smart-energy.com/industry-sectors/smart-meters/indias-smart-meter-rollout-250-million-meters-by-2025/"

28.3.2. Global market leaders

One market analysis mentions the following significant non-European market players: Azbil Kimmon Co. Ltd (Japan), Honeywell International Inc. (US), General Electric Company (US), Hexing Electric Company Ltd (China), Holley Technology Ltd (Zhejiang Huamei Holding Co. Ltd, (China), Itron Inc. (US), Jiangsu Linyang Energy Co. Ltd (China), Nanjing Xinlian Electronics Co. Ltd (China), Ningbo Sanxing Medical & Electric Co. Ltd (China), Sensus USA Inc. (US), Shenzhen Hemei Group Co. Ltd (China), Wasion Group Holdings (China)[607].

28.4. Conclusions (Smart meters)

The clear, early vision of EU-level actors for smart meters deployment, founded on the grounds of energy conservation and empowerment of customers, and supported with regulatory measures, has been the major driver for the development and rollout of these technologies. Even though the penetration rates of smart meters have not reached the established ambitious objectives by 2020, they have contributed directly not only to the introduction of top-down obligation schemes in various Member States, but also to bottom-up, voluntary initiatives of local stakeholders, for example with DSOs in Poland which started deploying smart meters ahead of any nationally binding regulations. Despite the recent introduction of more ambitious policies in the field (Clean Energy Package), according to some experts[608], the regulatory framework may need further strengthening to ensure full interoperability, data protection and security standards, as well as a competition for the best solutions at the national level.

The early regulatory push created a growing EU market for smart meters, supplied by mostly EU producers, at least when it comes to hardware; the software market for smart meters, even in the EU, seems to be more balanced, with the presence of some strong US actors. On the other hand, the Asian (and especially Chinese) markets are huge in terms of shipped units compared to the European one.

29. HOME ENERGY MANAGEMENT SYSTEMS (HEMS)

29.1. Technology Analysis (HEMS)

29.1.1. Introduction and technology maturity

Home Energy Management Systems (HEMS) development has been undergoing significant change in the past 5 years. While home area networks (HANs) and smart appliances have not spread at the speed expected earlier, other technologies (new data streams from smart thermostats for electric heating, heat pumps, as well as DERS like solar PV and EVs) have grown in importance, requiring new HEM information channels and setting new directions for HEMs development and projects (Figure 11). Connection to smart meters also remained important as they should ensure bi-directional dataflow to and from utilities (see also Figure 8).

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

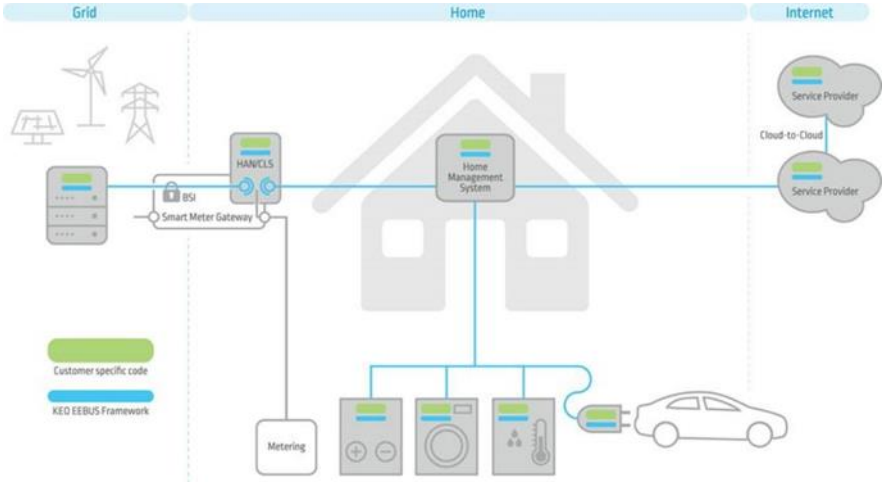
[607] Mordor Intelligence, Global smart meter market (2021-2026), 2020 (free sample).

[608] Kochanski, M., Korczak, K., Skoczkowski, T. (2020), "Technology innovation system analysis of electricity smart metering in the European Union", *Energies,* 18 February 2020

occupants. Additionally, residential customers now also have options to efficiently manage their energy consumption without a smart meter.

As a result, utilities have had to change their thinking about how they play in the HEMS space in order to engage consumers. Utilities now emphasise advanced analytics, personalisation, 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 personalisation and disaggregation and help identify faulty equipment or similar appliance-level data[609].

Figure 11 HEMS as a central point in the smart house



Source: 'Technology', EEBus Initiative e.V, 2021[610].

HEMS technologies nowadays are based on microcontrollers and work with distributed protocols. The latter means that devices do not have to interact in a centralised system and this provides more resilience to the whole ecosystem. HEMS also use cloud technologies for data storage and processing[611]. The usage of several techniques improve the response time of the HEMS and the avoidance of data privacy issues since operations are executed locally. The components of a HEMS include sensors, measuring devices, smart controllers/actuators, infrastructure for communication, and a management controller for supervision and control of data. These components address primary functions: management, control, logging, and monitoring and fault detection for energy systems. The target application is to enable end-users to control and schedule appliances, including EV chargers, to consume more efficiently, following utility-sponsored demand-response programs based on incentives or price schemes. At the same time, HEMS might provide in the future detailed information about home energy use for demand side flexibility services.

609 Guidehouse Insights, Asset Study on Gathering data on EU Competitiveness on selected Clean Energy technologies, 2020.
610 EEBUS,
611 Zafar, S. Bayhan and A. Sanfilippo, "Home Energy Management System Concepts, Configurations, and Technologies for the Smart Grid," in *IEEE Access*, vol. 8, pp. 119271-119286, 2020, doi: 10.1109/ACCESS.2020.3005244.

29.1.2. Capacities installed

While in 2019, over 20 million homes were equipped with large electrical loads (e.g. electric heating, battery, EV, PV etc.) in the EU, only some 300 000 of these were connected to a HEMS; however, this number is expected to reach more than 2 million by the end of 2023[612].

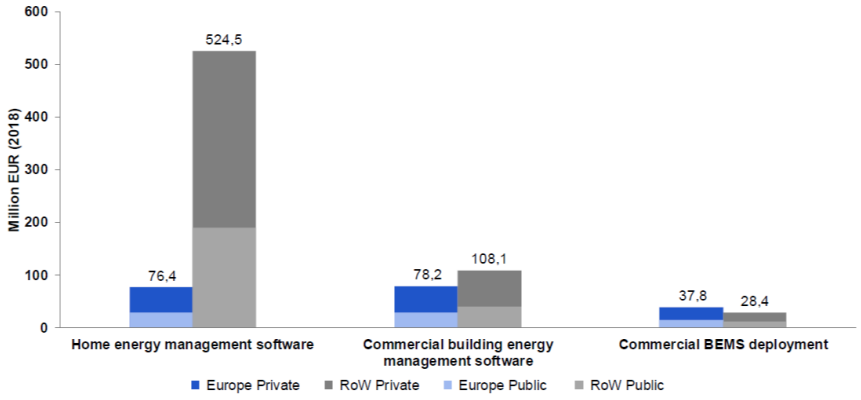
Similarly, electrified heating solutions already equip around 20 million households in the EU – reaching more than 50% penetration in some countries. The potential for HEM in these cases is therefore already large, and will grow higher as governments are pushing for more electrified or decarbonised heating. The Nordics and France, leaders in electrified heat, will have their HEM potential grow significantly on the back of that.

Lastly, with new trends in connectivity, white goods, batteries and PV can become part of a wider HEM ecosystem. By 2023, the percentage of batteries interoperable – and consequently accessible to HEM – is expected to have reached more than 70%. Countries with significant PV and battery markets today will therefore represent a large uptake in HEM. This is the case of Germany with 6% of households equipped with PV, and Belgium since the net metering has been removed from smart meter owners[613].

29.1.3. Public R&I funding

In the EU, the public investments are part of the Horizon 2020 programme and are estimated at 35% according to ETIP SNET in 2018. Overall, the research investments in both EU and the rest of the world are very similar, where EU leads commercial Building Energy Management Systems (BEMS) deployment research while the rest of the world leads HEMS and BEMS software research[614] (Figure 12).

Figure 12 R&D investments in Energy Management



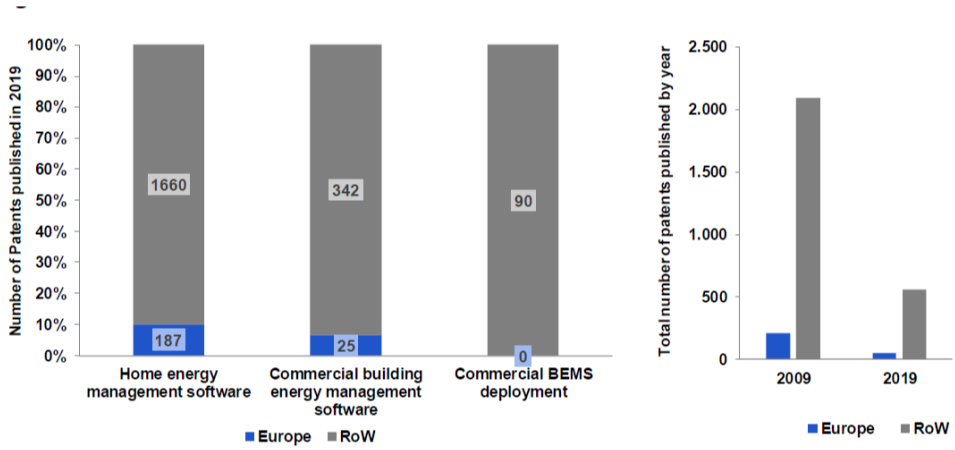
Source: Guidehouse Insights, Asset Study on Gathering data on EU Competitiveness on selected Clean Energy technologies, 2020

[612] Guidehouse Insights, ASSET Study on Gathering data on EU Competitiveness on selected Clean Energy technologies, 2020.
[613] Delta-EE, Accelerating the energy transition with Home Energy Management, *New Energy Whitepaper*, February 2020, https://www.delta-ee.com/downloads/2458-delta-ee-whitepaper-accelerating-the-energy-transition-with-home-energy-management.html#form-content
[614] Guidehouse Insights, ASSET Study on Gathering data on EU Competitiveness on selected Clean Energy technologies, 2020

29.1.4. Patenting trends

On the patenting side, the EU seems to have a share of 5-10% of the patents published over the 10-year period. Both the EU and the rest of the world have seen a decline in the number of patents being published over the 10-year period. HEM software segment had the most patents in the value chain.

Figure 13 Patents for Home and Building Energy Management Systems



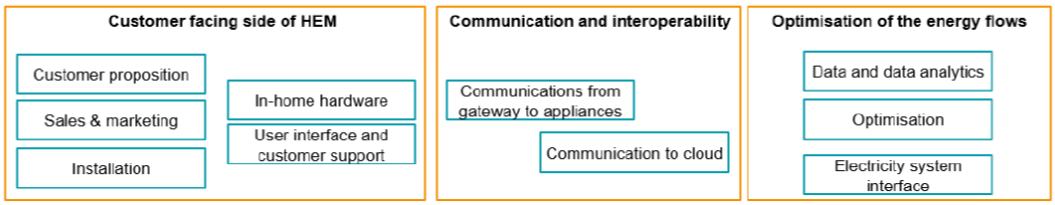
Source: Guidehouse Insights, ASSET Study on Gathering data on EU Competitiveness on selected Clean Energy technologies, 2020

29.2. Value chain analysis (HEMS)

29.2.1. The HEMS value chain

The long and complex HEMS value chain can be divided into three segments: i) customer facing side, ii) communication and interoperability and iii) energy flows optimisation (Figure 14), with specialised technology and service providers in each segments[615].

Figure 14 The HEM value chain



Source: Accelerating the energy transition with Home Energy Management, Delta-EE New Energy Whitepaper, February 2020

Some companies have their focus set on the customer facing side of HEM, with the objective of developing innovative marketing and business models. Often these are the companies which already have a relationship

[615] Delta-EE, Accelerating the energy transition with Home Energy Management, *New Energy Whitepaper*, February 2020, https://www.delta-ee.com/downloads/2458-delta-ee-whitepaper-accelerating-the-energy-transition-with-home-energy-management.html#form-content

with the customer, either by selling products (e.g. PV, EV charging point, etc.) or by offering services (e.g. energy supply, installation etc.). Energy suppliers such as Fortum (FI) or EDP (PT), and product manufacturers such as NIBE (SE) and Vaillant (UK) are good examples of this (Table 5).

Other companies may specialise on communication and interoperability solutions. Their role is to ensure data flows between the HEM, the gateway, the appliances and the cloud. They will also often look up appliance manufacturer APIs (Application Programming Interface) and integrate the functionalities available to their platform. Connected home companies such as GEO (UK) and Passiv Systems (UK) are typically those specialising in this segment; or others would develop products in this segment while also working on more parts of the value chain (e.g. Greencom Networks (DE)).

Finally, the 'actual' optimisation of the energy flows is done in the background by companies specialising in this, who often aim at providing a white label platform on a B2B model for other companies involved in HEM. Tiko (CH) or Kaluza (UK) are good examples of such companies.

Table 5 Non-exhaustive list of companies active in HEM, by type of company

Home Energy Management				
Energy suppliers	**HVAC companies**	**Electricity OEM**	**Tech Companies**	**PV/ Storage Specialists**
Fortum (FI) Shine (AU) Octopus (UK) Tibber (NO) Verbund (AT) LichtBlik (DE) Centrica (UK) E.ON (DE) EDF ENR (FR) EDP (PT) Enel X (IT))	NIBE (SE) Stiebel Eltron (BE) IVT (UK) Vaillant (UK) Viessmann (DE) Bosch (DE)	DeltaDore (DE) Hager (DE) Legrand (FR) Schneider Electric (FR)	Smappee (BE) Kiwigrid (DE) Resilience Energy (UK) Beegy (DE) Tribe (BP) (UK) Wondrwall (UK) BeNext (BE) Enervalis (NL)	Senec (DE) Tesla energy (US) Fenecon (DE) Coneva (DE) E3/DC (Hager) (DE) EO charging (UK) Myenergi (UK) Solaredge (IL) Solarwatt (DE)
Home energy Management Offerings + Electricity Systems value				
Energy Supplier	**HVAC companies**	**Electricity OEM**	**Tech Companies**	**PV/ Storage Specialists**
EDF Energy (UK) Solo Energy (UK) True Energy (UK) aWATTar (AT) SocialEnergy (UK) Fortum (FI) LichtBlick (DE) Ishavskraft (NO) EON-GridX (DE)	tepeo (UK)	TIKO (CH)	GreenCom Networks (DE) Kaluza (UK) Beegy (DE) There Corp. (FI) Climote (IE) Peeeks (NL) PassivSystems (UK) TW-TG (NL) GEO (UK) Kiwigrid (DE) Resilience Energy (UK) Tiko (Engie) (CH) Rockethome (DE) GridX (DE)	Moixa (UK) Sonnen (Shell) (DE) Coneva (DE) Fenecon (DE)

Source: Delta-EE, Accelerating the energy transition with Home Energy Management, New Energy Whitepaper, February 2020

Overall, over 50 companies are somehow active in the HEM market, some of which have a strong legacy in energy. This is the case of many energy suppliers, heating ventilation and air conditioning (HVAC) manufacturers or electricity original equipment manufacturer (OEMs), which are now diversifying their offer to include HEM products. Most aggregators or tech companies, have appeared more recently in this market, focusing their business models solely around HEM and sometimes positioning themselves as enablers. Enablers offer products or services to major companies, avoiding these ones to cover the whole HEM production chain.

29.2.2. Market size

The HEMS value chain is closely related, and to some extent embedded, to the BEMS value chain, with some overlaps across market leaders and a potential for integrating functionalities on the longer run. However, today, the two are still fairly distinct markets, with BEMS having longer history and larger size (Table 6).

