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REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL

Progress on competitiveness of clean energy technologies

{COM(2021) 950 final} - {SWD(2021) 307 final}

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CONTENTS

1. INTRODUCTION

The European Green Deal is the overarching framework for the EU clean energy policy. It is a new growth strategy that aims at making Europe the first climate neutral continent in the world, in a fair, resource efficient, cost effective and competitive way. To operationalise the climate objectives of the European Green Deal, the EU Climate Law[1] has enshrined into law the political priority of becoming climate neutral by 2050 and of reducing greenhouse gas emissions by 55% by 2030, compared to 1990 levels.

This policy context is complemented by the release of unprecedented financial means at EU level, comprising both a new EU budget[2] as well as the NextGenerationEU recovery and resilience package agreed in 2020[3]. These will help translate into high contributions to deliver on the European Green Deal objectives, with an earmarked 30% of climate spending overall. In particular, fully recognising the role of research and innovation to contribute to those objectives, the EU research and innovation programme Horizon Europe has been significantly strengthened[4], as other funding programmes like the Innovation Fund or LIFE.

Furthermore, in July 2021, the European Commission presented a comprehensive package to deliver the European Green Deal, which proposes to revise existing instruments as well as propose new ones[5] in order to set the EU on a path to reach its climate targets by 2030. This package constitutes one of the most comprehensive set of proposals on climate and energy the Commission has ever presented. Among others, it will contribute to the development of the clean energy system in the next decade by spurring innovation, investment, and creating new market demand in the EU, while ensuring a socially-just transition, cementing EU global leadership in the fight against the climate crisis.

Technological advancement in the clean energy system[6] is of critical importance to achieve the EU's climate and energy objective by 2050, as highlighted in the "Impact Assessment of the Climate Target Plan 2030"[7]. The International Energy Agency (IEA) projects that, while most of the reductions in CO_2 emissions through 2030 will come from technologies already on the

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[1] Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021.

[2] The multiannual financial framework covering the period 2021-2027.

[3] In 2018 prices and over seven years, the EU budget amounts to EUR 1 074 billion and NextGenerationEU to EUR 750 billion.

[4] EUR 95.5 billion over 2021-2027, current prices.

[5] The legislative files include proposals to revise the Renewable Energy Directive (RED), the Energy Efficiency Directive (EED), the Energy Performance of Buildings Directive, the Energy Tax Directive (ETD), the EU Emissions Trading System (EU ETS), the Revision of the Third Energy Package for gas, the Effort Sharing Regulation (ESR), the Alternative Fuels Infrastructure Directive (AFID), the Regulation on Land Use, Forestry and Agriculture, the CO2 emission standards for cars and vans, as well as also proposals to create a new emissions trading for the road transport and building sectors, a Carbon Border Adjustment Mechanism (CBAM), the ReFuelEU Aviation and FuelEU Maritime initiatives, an EU Forest Strategy and a proposal to create a Social Climate Fund.

[6] In this report, the clean energy system covers three market segments: (1) Renewable energy, including manufacturing, installation and generation; (2) Energy efficiency and management systems that include technologies and activities such as smart meters, smart grids, storage and renovation of buildings; and (3) Electric mobility, which includes components such as batteries and fuel cells essential for electric vehicles and charging infrastructures.

[7] Impact Assessment accompanying the Commission Communication on Stepping Up Europe's 2030 climate ambition – Investing in a climate neutral future for the benefit of our people, SWD(2020) 176 final.

market today, almost half of the reductions needed by 2050 will come from technologies that are currently at demonstration or prototype phase[8]. This second annual competitiveness report[9] tracks the current and projected state of play of different clean energy technologies and provides insight on how the clean energy system contributes to making the EU climate neutral by 2050, while respecting the European Green Deal's green oath to "do no harm". Looking at the different facets of competitiveness, this report identifies strengths, challenges and points of attention for the EU clean energy system. In particular, it shows that trends in both gross value added and employment in clean energy – barring disparities within the sector – are surpassing those of the overall EU economy, while public investment in clean energy R&I continues to see a rebound trend over the last five years, though not yet reaching the level of 2010. The European innovation ecosystem is in a leading position when it comes to high value patenting as well as in the support of early-stage climate tech start-ups. However, we are far behind other geographical regions when it comes to scaling up. From a technological perspective, the EU retains a strong position in the wind industry, however may be at crossroads in multiple other industries including solar PV, renewable hydrogen, heat pumps or renewable fuels.

The assessment of the competitiveness of the EU clean energy system is done, in this report, in accordance with Article 35.1(m) of the Regulation on the Governance of the Energy Union and Climate Action, as part of the State of the Energy Union report. As competitiveness is a complex and multifaceted concept which cannot be defined by a single indicator[10], this report proposes a set of widely accepted indicators[11] capturing the entire energy system (generation, transmission and consumption) and analysed at three levels (technology, value chain, and global market). The underpinning data for each indicator are contained in the accompanying Staff Working Document.

2. OVERALL COMPETITIVENESS OF THE EU CLEAN ENERGY SECTOR

2.1 Setting the scene: recent developments, Covid-19 impact, recovery, human capital, and value-added

2.1.1 Recent developments

The European Union, like many other regions in the world, is currently facing a sharp spike in energy prices. The spike in prices is principally driven by increased global demand for energy at large and gas in particular, linked to the recovery from the COVID-19 crisis. The all-time high prices that have been observed in the last months[12] are the result of a combination of factors

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[8] IEA, Net Zero by 2050. A Roadmap for the Global Energy Sections. Flagship Report, May 2021.

[9] The first Progress of Clean Energy Competitiveness report was COM(2020) 953 final.

[10] Based on the conclusions of the Competitiveness Council of 28 July 2020.

[11] The indicators assessed in the section