Table 6 HEMS and BEMS market size, CAGR and leading vendors

Technology	EU *(vs global)* market size in 2020 (EUR million)	EU (*vs global*) market size in 2030 (EUR million)	CAGR *(both EU and global)*	Leading EU companies	Leading non-EU companies
HEMS	300 *(869)*	800	10%	Schneider Electric (FR)	Oracle, Uplight, Bidgely, Itron (all US)
BEMS	1.160 *(4.095)*	3.450	12%	Schneider Electric (FR), Siemens (DE), Johnson Controls (IE), Trane Tech (IE)	Honeywell (US)

Source: Guidehouse Insights, ASSET Study on Gathering data on EU Competitiveness on selected Clean Energy technologies, 2020

29.2.3. Employment

The HEMS (and BEMS) value chain employment consists of software development on the one hand, and deployment in downstream operation and management on the other. It is estimated that in 2020, some 5 000 jobs were found in software development in the EU (17 000 in RoW); by 2030, this figure would grow to 7 200 in the EU (and 25 000 in RoW).[616]

29.3. Global market analysis (HEMS)

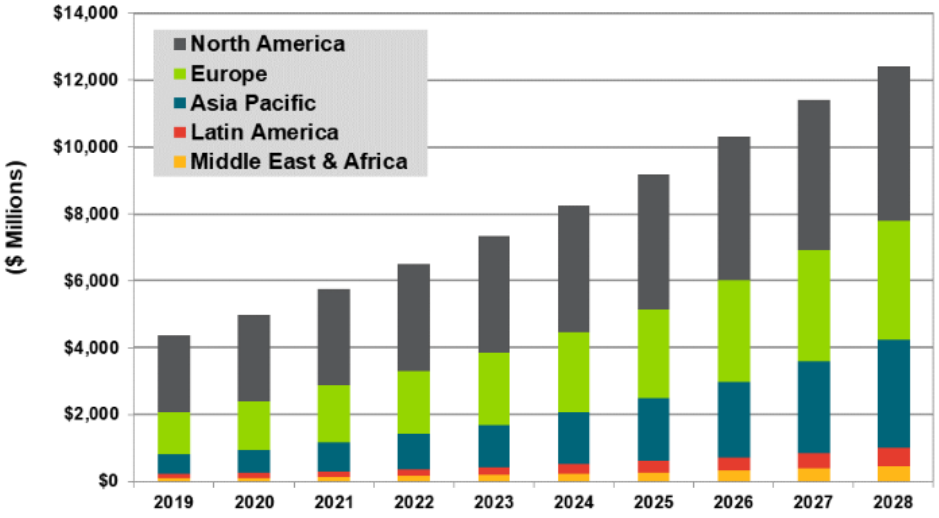
Global HEM revenue is projected[617] to grow from nearly USD 4.4 billion in 2019 to more USD 12 billion in 2028, at a CAGR of 12.3%. In North America where HEM technologies have an established foothold, revenue from HEM solutions is expected to increase from USD 2.3 billion in 2019 to USD 4.6 billion in the final year of the forecast, at a CAGR of 8%. The EU is forecast to have the next-highest annual totals,

[616] Guidehouse Insights, ASSET Study on Gathering data on EU Competitiveness on selected Clean Energy technologies, 2020

[617] Navigant Research: Home Energy Management Overview HERs, HEM Software, HEM Hardware, and Services: Global Market Analysis and Forecasts

with revenue growing from nearly USD 1.3 billion in 2019 to almost USD 3.6 billion in 2028 at a CAGR of 12.1%.

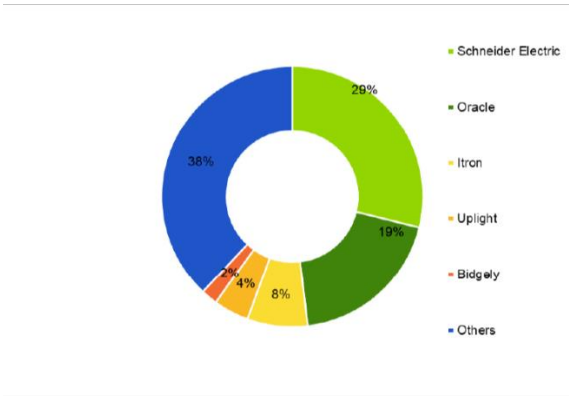
Figure 15 HEM revenue by region (World Markets: 2019-2028)



Source: Navigant Research

The smart home market has had its beginning in the US, and North America currently leads the world in smart home IoT device adoption. Consequently, most innovative HEMS solutions that emphasise data aggregation and personalisation have evolved in the US to capitalise on data-driven opportunities for efficiency. Schneider Electric is the only HEMS market leader that is headquartered in EU. However, it holds significant market share, estimated at 29% (Figure 16).

Figure 16 Top 5 HEMS Market Players Global 2020



Source: Guidehouse Insights, ASSET Study on Gathering data on EU Competitiveness on selected Clean Energy technologies, 2020

29.4. Conclusions (HEMS)

The direction of travel of the European HEMS market is clear: strong growth, in line with the trends of digitalisation and decentralisation of the energy system. However, there are many uncertainties, affecting

exactly how the market will grow. While there is a rather large choice of HEMS platforms (applications, software) available on the market for managing smart home devices, the high cost of advanced HEM devices remains an important barrier. Another major barrier is the lack of standardisation and a common framework for interoperability testing[618], which is an enabler for smart home technologies to interoperate thus expanding their usefulness and offering to consumers more choices.

It is estimated that the number of households with HEMS will grow from hundreds of thousands by end 2019 to millions of homes equipped with HEM systems by 2023[619]. A big part is due to the electrification of heat in EU: high penetration of electric-based heating or cooling for space and hot water and the possibility of controls being retrofitted onto these systems. The increasing need for self-consuming PV is driving the battery market in countries like Germany and Italy, meaning HEM will have a role to play to help customers maximise their installation. Finally, the booming EV market could create enormous opportunities for the HEMS market, as this will become one of the most important electric loads in the home.

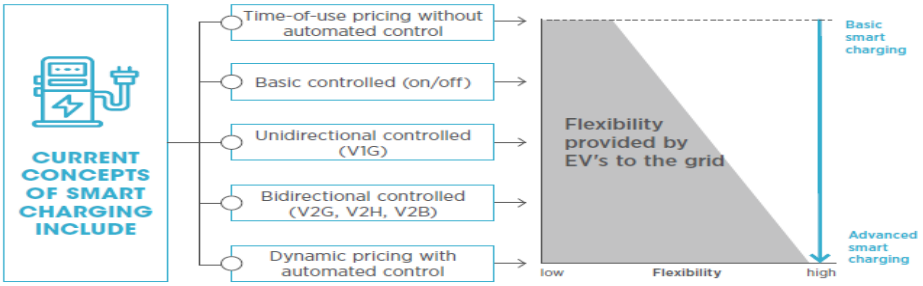
30. SMART CHARGING

30.1. Technology analysis (Smart Charging)

30.1.1. Technology maturity

Smart charging allows a certain level of control over the charging process. Smart charging has evolved from simple controls to sophisticated intelligent applications over the years and it comprises several pricing and technical charging options. The simplest form of incentive – time-of-use pricing – encourages consumers to transfer their charging from peak to off-peak periods. More advanced smart charging approaches, such as direct control mechanisms, will be necessary as a long-term solution at higher penetration levels and for the delivery of close-to-real-time balancing and ancillary services[620], as illustrated in Figure 17.

Figure 17 Smart charging enables EVs to provide flexibility



Source: IRENA, 2019c

[618] Papaioannou, I., Tarantola, S., Rocha Pinto Lucas, A., Kotsakis, E., Marinopoulos, A., Ginocchi, M., Masera, M. and Olariaga-Guardiola, M., Smart grid interoperability testing methodology, EUR 29416 EN, *Publications Office of the European Union*, Luxembourg, 2018, ISBN 978-92-79-96855-6, doi:10.2760/08049, JRC110455.

[619] Delta-EE, Accelerating the energy transition with Home Energy Management, *New Energy Whitepaper*, February 2020, https://www.delta-ee.com/downloads/2458-delta-ee-whitepaper-accelerating-the-energy-transition-with-home-energy-management.html#form-content

[620] International Renewable Energy Agency (IRENA), Electric- Vehicle Smart Charging, Innovation Landscape Brief, 2019

Source: Electric-Vehicle Smart Charging, Innovation Landscape Brief, International Renewable Energy Agency (IRENA), 2019

Smart charging technology deployment will be mainly driven by Charging Point Operators (CPOs) and Mobility Service Providers (MSPs). CPOs own and operate a pool of charging points, collect data on diagnostics and service maintenance. MSPs help clients find available charging points, activate charging, handle payments, billing, and e-roaming. Smart digital platforms enable the communication between the CPOs, MSPs and EVs, as well as energy providers[621].

Table 7 Types of smart charging and maturity 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 7 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

Smartly (dis-)charged EVs can help to reduce VRE curtailment and emissions, to improve local consumption of VRE production and to avoid investment in peaking generation capacity and mitigate grid reinforcement needs.

Source: International Renewable Energy Agency (IRENA), Innovation Outlook, Smart Charging for Electric Vehicles, 2019

Private chargers have different applications and requirements than public charge points as they are typically with lower power and are used for longer charging periods (when the vehicle is left parked during the day or night). Because there are less constraints on when and how the energy should be delivered, a higher level of flexibility or "smartness" can be included for these chargers. According to a study[622], in the short to mid-term, about 20% of kWh will be charged at public sites in and between cities, while 80% of kWh will be charged at private sites (at home or at work), mostly in buildings where normal-power smart charging points (between 3.7 and 22 kW) will be enough.

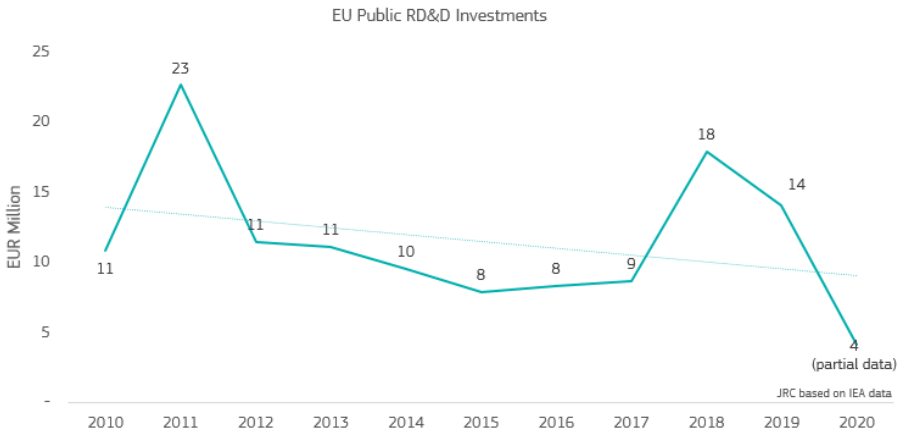
30.1.2. Public R&I funding

The summary results for EV charging infrastructure, after a peak in 2018 show a decrease in EU Public Research Development and Deployment (RD&D) investments (Figure 18). The leading country in EU for

621 Guidehouse Insights, Asset Study on Digital Technologies and Use Cases in the Energy Sector, 2020
622 SmartEn, White Paper, Making electric vehicles integral parts of the power system, July 2019

the period 2017-2019 is France with total public investments of approximately EUR 27 million. The total amount for EU Member States for the same period is approximately EUR 4 127 million[623].

Figure 18 EU Public R&D Investments



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

This trend will change in the coming two years, where the main source of support for R&I investments in smart EV charging at EU level, the Horizon Europe Framework Programme, will invest around EUR 150 Mio in various smart changing call (i.e. calls[624] [625] [626]).

30.1.3. Private R&I funding

The total capital invested by EU from 2015 to 2020 for early stage investments reached almost EUR 40 million compared to the EUR 480 million invested by RoW with a big jump in both for 2020. As far as the later stage investments are concerned, EU spent around EUR 77 million from 2015 to 2020, compared to EUR 1 600 million of the RoW.

Figure 19 Early stage investment by region [EUR Million]

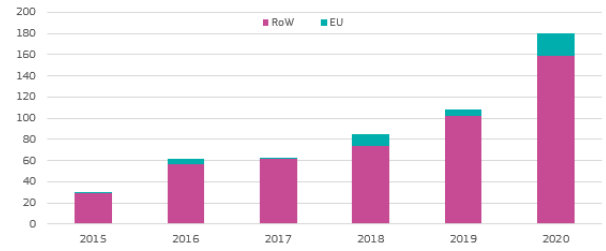
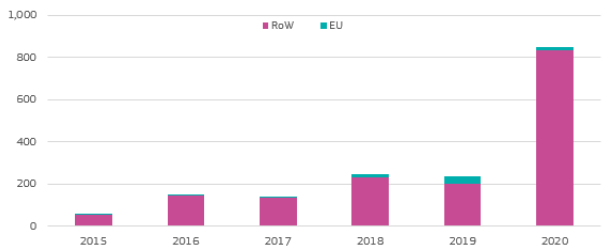


Figure 20 Late stage investment by region [EUR Million]



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

623 Some countries keep their data confidential or do not report to this level of detail.
624 https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/horizon-cl5-2021-d5-01-03
625 https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/horizon-cl5-2021-d5-01-01
626 https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/horizon-cl5-2022-d5-01-08

30.1.4. Patenting trends

On the patenting side, the EU has a share of 15% (678 out of the 4309) of the patents published from 2015 to 2017 regarding electric vehicle charging infrastructure (Figure 21Figure 21) is leading the patent applications in total, but its high value and international share remains relatively small.

Figure 21 Number of inventions and share of high-value and international activity (2015-2017)

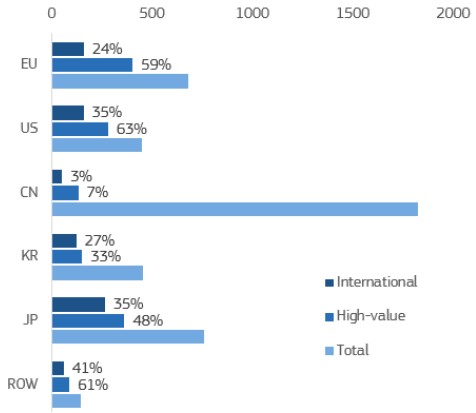
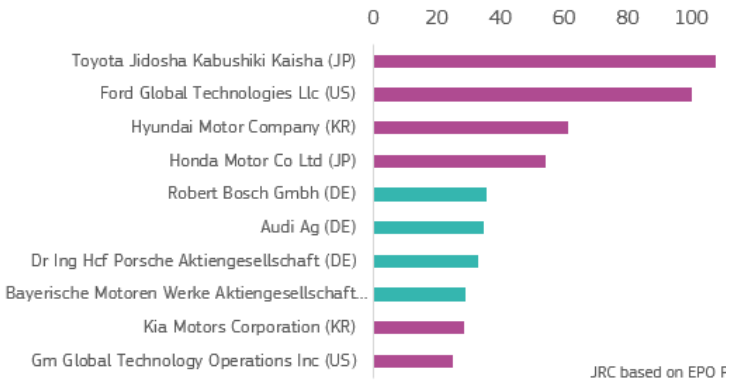


Figure 22 Top 10 high-value inventions companies in the world (Fig. 28b)



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

30.2. Value chain

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[627] are: (i) supply chain of manufacturers is mainly local and/or regional, in particular for EU based vendors, (ii) the basic electronic parts 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.

30.2.1. Turnover

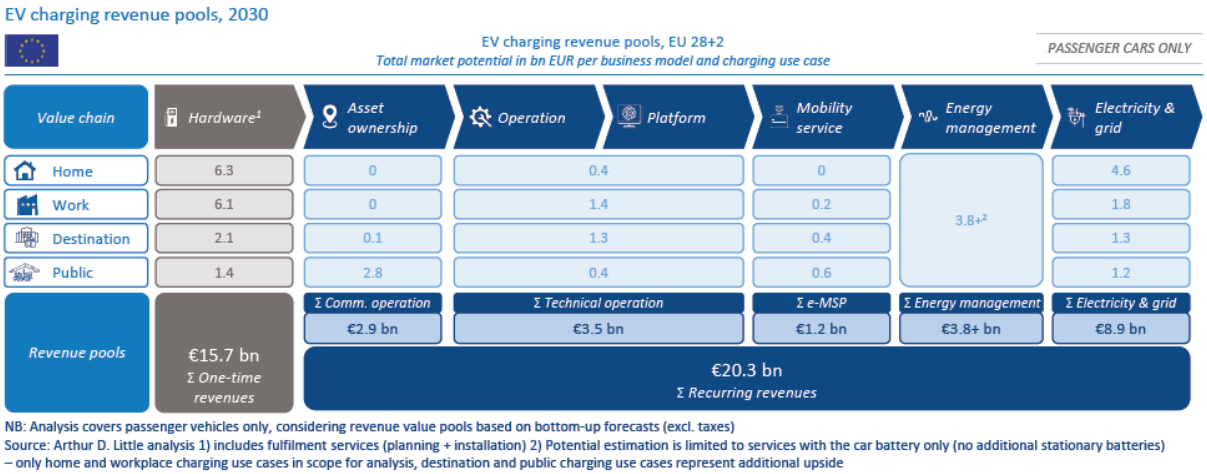
The increased penetration of EVs to the market will lead revenues from EV charging to surge and likely hit EUR 36 billion in 2030 (Figure 23). This is a seven times increase from 2021 and implies a massive growth rate of about 25% per year. EV charging opens up enormous opportunities for business models. The EV charging market can be divided into the following revenue pools: (*i*) hardware, (*ii*) asset ownership, (*iii*) technical operation, (*iv*) electric mobility service provider (e-MSP), (*v*) energy management, and (*vi*) electricity and grid[628].

Recurring revenues will increase from a 20% share today to more than 50% in 2030. In the long run recurring revenues will outgrow one-time revenues, but even by 2030, hardware and related fulfilment services will still account for almost 50% of the market potential. It is also projected that electricity and grid only accounts for 25% of total revenues.

[627] Guidehouse Insights, Asset Study on Digital Technologies and Use Cases in the Energy Sector, 2020

[628] Alexander Krug, Thomas Knoblinger, Florian Saeftel: Electric vehicle charging in Europe, *Arthur D. Little Global*, website publication, January 2021, www.adlittle.com/en/insights/viewpoints/electric-vehicle-charging-europe

Figure 23 EV charging revenue pools, 2030

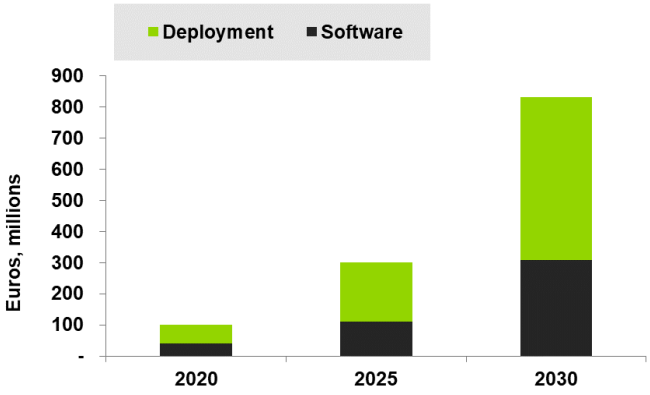


Source: Alexander Krug, Thomas Knoblinger, Florian Saeftel: Electric vehicle charging in Europe, Arthur D. Little Global, website post, January 2021

Energy management refers to smart charging services (i.e., optimizing charging behaviour of consumers on power connection level – peak load shaving, PV integration, time-based tariffs) and the provision of balancing power to the electricity grid by pooling EVs connected to the grid. The latter, is increasingly happening as an aggregator business model under a Virtual Power Plant (VPP)[629] logic.

Europe has been and continues to be the global VPP leader in terms of capacity (GW); largely reflecting the supply-side VPP capacity [630].Germany is the largest and most mature VPP market, and is anticipated to capture about one-third of VPP market's annual capacity by 2028.

Figure 24 EU-27 Market Size



Source: Guidehouse, Digital Technologies and use cases in the energy sector, 2021

[629] VPP is system that relies on software and a smart grid to remotely and automatically dispatch DER flexibility services to a distribution or wholesale market via an aggregation and optimization platform.

[630] Digital technologies and use cases in the energy sector - Publications Office of the EU (europa.eu) 2021. The VPP related information in this chapter is coming from this study by the EC.

Comparatively the VPP market, in 2028, in Japan is expected to be USD 45 million and in Australia USD 250 million[631].

The VPP aggregation software supply chain is highly integrated and the leading vendors in Europe are EU companies such as Schneider Electric, Next Kraftwerke, Enel X or ABB. These leader companies are in a strong position for long-term success in the VPP arena.

Europe has also been the driving force behind VPP spending, accounting for nearly 45% of global investment in 2020. This is a function of several factors, including Distributed Energy Resources, DER, growth, market opening, valuation of non-traditional assets, and carbon reduction and efficiency goals. At the same time, Europe is opening doors to new value streams linked to creative ancillary service markets and real-time energy trading.

As advanced grid management technologies continue to evolve and DER penetration on the grid increases, grid operators may require both the economic optimization provided by VPP platforms and the physics-based management provided by a DER management system (DERMS). Thus, a hybrid VPP-DERMS solution may become more prominent moving towards 2050.

30.2.2. Compound annual growth rate

EV smart charging can be segmented in two wide technology categories: (i) EV charging infrastructure, which is broadly defined as charging hardware technology that supplies electric energy from the grid for recharging plug-in EVs, and (ii) EV charging platforms, broadly defined as a software tool for managing charge point business activities and energy demands.

Table 8 EV smart charging overview

Use case	Technology	EU Market Size 2020 (EUR Million)	EU Market Size 2030 (EUR Million)	CAGR	Leading EU companies	Leading non-EU companies
EV Smart Charging	EV charging infrastructure	500	5,200	26%	ABB, EVBox, Efacec, Alfen, New Motion	Tritium
	EV charging platforms	130	1,500	28%	Virta, Fortum Charge & Drive, has.to.be, Green Flux, Last Mile Solutions	

Source: Asset Study on Digital Technologies and Use Cases in the Energy Sector, Guidehouse Insights, 2020

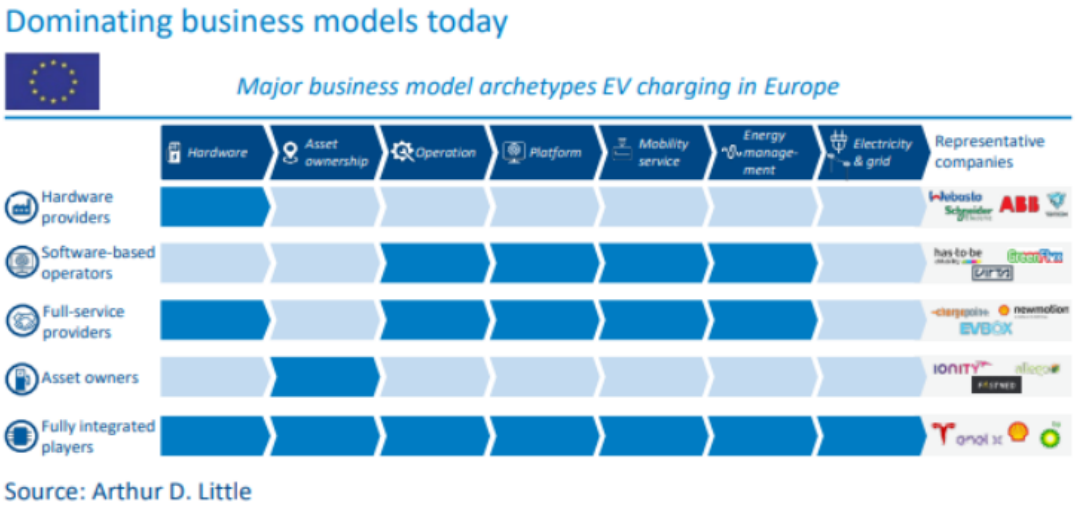
30.2.3. EU market leaders

Leading charging hardware suppliers are producing solutions across the major use cases and technology segmentations. The EU is highly competitive with a dense network of suppliers. The market has seen significant investment from established power and automation suppliers, oil and gas companies, and

[631] Navigant Research, 2019

electricity suppliers. Among the vendors of EV charging infrastructure in the EU today, the leading companies are ABB, EV Box, Enel X, New Motion, etc. with an important role for Tesla (US). In terms of EV charging platforms, the leading companies in EU are Virta, Fortum Charge & Drive, GreenFlux, has.to.be, etc.

Figure 25 Dominating business models in the market and major players

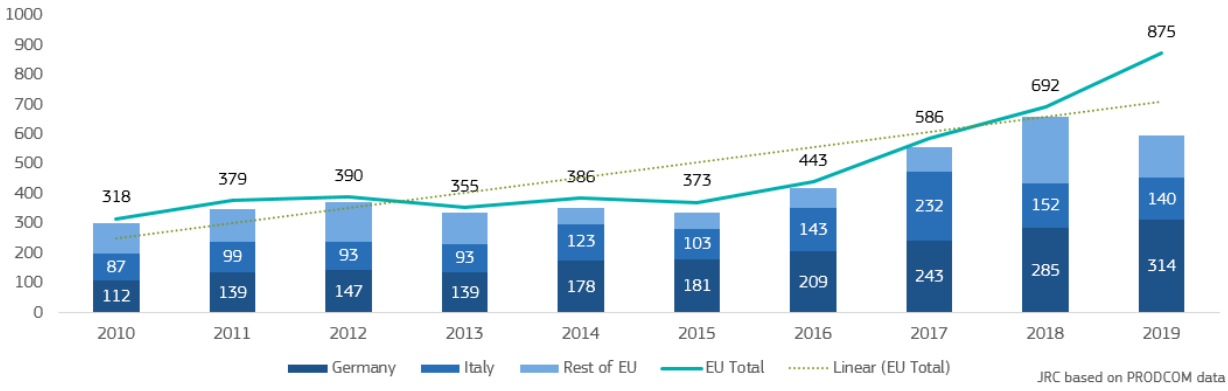


Source: Alexander Krug, Thomas Knoblinger, Florian Saeftel: Electric vehicle charging in Europe, Arthur D. Little Global, website post, January 2021

30.2.4. Community Production

The total production value on the electric vehicle charging infrastructure value chain in the EU reached EUR 875 million 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 26.

Figure 26 Total production value in the EU and top producer countries [EUR Million]



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

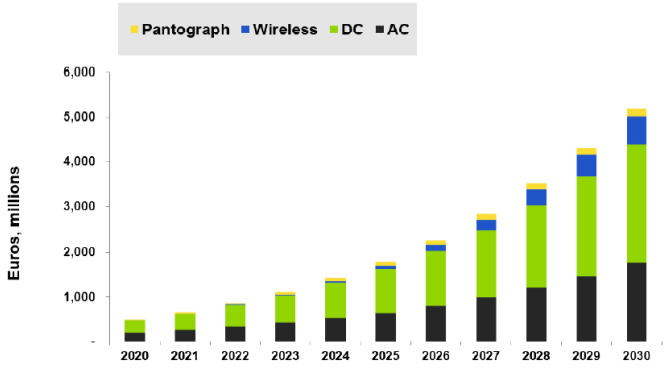
30.3. Global Market Analysis

By the end of 2019, there were 7.3 million electric vehicle chargers installed worldwide[632], of which 6.5 million chargers were private light-duty vehicle (LDV) slow or normal chargers[633]. The estimated number of private LDV chargers in 2020 is 9.5 million[634], of which 7 million are at residences and the remainder at workplaces. This represents 40 GW of installed capacity at residences and over 15 GW of installed capacity at workplaces.

30.3.1. EU market leaders

The market of EV charging equipment in the EU is estimated at nearly EUR 500 million in 2020, and the prediction is that it will surpass EUR 5.2 billion by 2030, as shown in Figure 27. Most of the market is captured via development of public infrastructure: destination chargers and fast charge services. These sectors together account for 65% of the market. However, substantial growth in home and fleet charging is expected on behalf of technological innovations in passenger EV on board charging capacity and vehicle grid integration and growing availability of commercial EV options. By 2030, home and fleet charging will represent 27% and 16% of market revenues respectively[635].

Figure 27 EV Charging Equipment Sales Revenue, EU market



Source: Guidehouse Insights, Asset Study on Digital Technologies and Use Cases in the Energy Sector, 2020

While smaller than the equipment's revenue, that of the O&M of the platform will grow similarly (Figure 28).

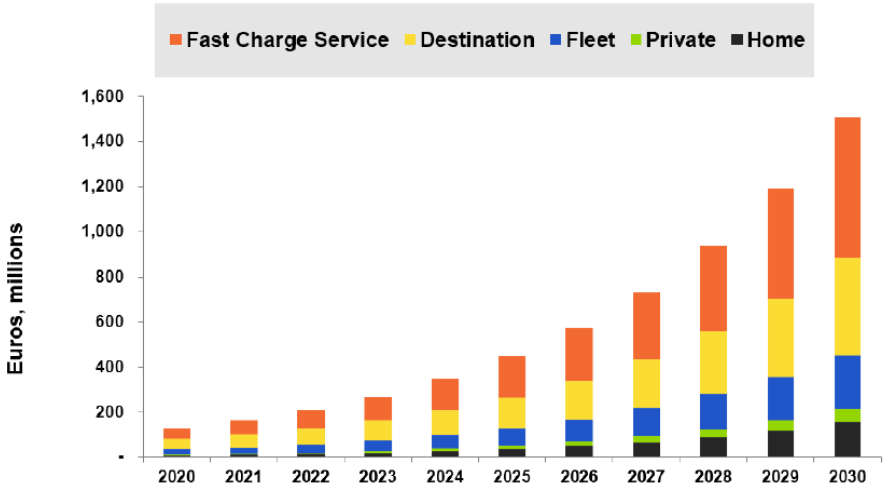
632 International Energy Agency, Global EV Outlook 2020, Entering the decade of electric drive?, 2020

633 Normal or slow charging refers to charging power less than or up to 22 kW and the distinction is mostly region specific. For example, in the European Union, the European Alternative Fuels Observatory (EAFO) classifies chargers rated up to 22 kW as normal, whereas in the United States, they are classified as slow charge (EAFO, 2020a; AFDC, 2020).

634 International Energy Agency, Global EV Outlook 2021, Accelerating ambitions despite the pandemic, 2021

635 Guidehouse Insights, Asset Study on Digital Technologies and Use Cases in the Energy Sector, 2020

Figure 28 EV Charging Platforms O&M Revenue, EU market



Source: Guidehouse Insights, Asset Study on Digital Technologies and Use Cases in the Energy Sector, 2020

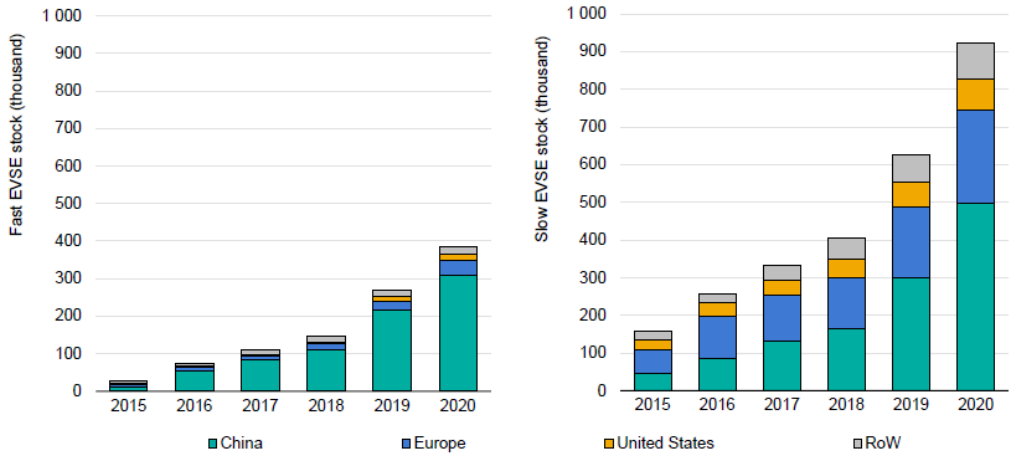
30.3.2. Global market leaders

Publicly accessible chargers reached 1.3 million units in 2020, of which 30% are fast chargers. Installation of publicly accessible chargers increased 45%, a slower pace than the 85% in 2019, possibly because the pandemic interrupted work in key markets. China leads the world in availability of both slow (charging power less than 22 kW) and fast (more than 22 kW) publicly accessible chargers. In the EU, fast chargers are being rolled out at a higher rate than slow ones.[636]

The pace of slow charger (charging power below 22 kW) installations in China in 2020 increased by 65% to about 500 000 publicly accessible slow chargers. The EU is second with around 250 000 slow chargers, with installations increasing one-third in 2020. Installation of slow chargers in the US increased 28% in 2020 from the prior year to total 82 000. The number of slow chargers installed in Korea rose 45% in 2020 to 54 000, putting it in second place.

Figure 29 Stock of fast and slow publicly accessible chargers for electric light-duty vehicles over 2015-2020.

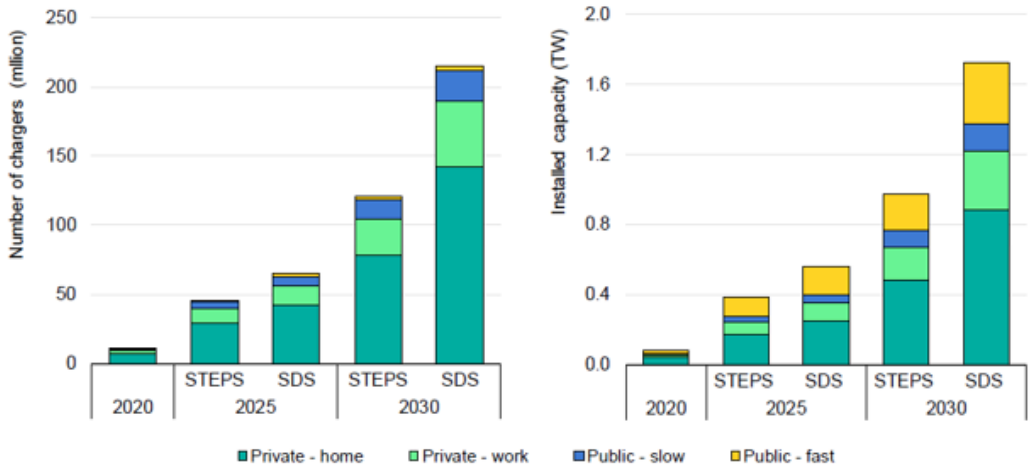
[636] International Energy Agency (IEA), Global EV Outlook 2021, Accelerating ambitions despite the pandemic, 2021



Source: Global EV Outlook 2021, Accelerating ambitions despite the pandemic, International Energy Agency

The number of *private chargers* for Long Distance Vehicles and dedicated chargers for buses and trucks is estimated around 6.4 million in 2019[637], while the estimated number of private LDV chargers in 2020 is 9.5 million, of which 7 million are at residences and the remainder at workplaces. This represents 40 GW of installed capacity at residences and over 15 GW of installed capacity at workplaces. According to a study of the IEA[638], private charging will dominate in numbers and capacity (Figure 30).

Figure 30 Electric LDV chargers and cumulative installed charging power capacity by scenario, 2020-2030



Source: Global EV Outlook 2021, Accelerating ambitions despite the pandemic, International Energy Agency

[637] International Energy Agency (IEA), Global EV Outlook 2020, Entering the decade of electric drive?, 2020
[638] International Energy Agency (IEA), Global EV Outlook 2021, Accelerating ambitions despite the pandemic, 2021

30.4. Conclusions (Smart charging)

The major drivers of smart EV charging are the need for reduced vehicle downtime through increased charging speed; improved charging convenience through wireless and on-demand mobile charging; and more efficient charging through grid and renewables integration. EV charging infrastructure and charging management platforms are the key components to meet these market demands.

Technology is there for most of the smart EV charging required system components (e.g., bidirectional converters, connectivity modules, smart energy optimisation software, e-mobility and roaming, etc.). It also seems that slow chargers (compared to fast chargers) are more suitable to support the smart EV charging ecosystem for a number of reasons (e.g., they can be used for longer charging periods providing a higher level of flexibility, there are less constraints on when and how the energy should be delivered, etc.). Another important factor for a potential successful implementation of smart EV charging is the presence of time-varying price energy tariffs in the residential sector.

The number of tests, pilots, and demonstrations have grown alongside development of the larger EV market. There are many pilots, programs and projects about smart EV charging, but it seems that overall, the market is not mature yet. It also seems that EVs smart charging is evolving more towards a services market. Nevertheless, as the adoption of DER and EVs will progress at speed during this decade, the smart charging sector will also consolidate as a growing part of a multibillion euro EV charging market.

31. CONCLUSIONS

Smart (digital) technologies are key enablers for the transformation (decarbonisation) of the power sector, as they allow for the integration of variable renewable energy resources at scale, flexibility services on the demand and supply side, more efficient asset control and management, and new, innovative energy services (business models). While in terms of technology readiness there are some differences among the four examined technology areas (distribution automation, smart metering, HEMS and smart charging), the revealed innovation efforts and perspectives for strong market growths make them clearly sit on the same trend.

The technology analysis showed that distribution automation and smart metering can rely on mature, market-ready devises and software, whose deployment has been ongoing from a few years (second generation of smart meters) to almost a decade (advanced distribution management or ADMS). On the other hand, HEMS and smart charging are in advanced testing phase, with many promising projects running in the EU and elsewhere. Standardisation, interoperability and cyber security are common challenges across the board. It is also clear that the systemic, large-scale deployment of all these tools will be critical for realising the potential of DERs and demand-side flexibility.

However, the digitalisation of end-use and low-voltage distribution may only happen in parts if it is simply let to market forces and cost-efficiency considerations. For instance, in some countries, DSOs have been strong promoters of smart meter deployment and substation automation, as they provided clear benefits in terms of consumption data and operational efficiency, while the implementation of a fully decentralised energy network based on bi-directional electricity flows and enhanced prosumer participation will probably require a stronger policy and regulatory push, since it will profoundly challenge existing practices and businesses.

Having said this, the direction of travel towards more digitalisation and growing markets, in all four technology areas, is clear. Distribution automation, the biggest global market among the four today with an

estimated USD 12.4 billion value in 2020, is expected to grow by a 7.4 % CAGR to reach USD 17.7 billion by 2025. Smart meters are projected to follow a similar (global) trend, with the number of units shipped growing by 7% in a year until 2024 that could be even higher in the EU. The global HEMS revenue is projected to grow from nearly USD 4.4 billion in 2019 to more than USD 12 billion in 2028, at a CAGR of 12.3% (and of 12.1% in EU). Finally, EV charging infrastructure and platforms may experience a genuine boom in EU during this decade, with their combined markets expected to grow from EUR 0.63 billion in 2020 to EUR 6.7 billion by 2030, at a CAGR higher than 26%.

With ambitious policy objectives (e.g. European Green Deal, Energy system integration, etc.), favourable regulatory environment (e.g. the Electricity Directive) and public funding (e.g. Horizon Europe, European Innovation Fund, Recovery and Resilience Facility), the EU seeks leading the way in deploying smart grids, and this has contributed to the emergence of European market leaders and solid technology manufacturers in all four technology domains. However, the global market analysis reveals strong developments in the US, as well as in Asia Pacific (China, Japan, South Korea), too, which suggesting that EU will probably have to face tough competition along the way to 2030.

RENEWABLE FUELS IN AVIATION AND SHIPPING

INTRODUCTION

Renewable fuels are a cornerstone of the future EU energy system.[639] They are necessary where direct heating or electrification are not feasible or have high costs. Renewable gases including hydrogen can offer solutions to store the energy produced from variable renewable sources, exploiting synergies between the electricity, gas, waste and end-use sectors. Renewable synthetic fuels can be produced with excess renewable energy when its supply peaks exceed other energy end-use demands.

Renewable liquids provide high energy density where space and weight limit the viability of other solutions, particularly in the long-haul aviation and shipping sectors, as well as in heavy duty road transport. Renewable fuels will therefore be key in decarbonising these sectors.

Yet renewable fuels, and in particular advanced renewable fuels, still require demonstration, scaling up and market uptake. The high investment costs for their production are a strong barrier to competing with and replacing fossil fuels. However, they can use existing logistic infrastructure of fossil fuels for their distribution.

Renewable fuels for aviation and maritime sectors will be of strong policy focus in the coming years. The package for delivering the Green Deal presented in July includes the revision of the Renewable Energy Directive[640] as well as the introduction of two new regulations, ReFuelEU Aviation[641] and FuelEU Maritime[642]. Together these policy instruments aim to leverage demand for renewable fuels in the aviation and maritime sectors. The Renewable and Low Carbon Fuel Value Chain Alliance is a further instrument under the Sustainable and Smart Mobility Strategy[643] which will accompany these other measures to mobilise investment in the scaling up of renewable fuel production.

Renewable fuels in this document refer to liquid and gaseous biofuels produced from organic matter, as well as liquid and gaseous synthetic fuels produced from renewable energy. Biofuels include both conventional and advanced biofuels that are sustainable according to Article 29 of the Renewable Energy Directive[644]. They are defined as low indirect land use-risk according to Article 26 if they are made from food and feed crops or advanced if they are made from the feedstocks listed in Annex IX of the same Directive. Synthetic fuels in this document are those produced from renewable energy combining hydrogen and carbon or nitrogen.

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639 European Commission, Powering a climate-neutral economy: An EU Strategy for Energy System Integration, COM(2020)299,

640 European Commission, Proposal for a Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Directive (EU) 2018/2001 of the European Parliament and of the Council, Regulation (EU) 2018/1999 of the European Parliament and of the Council and Directive 98/70/EC of the European Parliament and of the Council as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652, COM (2021) 557

641 European Commission, Proposal for a Regulation of the European Parliament and of the Council on ensuring a level playing field for sustainable air transport, COM(2021) 561

642 European Commission, Proposal for a Regulation of the European Parliament and of the Council on the use of renewable and low-carbon fuels in maritime transport and amending Directive 2009/16/EC, COM(2021) 562

643 European Commission, COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Sustainable and Smart Mobility Strategy – putting European transport on track for the future, COM (2020) 789

644 Directive (EU) 2018/2001 of the European Parliament and of the Council on the promotion of the use of energy from renewable sources

Conventional biofuels (i.e. first generation biofuels made from food and feed crops) have reached commercialization, but due to their indirect land use change impacts they have a limited role in decarbonising the transport sector. In accordance with the Renewable Energy Directive, they must meet the EU sustainability criteria set out in Article 29. They can also be certified as low indirect land use – in order to address concerns for emissions linked to land displacement. Economic indicators are only available for conventional biofuels and are often aggregated for all sectors. However, data from the road transport biofuels form the basis for the biofuels market in general and are essential to understand the potential of the market development for the shipping and aviation sectors.

Carbon capture and use/storage (CCUS) technologies are relevant for both bioenergy with carbon capture and storage (BECCS) and recycled carbon fuels (made with fossil carbon dioxide) but they are not addressed in this chapter. Renewable fuels also include hydrogen, which is an important feedstock for production of synthetic fuels. Hydrogen production from electrolysers is covered in a separate chapter titled "Hydrogen electrolysers".

32. TECHNOLOGY ANALYSIS – CURRENT SITUATION AND OUTLOOK

32.1 Technology readiness level (TRL)

Renewable fuels are produced from diverse feedstocks and production pathways. The stages in their technical and commercial maturity are therefore equally diverse. Only conventional (and to an extent cellulosic) bioethanol, biodiesel (i.e. bio-oil), some advanced hydrotreated vegetable oils (HVO), and co-processed biomass pyrolysis oils have reached commercialisation. All other renewable fuels based on advanced feedstocks, particularly those relevant to aviation and shipping, are at various stages of demonstration or even only development. However, some hydroprocessed esters and fatty acids (HEFA) for aviation which are based on HVO and bio-oils for shipping start becoming available at large scale as the technology is demonstrated already.

Power-to-liquids are liquid fuels produced from electricity to obtain hydrogen through water electrolysis. Such hydrogen could be either liquified for use as a non-drop in fuel or to synthesize hydrocarbon fuels that can be blended to drop-in liquid fuels or ammonia that requires specific infrastructure to be used as a fuel.

32.1.1. Shipping

Diesel engines in modern merchant ships use Heavy Fuel Oil (HFO), Marine Diesel Oil (MDO) and Low Sulphur Heavy Fuel Oil (LSHFO). On the other hand, petrol- or gas-fired spark ignition engines usually propel smaller vessels. Steam turbines and gas turbines are also possible engines.

Alternative renewable options to reduce sulphur and GHG emissions include[645] biofuels, renewable hydrogen, and electricity. Ammonia has recently been gaining attention as an alternative energy carrier for ships.

Biofuels are good alternatives for ship engines because they contain little or no sulphur and are suitable for Emissions Control Areas. Bio-methanol, bioethanol, liquefied or gaseous bio-methane and bio-butanol are appropriate for spark ignition engines. Good substitutes for diesel engines are diesel-type bio-hydrocarbons

[645] Besides installing Sulphur Oxides scrubbers

like biodiesel (fatty acid methyl ester - FAME) and bio-dimethyl-ether (DME), along with bio-crude from hydrothermal liquefaction and HVO.

Marine fuel standards for fossil fuels accept FAME blends up to 7% by volume, HVO and fuels derived with Fischer-Tropsch technology based on biomass gasification to syngas, as well as fuels from co-processing of renewable feedstocks. Although most biofuels are drop-in alternative fuels, the use of certain options would require some changes to the engines and the on-board storage (e.g., bio-LNG), and require a secure bunkering logistic at ports.

Main barriers to the deployment of marine biofuels include the higher price compared to fossil marine fuels, insufficient logistic support at ports for fuels not compatible with bunker type fuels, and safety requirements when using methanol, ammonia or gaseous fuels.

The technology readiness levels (TRLs) range from lab or pilot scale to commercial production of conventional biofuels such as straight vegetable oil (SVO), biodiesel (FAME), ethanol and butanol from sugar and starch crops, renewable diesel from tall oil, and renewable diesel from hydro-treated vegetable oil (HVO).

Table 9 TRL of renewable fuels compatible with shipping

Energy carrier	TRL	Energy carrier	TRL
C2H5OH (sugar/starch hydrolysis)	9	Diesel (MSW, crop residues)	7
Diesel (20% FAME UCO)	9	eCompH2 300 bar (Renewable)	7
Diesel (20% FAME UCO, 30% HVO rapeseed)	9	CNG (organic waste)	6
Diesel (palm oil)	9	eCompH2 700 bar (Renewable)	6
Diesel (soybean oil)	9	LNG (organic waste)	6
Diesel (waste oil)	9	eLH2 (renewable)	5.5
CH3OH (black liquor, glycerin)	7	eNH3	5

Source: European Sustainable Shipping Forum MARIN 2021[646]

32.1.2. Aviation

Jet fuels in use are derived from the kerosene fraction of crude oil. Jet fuels are a mix of hydrocarbons, including mostly normal paraffins, iso-paraffins, cycloparaffins and aromatics, which comply with very strict specifications due to critical safety concerns. Renewable liquid fuels with a similar functionality to oil-derived jet fuels remain a strong candidate to replace traditional jet fuels in the short/medium and even long term. Drop-in aviation biofuels have the same properties as the jet fuels, therefore they can be blended readily in jet fuels after certification for full compatibility with aircraft and fuel logistics.

Power-to-liquid drop-in fuels (or e-fuels or electrofuels) are not yet commercially available, and their viability will depend on the cost of electricity, cost and supply of captured CO2, conversion efficiency to liquid fuels and life-cycle emissions performance. Their contribution is expected to be significant only after 2030.

As shown in Table 10 and Table 11, apart from Fischer-Tropsch Synthetic Paraffinic Kerosene (FT-SPK), most e-fuels are not yet certified for use in aviation and they are generally at a lower

646 https://sustainablepower.application.marin.nl/energy-carriers/custom-bar-chart

maturity level than advanced biofuels. Only advanced biofuels are mature enough for commercial use and even these are still limited to HEFA and co-processed waste oils and fats.

Table 10 Maturity Level of Certified Advanced Biofuels for Aviation

Route	Feedstocks	Certification	TRL
Hydroprocessed Esters and Fatty Acids (HEFA)	Vegetable and animal lipids	HEFA-SPK, up to 50% blend	8-9
Co-processing waste oils/fats	Vegetable and animal lipids	D1655, 5 to 10% blend	8-9
Direct Sugars to Hydrocarbons (DSHC)	Conventional sugars, lignocellulosic sugars	HFS-SIP, up to 10% blend	7-8 or 5[647]
Alcohols to Jet (AtJ)	Sugar, starch crops, lignocellulosic biomass	ATJ-SPK, up to 50% blend	6-7
Biomass Gasification + Fischer-Tropsch (Gas+FT)	Energy crops, lignocellulosic biomass, solid waste	FT-SPK, up to 50% blend	7-8
Biomass Gasification + FT with Aromatics	Energy crops, lignocellulosic biomass, solid waste	FT-SPK/A, up to 50% blend	6-7
Catalytic Hydrothermolysis (CHJ)	Vegetable and animal lipids	CHJ, up to 50% blend	6
HEFA from algae	Microalgae oils	HC-HEFA-SPK, up to 10% blend	5

Source: Impact Assessment ReFuelEU Aviation Regulation 2021, SWD(2021) 633

For electrofuels based on the production of hydrogen through electrolysis, information is provided in the "Hydrogen electrolysers" chapter.

Table 11 Summary of aviation electrofuel production pathways and their critical technical processes

Route	Certification	Critical technical processes
FT route (LT electrolysis) Low Temperature Electrolysis	FT-SPK, up to 50% blend	Reverse water gas shift reaction (TRL 5-6)
FT route (HT electrolysis) High Temperature Electrolysis	FT-SPK, up to 50% blend	Solid oxide electrolysis (TRL 4-7) Reverse water gas shift reaction (TRL 5-6) or Co-electrolysis (TRL <5)

[647] TRL 7-8 when conventional sugars are used as feedstock; TRL 5 when the feedstock consists in lignocellulosic sugars

Methanol route (two-step methanol synthesis / LT electrolysis)	Not certified	Reverse water gas shift reaction (TRL 5-6) Final conversion to jet fuel (TRL 7-8)
Methanol route (two-step methanol synthesis / HT electrolysis)	Not certified	Reverse water gas shift reaction (TRL 5-6) Final conversion to jet fuel (TRL 7-8) Solid oxide electrolysis (TRL 4-7) or Co-electrolysis (TRL <5) Final conversion to jet fuel (TRL 7-8)
Methanol route (one-step methanol synthesis / LT electrolysis)	Not certified	Methanol synthesis (TRL 6-7) Final conversion to jet fuel (TRL 7-8)
Methanol route (one-step methanol synthesis / HT electrolysis)	Not certified	Methanol synthesis (TRL 6-7) Final conversion to jet fuel (TRL 7-8) Solid oxide electrolysis (TRL 4-7)

Source: Impact Assessment ReFuelEU Aviation initiative 2021, SWD(2021) 634 final

32.2. CAPACITY INSTALLED, GENERATION/PRODUCTION

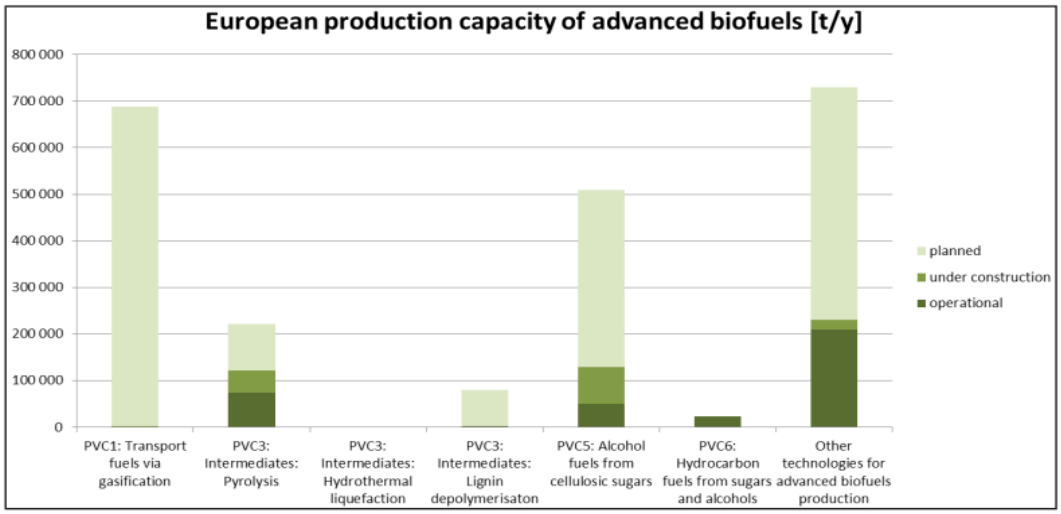
The current EU installed capacity of conventional biofuel is 14.4 Mt/y for biodiesel and 3.7 Mt/y for bioethanol[648]. HVO installed capacity currently stands at 3.4 Mt/y, with an expected increase to reach 4.2 Mt/y in 2025[649]. The fuel consists of paraffin made through HVO technologies. On the other hand, advanced biofuel production technologies are by large still not commercial. Current EU installed capacity of advanced biofuels is 0.36 Mt/y, mainly from cellulosic ethanol, hydrocarbon fuels from sugars and pyrolysis oils. An additional 0.15 Mt/y is under construction, and another 1.7 Mt/y is planned with about half of it from biomass gasification[650].

[648] European Commission, EU energy in figures – Statistical pocketbook 2020, 2020

[649] ETIP, Hydrogenerated vegetable oil (HVO), Bioenergy factsheet, 2020 https://www.etipbioenergy.eu/images/ETIP_B_Factsheet_HVO_feb2020.pdf

[650] ETIP, Current Status of Advanced Biofuels Demonstrations in Europe, 2020 https://www.etipbioenergy.eu/images/ETIP-B-SABS2_WG2_Current_Status_of_Adv_Biofuels_Demonstrations_in_Europe_Mar2020_final.pdf

Figure 31 European production capacity of advanced biofuels by pathway



Source: ETIP, 2020

32.2.1. Shipping

Capacity for intermediate bio-oils (installed, under construction and planned) is about 0.2 Mt/y[651]. Power-to-methanol capacity[652] in the EU is currently very limited, amounting to only 0.3Kt/y and power-to-liquid (petrol, diesel and kerosene) is about 0.005 Kt/y. Power-to-methane capacity[653] in the EU is about 0.003 Mt/y with an expansion potential to 0.007 Mt/y[654]. There is currently no installed capacity for power-to-ammonia.

The Commission proposal for the FuelEU Maritime Regulation is expected to increase the consumption of renewable and low carbon fuels (including electricity) to 8.6% of total maritime shipping fuels in 2030 and roughly 89% by 2050. Notably, nearly all (94 to 99%) of the electricity required is for at berth, while fuels with high energy density are required for actual transport at sea. Viewing just the advanced biofuel and renewable synthetic fuels, this would require a supply of 3 Mtoe by 2030 and approximately 28 Mtoe by 2050, while non-agricultural oils would cover the remainder of the biofuel demand (0,7 Mtoe by 2030 and 1,4 Mtoe by 2050). The total demand could theoretically be met entirely by EU domestic production, but is unlikely since ships are also capable of carrying enough fuel to make a round trip from a third country port and would not need to refuel in an EU port[655].

32.2.2. Aviation

To achieve net zero emissions by 2050, the IEA considers advanced biofuels will need to make up 15% of global aviation fuels in 2030 and 45% in 2050, with synthetic fuels accounting for roughly one third in 2050. The IEA expects hydrogen and electric applications to make just under 2% of aviation fuel

651 ibid
652 A. O'Connell, A. Konti, M. Padella, M. Prussi, L. Lonza, Advanced Alternative Fuels Technology Market Report 2018
653 ibid
654 Tonnes of bio-methane conversion factor to toe is 0.5 (1 toe=0,5 t).
655 SWD(2021) 635 final

consumption in 2050 while the remaining 20% would still be fossil based (with residual emissions compensated by net CO2 removals in other sectors)[656].

So far, eight production pathways for sustainable aviation fuels (SAF) received approval for meeting the American Society for Testing and Materials (ASTM) international standard. The related technologies are mostly under development, demonstration and scale-up, except for the already commercial Synthesised Paraffinic Kerosene from Hydroprocessed Esters and Fatty Acids (HEFA), and co-processed vegetable and waste oils in refineries. However, current production capacities are limited. In the EU, new HVO plants are under construction or planning and announcements for HVO based aviation fuels (both HEFA and co-processed vegetable and waste oils) and power-to-liquid through Fischer-Tropsch reach a total capacity of 1.7 Mt/y. Table 12 summarises the announced capacities for sustainable aviation fuels by 2025.

Table 12 Announced capacity for sustainable aviation fuels in Europe

Country	Company	SAF type	Capacity in Europe Kt/y
Sweden	ST1	biofuel	40
	Preem		240[657]
Finland	Neste		100
Belgium	SkyNRG/ LanzaTech		30
France	TotalEnergies		270[658]
Spain	REPSOL		50
Netherlands	SkyNRG		100
	UPM		100
	Neste		500[659]
Italy (Sicily)	ENI		150[660]
United Kingdom	ALTALTO		45
Total Biofuel			***1715***
Netherlands	Synkero	e-fuel	50
Norway	Norsk e-fuel		8

[656] International Energy Agency, Net Zero by 2050, 2021.

[657] https://www.preem.com/in-english/investors/corral/renewable-fuel-projects/

[658] 170kt Bio-Unit in Grandpuits, 100kt for La Mède (July 2019 plant conversion) https://www2.argusmedia.com/en/news/2203248-total-starts-biojet-production-at-la-mede-biorefinery

[659] https://www.fuelsandlubes.com/neste-to-produce-sustainable-aviation-fuels-in-rotterdam/

[660] Q&A transcript of the Eni Q2 2021 results reports, pg 13 https://www.eni.com/assets/documents/eng/investor/presentations/2021/Transcript-ENI-Q2-2021-results.pdf

Total e-fuel	***58***
Total SAF	***1773***

Source: ETIP Bioenergy 2021

Co-processing in oil refineries already takes place in the EU. As regards the HVO biofuel, a roughly estimated volume potential is 3.45 Mt/y, provided that 30% of the EU refining capacity (230 Mt/y) use 5% bio-feed. Overall, capacity for commercial ready sustainable aviation biofuel could reach 3.5 Mt/y by 2030 if the HVO capacity is also used. Most of the HVO from current production facilities is used as a diesel blending component and in some cases as an alternative to diesel in road transport. In addition, the limited availability of sustainable feedstock for HEFA underpins the need of research and innovation to increase the production of sustainable feedstock and of building additional capacity for the many other biofuel and synthetic fuel technologies under development and demonstration.

Among these technologies, the most relevant are:

- gasification of biomass Fischer-Tropsch process, a primary pathway for mid to long-term[661],
- fermentation of alcohol to jet, but slow to commercialise, due to additional steps and costs after bioethanol production[662].

The Commission proposal for the ReFuelEU Aviation Regulation[663], according to the impact assessment, could generate a demand of 2.3Mtoe of SAF per year by 2030 (5% of total jet fuel consumption) and 28-29Mtoe (63%) by 2050[664]. Assuming most of the fuel is produced in the EU with average plant capacities[665], the installation of roughly 105 additional plants will be required between 2021 and 2050. Current EU installed capacity of 1.7 Mt/yr is approximately 75% of expected EU consumption in 2030.

As shown in figure 4, a global comparison of current and planned installed capacity of sustainable aviation fuel production by 2025 indicates that US companies have a large head start over the rest of the world, with a total planned annual capacity of 3.6 Mt.

661 ETIP, Fischer-Tropsch synthesis, Bioenergy factsheet on technology and demonstration sites, 2021 https://www.etipbioenergy.eu/new-etip-bioenergy-factsheet-fischer-tropsch

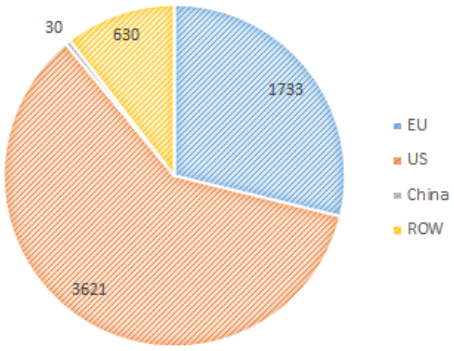
662 ETIP Bioenergy https://www.etipbioenergy.eu/index.php?option=com_content&view=article&id=273

663 SWD(2021) 634 final

664 SWD(2021) 633 final

665 Average plant capacity according to Energy Transition Commission Analysis for the Clean Skies for Tomorrow Coalition (2021) for this analysis was: HEFA - 0.5 Mt/yr, FT-Bio- .15 Mt/yr, ATJ – 0.2 Mt/yr., PtL – 0.4 Mt/yr.

Figure 32 Sum of companies' current and planned installed annual production capacity of Sustainable Aviation Fuels in thousand tonnes per year by country of origin, by 2025.



Source: Compiled from internal database of Flightpath 2020

32.3. COST / LEVELISED COST OF ENERGY

32.3.1. Shipping

Conventional biodiesel and HVO have reached commercial production and a relative cost of USD 0.02-0.039 per MJ, competing with fossil fuel costs of USD 0.016 per MJ. Advanced biofuels for shipping require higher upfront capital costs, despite larger feedstock availability. Current costs of advanced biofuels for shipping are much higher. Due to slow pace of refinery construction, commercial costs of lignocellulosic biomethanol highly uncertain, yet estimated at USD 0.021 - 0.037 per MJ. FT diesel relative costs are even more uncertain and therefore difficult to compare to conventional biodiesel, yet estimated at USD 0.024-0.066 per MJ[666].

Particularly for FT-diesel and bio-methanol based on lignocellulosic waste, scaling up demonstration as well as low interest financial products can bring production costs closer to fossil fuel costs by 2030 but have not reached commercial production levels and will therefore require stable incentives and long-term policy support before parity is possible[667].

Meanwhile technologies are emerging as promising cost-competitive biofuels for shipping aiming at costs less than EUR 0.43 and 0.36 per litre respectively in 2030 and 2050[668] which is comparable to Ultra-Low Sulphur Fuel Oil (ULSFO). Other technologies are expected to reduce the cost of biomethane and marine biodiesel by 30-35% from current levels by 2030, that is to EUR 0.16 and 0.75 per litre respectively[669].

For hydrogen, ammonia and synthetic carbon-based fuels, production via electrolysis is likely to remain more expensive than pathways using fossil fuels for the near-to-medium term. Sufficiently high electrolyser load hours (around 4 000 hours per year) and low electricity costs (in the range of EUR 10-30 per MWh) are required to reach cost-competitive production. Production costs for ammonia via electrolysis are approximately EUR 110 per MWh (with electricity at EUR 40 per MWh at 3 000 full load hours for

666 ICCT- International Council on Clean Transportation, The potential of liquid biofuels in reducing ship emissions, 2020.
667 IEA, Advanced biofuels- potential for cost reduction, 2020
668 H2020 project IDEALFUEL https://cordis.europa.eu/project/id/883753
669 (Project FlexSNG... and GLAMOUR https://cordis.europa.eu/project/id/884197)

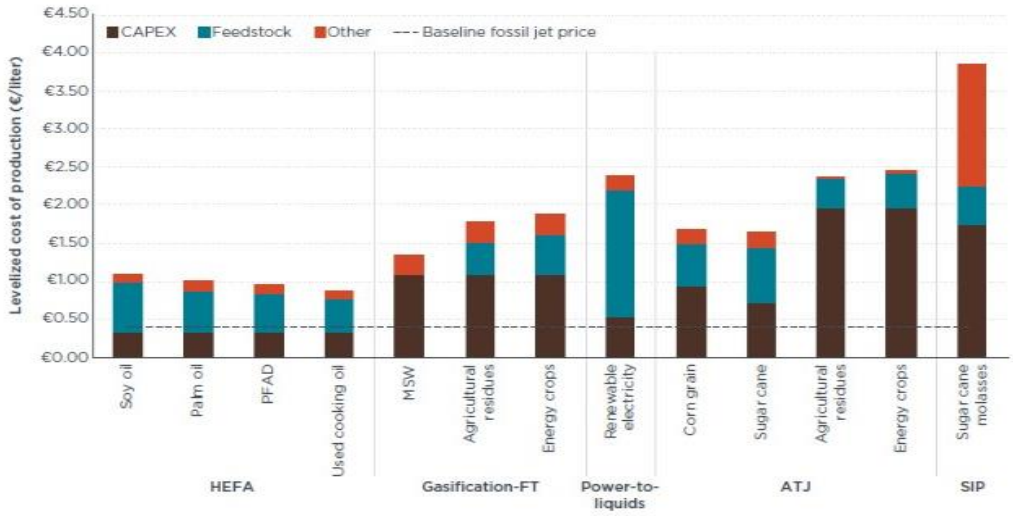
hydrogen electrolysers), possibly falling to EUR 55 per MWh with lower electrolyser costs and electricity at EUR 20 per MWh[670]. The cost of ammonia from steam methane reforming today is approximately EUR 40 per MWh.

32.3.2. Aviation

As shown in Figure 33, for all existing sustainable aviation fuels the current levelised cost of production is well above the current fossil jet fuel price, with a broad set of ranges depending on feed stock and conversion pathways. The least expensive pathways are via vegetable and waste oils, while the most expensive are the alcohol to jet when processing advanced bioethanol, as well as the power-to-liquids through Fischer-Tropsch.

Waste and residue generally have the lowest feedstock costs, being by-products of other goods (agriculture residues) or services (municipal waste – no feedstock cost). HEFA is the most mature conversion pathway and has the lowest capital expenditures (CAPEX), but relatively high feedstock costs, resulting in the lowest total cost of EUR 0.88 - 1.09 per litre[671]. However, if wasted animal fats are used as feedstock the total cost can be lowered to EUR 0.51 per litre[672].

Figure 33 Current levelised costs of aviation fuels



Source: ICCT, The cost of supporting alternative jet fuels in the European Union, 2020

The high feedstock costs make it unlikely for technological improvements to greatly reduce the total cost of HEFA fuels[673] unless cheaper feedstocks are utilised, such as waste animal fats. The expansion of such feedstocks is challenging, and scaling up SAF will require additional fuel technologies beyond HEFA fuels.

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670 IEA 2019?

671 ICCT – International Council on Clean Transportation, The cost of supporting alternative jet fuels in the European Union, 2020.

672 IEA Bioenergy, Advanced Biofuels – Potential for Cost Reduction, 2020 https://www.ieabioenergy.com/wp-content/uploads/2020/02/T41_CostReductionBiofuels-11_02_19-final.pdf

673 WEF 2020; IEA 2020; ICCT 2020

Gasification-FT fuels are driven by high capital costs but currently have low to no feedstock costs[674] (depending on feedstock), and low operational costs. Though scaling up and learning effects offer significant cost reduction potential, they will likely remain more costly than HEFA in future[675].

Emerging technologies using waste bio-based feedstock are expected to reduce the cost levels of aviation synthetic paraffin kerosene FT-SPK by 35% and 65% in 2030 and 2050, to EUR 1.17 and 0.63 per litre respectively[676]. Other technologies will make aviation and maritime biofuels available at a selling price of EUR 0.7-0.8 per litre[677].

While power-to-liquid (e-fuels) jet fuels currently display large production costs, these are almost entirely driven by capital expenditures (CAPEX) and operating expenses (OPEX) of the hydrogen feedstock. As hydrogen production costs decline with the scale up of solar power electrolysis, particularly in highly productive regions, power-to-liquid jet fuels are expected to drop by roughly 50% by 2030 and could even achieve HEFA production costs by 2050[678]. Still, the cost for e-fuels is at present relatively high at EUR 7 per litre because of high conversion losses and high distribution costs of hydrogen feedstock.

32.4. PUBLIC RESEARCH AND INNOVATION (R&I) FUNDING

Under the Horizon2020 programme, R&I support to advanced biofuels, bioliquids, biomass fuels and renewable synthetic fuels encompasses 167 grants from 2014 to 2021 amounting to EUR 531.4 million EU contribution and EUR 655.5 million total costs. The highest part of support lies with the thematic priority of Secure, clean and efficient energy, with 107 signed grants of EUR 377.6 million EU contribution and EUR 458.9 million total costs.

Data is limited on national funding from EU Member States after 2014. From 2009 to 2014 EU 28 R&I funding spending was just under EUR 400 million annually. For the period 2012-2016 the amount of national funding for all bioenergy more generally was about EUR 4 billion euro from 24 EU Member States according to the 2016 SET Plan report[679]. Assuming half of this would be for biofuels, would imply a constant annual funding since 2009. However, granular data is not available to differentiate Member States R&I funding between bioenergy and biofuels, much less for aviation and shipping sectors.

32.4.1. Shipping

Although there were no distinctive projects for shipping fuels under the FP7 programme between 2012 and 2016, road fuels are also compatible with shipping. Therefore, nearly EUR 400 million funded the development of renewable fuels relevant for shipping.

Under dedicated Horizon2020[680] calls in secure, clean and efficient energy for maritime energy supply, EU support for technologies related to targeted lower cost advanced biofuels and renewable fuels reached EUR

[674] Biobased waste may be used for many material goods in future, posing potential resource scarcity for energy resources. Circularity may however increase the efficiency of resource use and therefore also the availability. These may cause changes in feedstock prices, but it is unclear to what extent.

[675] WEF – World Economic Forum, Clean Skies for Tomorrow: Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation, 2020.

[676] ref project GLAMOUR https://cordis.europa.eu/project/id/884197

[677] ref project BioSFerA https://cordis.europa.eu/project/id/884208

[678] WEF – World Economic Forum, Clean Skies for Tomorrow: Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation, 2020.

[679] European Commission, Transforming the European Energy System through Innovation, Integrated SET Plan Progress in 2016, 2016.

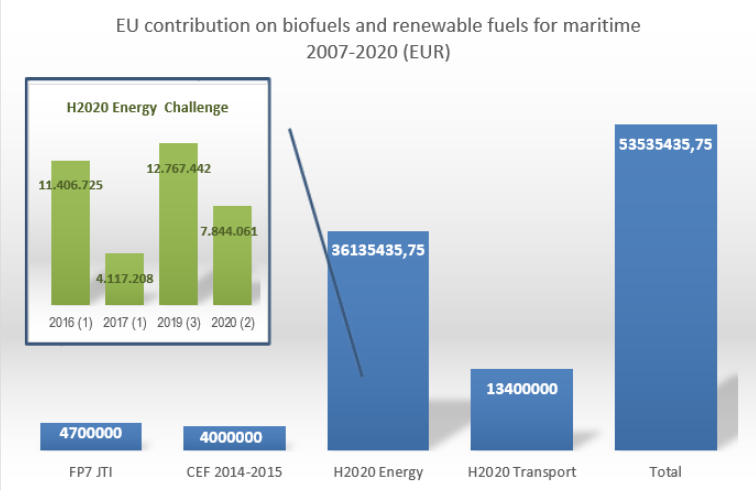
[680] European Commission database of EU-funded research and innovation projects https://cordis.europa.eu/projects/en

36 million for 7 projects, distributed per year in funds and number of projects as illustrated in Figure 34 below.

Horizon2020 provided further funding for sustainable shipping fuels under the smart, green and integrated Transport thematic priority, amounting to an additional EUR 13.4 million between 2016 and 2020. Similarly, between 2011 and 2014, two Joint Technology Initiatives of FP7 provided a further EUR 4.7 million.

Additionally, the Connecting Europe Facility funded two infrastructure projects between 2014 and 2015 for the development of renewable fuels in shipping, totalling roughly EUR 4 million.

Figure 34 EU R&I funding for renewable fuels in the maritime sector



Source: data compiled from CORDIS database

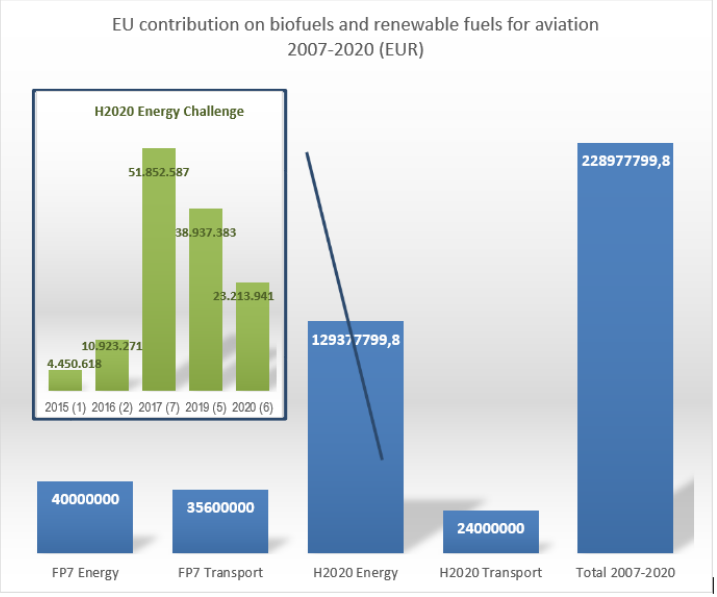
32.4.2. Aviation

Between 2012 and 2016, the FP7 programme[681] funded EUR 430 million in biofuel projects with approximately EUR 40 million designated to aviation. Under Horizon2020 and the secure, clean and efficient energy thematic priority, EU support for technologies related to advanced biofuels and renewable fuels for aviation reached EUR 130 million for 21 projects overall, distributed per year in funds and number of projects as illustrated in Figure 35.

The Horizon2020 programme provided further funding for sustainable aviation fuels through the smart, green and integrated transport thematic priority, totalling EUR 35.6 million between 2016 and 2020. Between 2008 and 2013, FP7 funded an additional EUR 24 million for sustainable aviation fuel projects under the Transport Programme.

[681] European Commission database of EU-funded research and innovation projects, CORDIS https://cordis.europa.eu/projects/en

Figure 35 EU R&I funding for renewable fuels in aviation sector



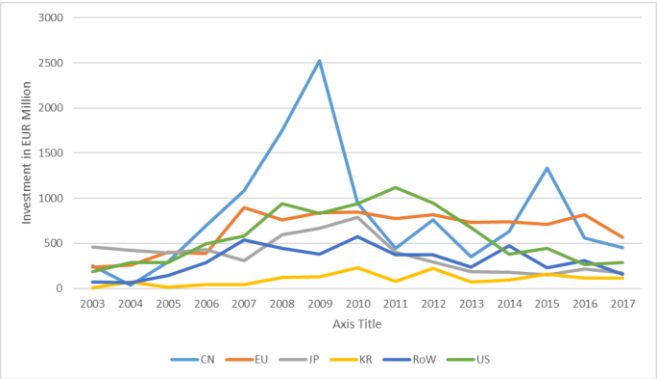
Source: Data compiled from CORDIS database

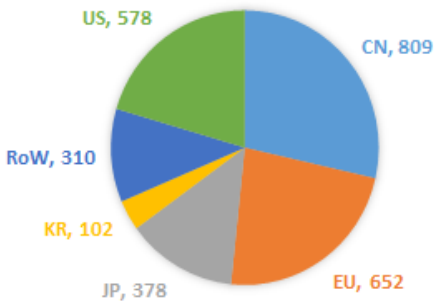
32.5. PRIVATE R&I FUNDING

Private investment tracked by the European Commission's Joint Research Center (JRC) includes data on biofuels and fuels from waste, but does not provide enough granularity to assess specific sectors or technologies. This data can still provide an indication of geographic emphasis and leading companies developing renewable fuel technologies which may be relevant for these sectors.

On average between 2003 and 2017, companies based in China invested EUR 809 million annually in R&I for renewable fuels, followed by the EU companies with EUR 652 million and US companies with EUR 578 million. However, the R&I investment from China based companies fluctuated with major peaks in investment around 2009 and 2015, while the EU companies reflect a more constant investment. In general, investments globally have slightly declined throughout the last decade.

Figure 36 Annual (left) and average (right) private R&I investment in biofuels and fuels from waste in EU compared to other countries during 2003-2017 (EUR million)

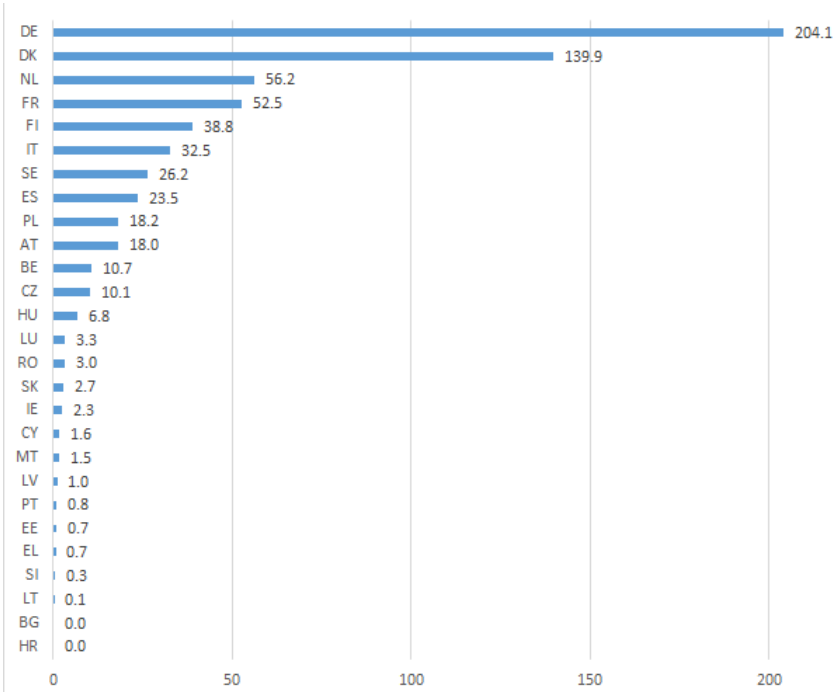




Source: JRC SETIS 2021

Within the EU, companies in Germany and Denmark show the largest annual average R&I investments by far, accounting for slightly more than half of the EU total. In ten other Member States, private R&I investments average between EUR 10 and 56 million. Overall, there is a strong focus of private investment in western EU.

Figure 37 Average private R&I investment in biofuels and fuels from waste by EU Member State of the private investors during 2003-2017 (EUR million)



Source: JRC SETIS 2021

Of the top twenty private R&I investors, six are EU companies, while five are located in China and five in the US. The top global R&I investors located within the EU are from Denmark, Finland, Netherlands, Hungary and France, while German companies are absent from this group and only two appear in the top twenty EU R&I investors. Since the highest average private R&I investments were in Germany, this implies a distribution of investments across multiple companies. For other Member States such as Hungary, this suggests a concentration of R&I investments in one or few companies[682].

32.6. PATENTING TRENDS - INCLUDING HIGH VALUE PATENTS

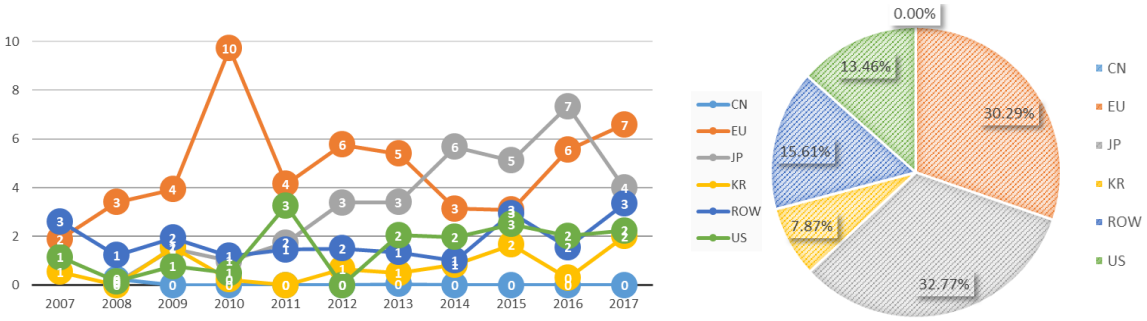
32.6.1. Shipping

The Patstat database of the European Patent Office includes data on high value inventions for alternative maritime fuels, which includes some non-renewable fuels. The data lacks the granularity to distinguish between different fuel types.

[682] JRC, SETIS, 2021

Overall, there is a modest amount of high value inventions regarding fuels in this sector. Yet there is indication they may have been increasing in recent years. Roughly two thirds of high value inventions are from either Japanese or European entities.

Figure 38 Annual distribution of high value inventions for alternative maritime fuels (including non-renewable fuels) in leading countries (left) and global distribution in percent for the years 2015-2017 (right)

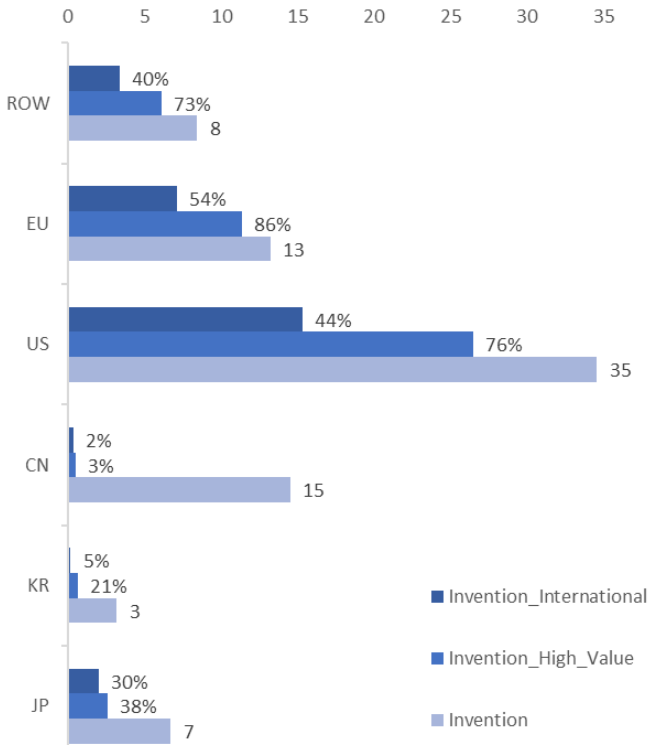


Source: JRC based on EPO Patstat data 2021

32.6.2. Aviation

The Patstat data on sustainable aviation fuels suggest a modest amount of high value inventions between 2007 and 2017, of which US companies have just over twice as many as companies based in the EU. Companies in China show slightly more inventions than companies in the EU, but few are high value or international.

Figure 39 Number of sustainable aviation fuels inventions by country 2007-2017



Source: JRC based on EPO Patstat data 20201[683]

Six of the ten leading inventors are US companies. However, between 2015 and 2017, the only additional high value inventions were from two companies in the EU; Neste (FI) and Total (FR) with 1 high value patent each.

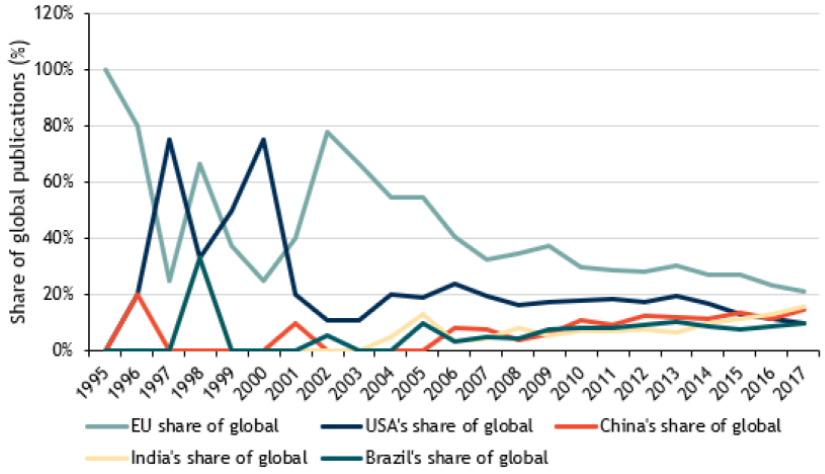
It is worth noting that vegetal biomass feedstock and fatty oil and fatty acid feedstock are assigned to 43% and 41% of patent families[684] respectively, suggesting a strong focus of innovation on HEFA-SPK and D1655 fuels, which are the most mature and the only commercial renewable aviation fuels.

32.7. LEVEL OF SCIENTIFIC PUBLICATIONS

32.7.1. Shipping

An analysis of publications related to renewable fuels was not available, particularly since publications on maritime transport decarbonisation differentiate in scope and research of renewable fuels relevant for maritime shipping is generally not sector specific. However, publication trends of biofuels in general may also be relevant insight for the maritime sector. The EU maintains the highest share of global biofuel publications. This lead has slowly decreased more recently due to the rapidly growing number of publications in India, China and Brazil.

Figure 40 Global biofuel publications



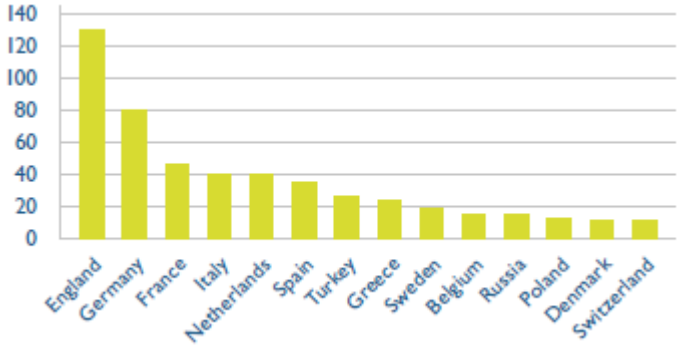
Source: Trinomics, commissioned by the European Commission, Study on impacts of EU actions supporting the development of renewable technologies, 2019.

[683] JRC SETIS reseach and innovation data: https://setis.ec.europa.eu/publications/setis-reseach-and-innovation-data_en
[684] European Energy Research Alliance Bioenergy, Bioenergy Technology Watch Report Number 8, EERA Bioenergy, 2021

32.7.2. Aviation

The global leader in publications related to SAF is the US with 37% of total publications between 2000 and 2019, followed by European institutions with 33%. More than 50% of publications were between 2016 and 2019, both worldwide and within Europe. The UK and Germany lead the publications within Europe[685].

Figure 41 Number of scientific publications on sustainable aviation fuels in Europe, by country



Source: European Energy Research Alliance Bioenergy, Bioenergy Technology Watch Report Number 8, EERA Bioenergy, 2021

32.8. CONCLUSIONS

Advanced biofuels are at varying stages of maturity, but many have reached large scale demonstration plants. Therefore, installed capacity is limited compared to conventional biofuels. Commercialisation and scaling up are hindered by high investment costs. Large scale deployment supported by long-term, low interest financing could reduce costs significantly. However, without strong policy support to overcome the price gap between advanced biofuels and conventional kerosene and bunker fuel, upscaling will remain slow.

The expected trend of demand for renewable fuels (from mainly road transport in the next few years to increasingly more for aviation and shipping in the medium term) offers the potential of cost reduction. In the case of a new manufacturing plant, in fact, the capital cost – heavily impacting the production cost of renewable fuels – can be repaid in the first years of the investment life. During this period, road transport, driven by existing (Renewable Energy Directive) and new (EU Emission Trading Scheme, Energy Taxation Directive) regulatory instruments, can absorb the higher cost of renewable fuels. Over time, the demand of fuels for road will shrink (due to electrification of especially light duty vehicles) while demand for ships and airplanes will progressively pick up. Once the capital cost of renewable fuels is repaid, the cost gap between renewable and fossil fuels for aviation and shipping may reduce very significantly.

HEFA, alcohols from sugars, lignin depolymerisation and pyrolysis oil are the closest fuels that can be used or further processed to jet or used directly for shipping, with total annual capacity in the EU of about 1.5 Mt for aviation fuel and 0.2 Mt for shipping fuel[686].

Expansion of HEFA feedstock will likely be challenging due to feedstock availability, preventing cost reduction. Less mature technologies based on diverse feedstock will be required yet face the challenge of

[685] European Energy Research Alliance Bioenergy, Bioenergy Technology Watch Report Number 8, EERA Bioenergy, 2021
[686] ETIP Bioenergy 2021

much higher investment costs. Shipping faces a similar challenge for expanding beyond waste oil-based fuels.

Public R&I funding from Member States for biofuels may have remained constant at roughly EUR 400 million since 2008, but data after 2014 depend on how funding is allocated between biofuels and other bioenergy technologies. Granularity of funding data is generally an issue. The EU research programme Horizon Europe has significantly increased R&I funding beyond the pervious FP7. Support to aviation is more evident than shipping after FP7 because the shipping sector can use road biofuels and lower grade biofuels. Yet ongoing R&I is focusing on dedicated marine biofuels as it can significantly decrease their production costs.

Evidence is limited for private R&I investment but suggests that Chinese companies lead in annual investments in renewable fuels in general, followed by EU based and US companies. The largest share of top R&I investing companies are in the EU, followed by China and the US. Within the EU, investments are highest from Danish and German companies, with the rest well spread throughout western EU.

Patenting trends suggest strong leadership of EU based institutions in renewable fuels in general. Japan and EU based companies each make up for one third of all patents in the maritime sector, but this may be misleading due to inclusion of some technologies beyond renewable fuels and a lack of granularity. The strong position of EU companies for renewable fuels in general suggest the influence of other technologies in shipping. Particularly in sustainable aviation fuels, the EU is well behind the US when it comes to patents, leading innovators and research. In general, patents indicate global innovation may risk too strong of a focus on HEFA fuels, due to the challenges for large-scale expansion.

33. VALUE CHAIN ANALYSIS OF THE ENERGY TECHNOLOGY SECTOR

33.1. INTRODUCTION/SUMMARY

Fuel production is the most relevant part of the value chain when discussing renewable fuels for aviation and shipping. Due to the limited commercialisation of advanced biofuels and synthetic fuels, particularly in these sectors, it is often only possible to consider conventional biofuels for the current state of indicators. Where possible this information is used as a reference for considering the potential for shipping and aviation or even estimating the impact of future policy developments.

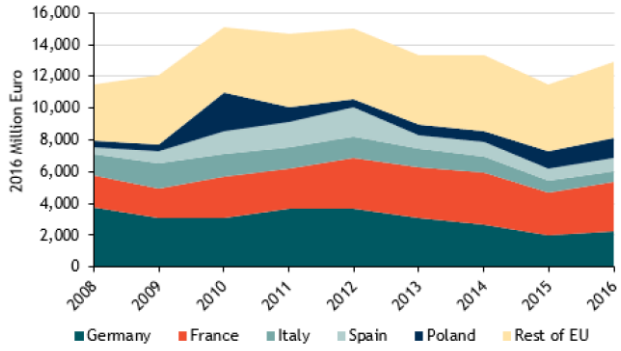
33.2. TURNOVER

The turnover data in the EU is limited to the conventional biofuel industry since advanced biofuels, particularly with relevance to the aviation and shipping sectors, have a relatively small installed capacity and miniscule contribution to total turnover. The Joint Research Centre (JRC) estimates a combined revenue of advanced biofuels of EUR 21 million[687], or 0.1% of the biofuel industry turnover (EUR 11.5 -15.1 billion) between 2008 and 2016[688].

[687] A. O'Connell, M. Prussi, M. Padella, A. Konti, L. Lonza, Sustainable Advanced Biofuels Technology Market Report, 2019

[688] Trinomics, commissioned by the European Commission, Study on impacts of EU actions supporting the development of renewable technologies, 2019.

Figure 42 Biofuels industry turnover in the EU

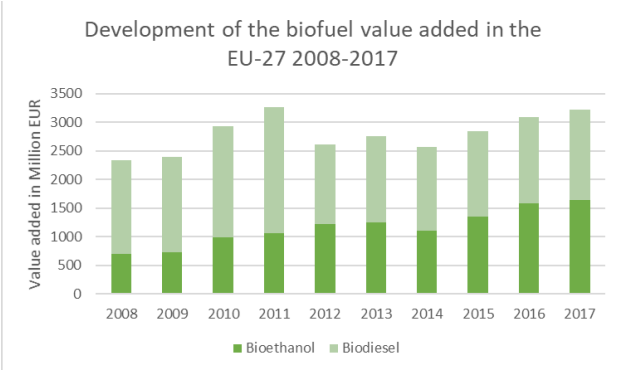


Source: Trinomics, commissioned by the European Commission, Study on impacts of EU actions supporting the development of renewable technologies, 2019.

33.3. GROSS VALUE ADDED (GVA) GROWTH

Biofuels (bioethanol and biodiesel) represented EUR 3 billion of the bioeconomy's gross value added. Since 2008, the GVA of biofuels has grown by 38%[689] as Figure 43 displays.

Figure 43 Liquid biofuel value added growth in the EU27



Source: European Commission, Bioeconomy, 2020

33.3.1. Shipping

Since a market for renewable shipping fuels has not yet developed, no data exists for gross value added. Assuming domestic production for all renewable shipping fuel required for achieving the targets in the Commission proposal for the EU Fuel Maritime Regulation, as well as the same ratio of GVA to employment as with current biofuels (not including resource sourcing), renewable maritime fuels could bring as much as EUR 2.5 billion GVA annually by 2030 and EUR 26 billion by 2050.

689 Data compiled from European Commission, Bioeconomy, 2020, https://ec.europa.eu/knowledge4policy/bioeconomy/topic/economy_en

33.3.2. Aviation

Similarly for aviation fuels, assuming domestic production for all renewable aviation fuels required to achieve targets in the Commission proposal ReFuelEU Aviation and ratio of GVA to employment as with current biofuels (not including resource sourcing), sustainable aviation fuels could add EUR 450 million to EUR 1.5 billion GVA by 2030 and EUR 207 billion by 2050.

33.4. NUMBER OF EU COMPANIES

There are approximately 40 companies within the EU with advanced biofuel facilities in production, under construction or planned. Each specialises in different production pathways so market leaders are difficult to determine. The company UPM produces HVO from tall oil, Clariant advanced bioethanol. St1 operates more, smaller and decentralised bioethanol plants. Neste specialises in HVO and HEFA production, and SkyNRG in HEFA and ATJ.

At the same time oil and gas companies (Total, Repsol, ENI, Shell) are increasingly mobilised in the production of advanced biofuels, participating in joint ventures or co-processing bio-oils in fossil refineries. As the refineries already exist, there are no additional investment costs for producing bio-blends, a major advantage considering the high investment costs for biorefineries.

33.4.1. Shipping

The Finnish Wärtsilä and the Dutch biofuel distributor GoodFuels jointly work to supply marine biofuels to ships in the Port of Rotterdam. The ship owner is aiming to use a diesel blend consisting of 30% biofuels with goal of using a blend of up to 100% biofuels by 2030.

33.4.2. Aviation

There is a high concentration of companies developing and scaling up operations for sustainable aviation fuel production within the EU (Neste, Total, SkyNRG, Preem, Lanzatech) and the US (Fulcrom Bioenergy, Red Rock Biofuels, Velocys, Shell, AltAir Fuels, and Gevo). Lanzatech is also expanding operation in China. Several biojet producing companies have also established partnerships with airlines and in a few cases even airports. Joint ventures are also common between oil majors and biojet companies.

33.5. EMPLOYMENT IN THE SELECTED VALUE CHAIN SEGMENT(S)

In 2019 the liquid biofuels industry employed 228 983 people within the EU[690].

33.5.1. Shipping

Since a market for shipping fuels has not yet developed, no data exists for current employment specifically in maritime renewable fuels. The employment values for the entire liquid biofuels industry imply approximately 9 700 jobs for every million tonnes of biofuel produced. Therefore, assuming domestic production for all renewable shipping fuel required for achieving the targets in the Commission proposal

[690] Data compiled from IRENA jobs database: https://irena.org/Statistics/View-Data-by-Topic/Benefits/Renewable-Energy-Employment-by-Country

for the EU Fuel Maritime Regulation, as many as 29 000 additional jobs could be created by 2030 and 270 000 by 2050.

33.5.2. Aviation

Similarly for aviation fuels, assuming domestic production for all renewable aviation fuels required to achieve targets in the Commission proposal ReFuelEU Aviation, 4 200-4 800 additional jobs could be created by 2030, roughly 97 000 jobs by 2040 and roughly 202 000 jobs by 2050[691].

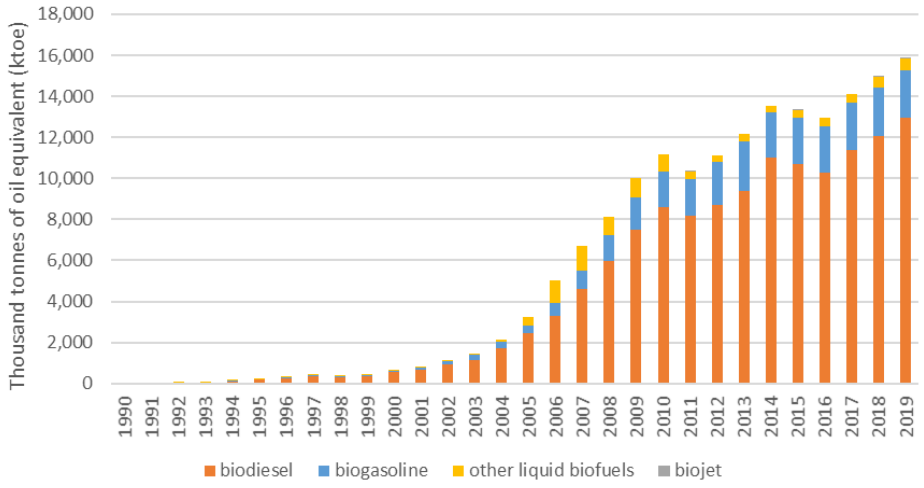
33.6. ENERGY INTENSITY CONSIDERATIONS, AND LABOUR PRODUCTIVITY CONSIDERATIONS

Employees of the EU biofuels industry (bioethanol and biodiesel) generate an average annual value of EUR 157 000[692]. Because no renewable fuels market for aviation and maritime shipping sectors has unfolded yet, there is no data for these sectors. However, similar average annual values could be expected with the expansion of production to meet these future markets.

33.7. COMMUNITY PRODUCTION (ANNUAL PRODUCTION VALUES)

Community production has grown steadily in the past few years, achieving 16 Mtoe in 2019. Biodiesel dominates EU production. As only some advanced biofuels and no synthetic fuels are reaching commercialisation these do not make up a significant part of production. Sustainable aviation fuels only made up a miniscule part of the annual production. In Finland 24,700 toe were produced in 2019, an increase from 7 206 toe in 2018.[693]

Figure 44 EU27 Annual production values of biofuels



Source: Eurostat 2021

691 SWD(2021) 634 final

692 Data compiled from European Commission, Bioeconomy, 2020, https://ec.europa.eu/knowledge4policy/bioeconomy/topic/economy_en

693 Eurostat 2021

33.8. CONCLUSIONS

Conventional biofuels have recently provided a constant growth to the EU economy. If primarily domestic, combined production of renewable shipping and aviation fuels could grow the economy by EUR 4 billion and create 25 000 additional jobs by 2030. By 2050 this could grow to EUR 230 billion and 470 000 jobs.

There is a strong representation of advanced biofuel producing companies in the EU with variation in technology pathway and feedstock focus. Particularly multinational fuel companies move into co-processing bio-oils in fossil refineries, thus reducing required investment costs per unit of product. Moreover, renewable liquid fuels do not need new dedicated infrastructures for their transport and distribution, as the well-developed logistics of fossil fuels can be re-used for this purpose. Competition will likely be strong in other parts of the world, particularly in the US where there is also a strong concentration of companies and demonstration plants.

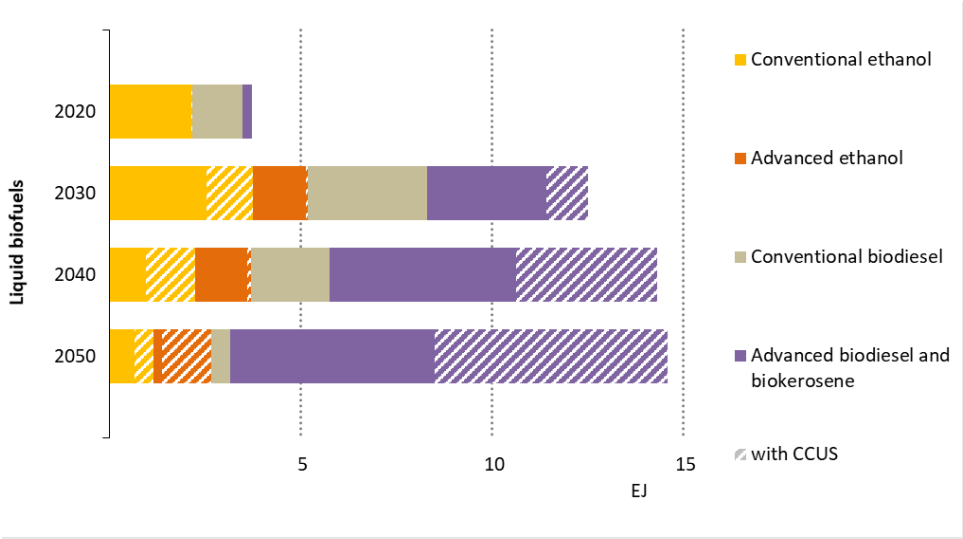
34. GLOBAL MARKET ANALYSIS

34.1. INTRODUCTION

The global combined annual production of advanced biodiesel and biokerosene is roughly 6 Mtoe (0.25 EJ), while conventional biodiesel production is around 31 Mtoe (1.29 EJ) and conventional bioethanol 51 Mtoe (2.15 EJ).[694] In the recent global energy scenario for reaching net-zero emissions by 2050, the IEA projects that a rapid expansion of advanced liquid biofuels is required already within this decade. Driven by the need for biodiesel and biojet kerosene until 2030 and primarily by biojet kerosene towards 2050, particularly Bio FT and cellulosic ethanol production pathways would have to scale up production to 2.7 million barrels of oil equivalents per day (mboe/d) by 2030 and to 6 mboe/d by 2050. This would imply installing one biorefinery every 10 weeks with a capacity of 55 tboe/d (or roughly twice the capacity of the largest biorefinery today)[695].

[694] International Energy Agency, Net Zero by 2050, 2021
[695] International Energy Agency, Net Zero by 2050, 2021.

Figure 45 IEA projection of global liquid biofuel production in Exajoules (EJ) in a net-zero-emission pathway for 2050



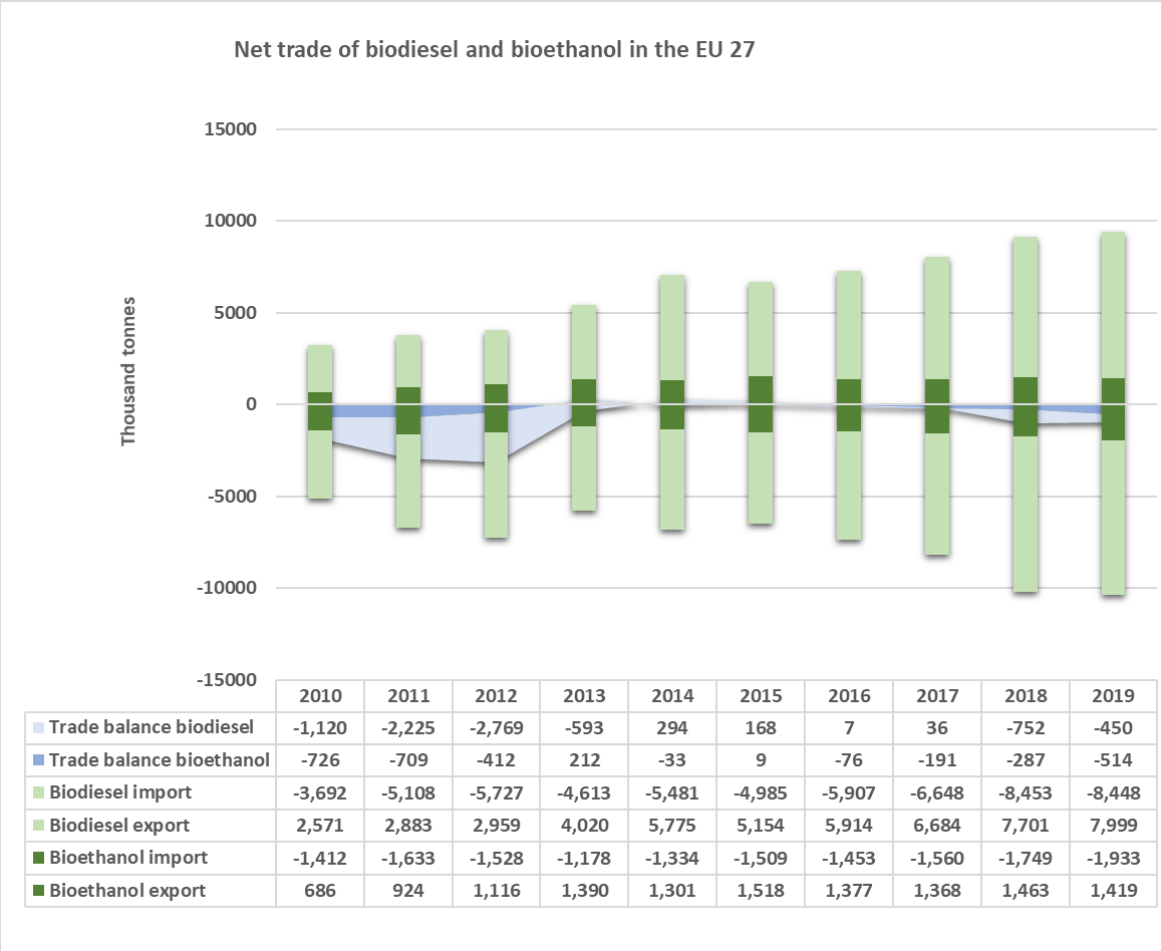
Source: International Energy Agency, Net Zero by 2050, 2021

34.2. TRADE (IMPORTS, EXPORTS)

Eurostat data show the gross export of conventional biofuels from the EU is slightly less than gross imports, leading to a net import. Figure 46 shows that there was a larger net import in the beginning of the decade which was then evened out. Since then, both imports and exports have steadily increased. The return of a net import since 2017 implies that growth in consumption is not matched by growth in domestic production. Recent market analysis of the United States Department of Agriculture (USDA) Foreign Agriculture Service confirms this, showing the EU is the largest producer of biodiesel globally, while consumption slightly exceeds domestic production for both biodiesel and bioethanol[696].

[696] Foreign Agriculture Service, United States Department of Agriculture (USDA), Biofuels Annual, 2020. https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Biofuels%20Annual_The%20Hague_European%20Union_06-29-2020

Figure 46 EU Net trade of biodiesel and bioethanol



	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Trade balance biodiesel	-1,120	-2,225	-2,769	-593	294	168	7	36	-752	-450
Trade balance bioethanol	-726	-709	-412	212	-33	9	-76	-191	-287	-514
Biodiesel import	-3,692	-5,108	-5,727	-4,613	-5,481	-4,985	-5,907	-6,648	-8,453	-8,448
Biodiesel export	2,571	2,883	2,959	4,020	5,775	5,154	5,914	6,684	7,701	7,999
Bioethanol import	-1,412	-1,633	-1,528	-1,178	-1,334	-1,509	-1,453	-1,560	-1,749	-1,933
Bioethanol export	686	924	1,116	1,390	1,301	1,518	1,377	1,368	1,463	1,419

Source: Data compiled from Eurostat 2021

34.2.1. Shipping

Currently less than 1% of the marine fuel supply uses biofuels, mostly in inland or short-sea shipping. Because there is no current market, it is not possible to assess trade balance. However, new policies are expected to unfold a new market, increasing demand within the EU to 3 Mtoe by 2030 and 32 Mtoe by 2050. It would be possible for the EU to produce these levels domestically and avoid a trade deficit. It is also unknown how the global market and production supply will develop.

34.2.2. Aviation

In the EU, the current consumption is very low when compared to the potential production capacity. In 2018, the global production of 15 million litres of aviation biofuels accounted for less than 0.1% of the total consumption of aviation fuels. The EU exported 24 000 tonnes of bio-jet fuels in 2019 and recorded no imports[697], suggesting a momentary edge in the global market, although these amounts are miniscule compared to fossil kerosene.

34.3. GLOBAL MARKET LEADERS VS. EU MARKET LEADERS (MARKET SHARE)

The current market is dominated by conventional biofuels, and only few advanced biofuels have entered or are close to market entry. It is not yet possible to determine share of the market, particularly specific to aviation or shipping fuels. The IEA foresees Japan, UK and US taking the lead to bring cellulosic ethanol and Bio FT fuels to market entry within the next few years[698]. Yet with one quarter of companies and one third of Bio FT plants based in the EU, the EU may also be well positioned to house market leadership of these fuels.

34.3.1. Shipping

In the EU, important market actors are GoodFuels (Dutch fuel producer and distributor), Maersk (Danish shipping company), BMW (German cargo owner), Wärtsilä (Finnish engine manufacturer). Wärtsilä and GoodFuels jointly work to supply marine biofuels to ships in the port of Rotterdam. The ship owner is aiming to use a diesel blend consisting of 30% biofuels with a goal of using a blend of up to 100% biofuels in the near future.

34.3.2. Aviation

Global market leaders in the sector of renewable aviation fuels are Neste (Finland), Gevo (USA), World Energy (USA), Eni (Italy), SkyNRG (The Netherlands), Fulcrum BioEnergy (USA), Velocys (UK), Ametis Inc. (USA), Lanzatech Inc. (USA), Red Rock Biofuels (USA), Total S.A. (France), SG Preston Company (USA), Amyris Inc. (USA) and Swedish Biofuels AB (Sweden)[699, 700].

In 2020, Neste produced about 120 million litres of aviation biofuels (5 million litres in 2018). Neste plans to increase the capacity to 1.5 million tons in 2023[701]. The majority of this capacity will not be located within the EU, rather in Singapore[702].

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697 EUROSTAT 2021

698 International Energy Agency, Net Zero by 2050, 2021

699 Absolute Market Insights, Renewable Aviation Fuel Market 2019-2027, 2020. https://www.absolutemarketsinsights.com/reports/Renewable-Aviation-Fuel-Market-2019-2027-366

700 Markets and Markets, Sustainable Aviation fuel Market by Fuel Type, 2020. https://www.marketsandmarkets.com/Market-Reports/sustainable-aviation-fuel-market-70301163.html

701 Neste to enable production of up to 500,000 tons/a of Sustainable Aviation Fuel at its Rotterdam renewable products refinery: https://www.neste.com/releases-and-news/renewable-solutions/neste-enable-production-500000-tonsa-sustainable-aviation-fuel-its-rotterdam-renewable-products

702 Tavares Kennedy, H., SAF, please prepare for take-off…even with aviation industry turned upside down due to pandemic, 2021 https://www.biofuelsdigest.com/bdigest/2021/05/02/saf-please-prepare-for-take-offeven-with-aviation-industry-turned-upside-down-due-to-pandemic/

In the EU, Copenhagen Airport, Schiphol Airport at Amsterdam and Frankfurt Airport have biofuel distributions for airplanes. However, Schiphol Airport depends on imports from the United States to cover much of its supply. SkyNRG therefore plans to install a 125 million litre plant to begin local production of bio-kerosene based on conversion of waste fats and oils by 2022[703].

While the top ten global SAF producers include four EU based companies (Total, Preem, Neste, SkyNRG), the two largest producers are in the US. There are also more SAF producers in the US which are expected to have a total production capacity twice the size of the EU by 2025 (according to existing and planned installations)[704].

Table 13 Top 10 worldwide SAF producers by 2025 based on current and planned production capacity

Top 10 producers by 2025	Country	Expected yearly production by 2025 (Kt/yr)
Phillips 66	US	831
World energy paramount	US	501.64
Total	EU	285
Preem	EU	222.57
Northwest Advanced Biofuel	US	171.93
Neste Oil	EU	167.92
Pertamina	IDN	150
SkyNRG	EU	95
Norsk e-Fuel	NOR	83.27
Readifuels	US/CAN	69

Source: data compiled from internal project database of Flightpath 2020

[703] Flightpath 2020.
[704] Data compiled from internal project database of Flightpath 2020.

34.4. RESOURCE EFFICIENCY AND DEPENDENCE

Advanced biofuels are not dependent on any of the critical raw materials presented in either the 2020 Commission communication or Foresight Study on critical raw materials. Particularly since they can also be produced throughout the EU and the rest of the world, this gives them a strategic advantage over other technologies. It is therefore possible to reduce foreign dependency through local and regional value chains.

The choice of biomass feedstock may have implications for sustainability, production costs and potential supply bottlenecks. Particularly regarding scaling up of biofuels, using alternative production pathways will enable the use of diverse feedstock from woody biomass or waste and residue. While these are currently less mature, their maturity will be necessary to avoid feedstock bottlenecks.

Feedstock expansion is also necessary to reduce the impact of aviation and maritime sectors absorbing local feedstock at cost of biodiesel for the road sector. Revitalising degraded and abandoned land with sustainable biomass production will likely also be necessary to help prevent such bottlenecks.

Feedstock production may be more labour intensive, generating less labour productivity than other segments of the value chain. Yet locally produced value chains strengthen operational resilience as well as regional economy.

Synthetic fuel production depends on availability of renewable hydrogen and renewable electricity. Due to the dependence of power-to-liquid on low-cost renewable electricity, production could results in a certain dependence on Middle East and North Africa (MENA) region for hydrogen feedstock (for which the US and China will likely also compete).

Any critical raw material dependencies of technologies producing renewable electricity and hydrogen are assessed in those sections of this report. Also the GHG reduction capacity of power-to-gas and power–to-liquid fuels will depend on the life-cycle emissions assessment of the entire value chain for power production, including critical materials, systems and components.

34.5. FINAL CONSIDERATIONS

While the EU is currently a global leader in production of conventional biofuels, a market for advanced biofuels and renewable synthetic fuels has not yet unfolded, particularly for aviation and shipping sectors. Yet the EU already has net exports in sustainable aviation fuels, even if the amount is insignificant compared to conventional biofuel trade. New policies are expected to drive market growth in both sectors in the next few years. The EU already has a strong global market position as well as a concentration of leading advanced biofuel producers including various joint ventures with airlines, airports and oil majors, suggesting the EU could maintain market leadership. Competition, particularly from the US or Brazil, may be strong as well as similar cooperation structures are forming. Utilising local and regional supply chains for waste and residue feedstock not only strengthens the regional economies, but can increase the resilience of the EU as a global market leader.

35. SWOT AND CONCLUSIONS

The EU shows strength in R&I funding, ensuring the development of multiple renewable fuel technologies for aviation and shipping. As a leading producer of conventional biofuels, with strong concentration of innovative advanced biofuel producers, the EU is also in a good starting position for driving aviation and shipping fuels market. Yet the hurdle of very high investment costs for new plants as well as the lower cost of fossil fuels present large risks to producers and potential investors. Co-processing in existing refineries and other industries is maturing and presents an advantage for lowering capital costs. Overcoming these barriers requires policy incentives to level the cost, to ensure a demand and to establish a market.

The dynamics of the demand for renewable fuels has the potential to support the progressive of the cost gap between fossil and renewable fuels. In the case of a new manufacturing plant, in fact, the capital cost – heavily impacting the production cost of renewable fuels – can be repaid in the first years of the investment life. During this period, road transport's demand for renewable fuels, driven by existing (RED) and new (ETS, ETD) strong regulatory instruments, can absorb the higher cost of renewable fuels. Over time, the demand of fuels for road will shrink (due to electrification of especially light duty vehicles) while demand for ships and airplanes will progressively pick up. Once the capital cost of renewable fuels is repaid, the cost gap between renewable and fossil fuels for aviation and shipping may reduce very significantly.

Although the EU biofuel industry currently has a strong footing there is also a risk of opening a market to be dominated by foreign production capacity. Particularly the US is a strong competitor for advanced biofuels production while Brazil is also rising in the global market as a strong player, followed by China and India which put forward expanding policies. Developing large scale production facilities to achieve economies of scale and lower production costs requires extremely large investment costs often up to 80% of total costs. Synergies with existing industries to explore installed facilities should be seriously investigated. To ensure EU leadership in a market created by EU policy, support is also necessary, such as government grants and low interest finance for large scale demonstration and First-of-a-kind commercial plants in addition to a steady long-term policy framework and market up-take measures including standardisation and higher blending limits.

Technology and feedstock diversification are the tools to mitigate risks of lock-in to dependencies, like focusing innovation and investments in technologies for which feedstock expansion is challenging, such as HEFA-SPK. While this pathway may be of advantage in the short term due to low investment costs and competitive feedstock and production costs, in the long run competition for supply may drive the production costs much higher. Nevertheless, new feedstocks from intermediate crops, catch and cover crops and those based on marginal and contaminated lands, as well as waste animal fats and algae or aquatic biomass present an opportunity to expand commercial production of HEFA-SPK and should be supported. If investments are made early enough in novel production pathways relying on a diverse set of more abundant feedstocks, their investment and production costs could be reduced in time to outcompete HEFA from crops as feedstock costs become a liability.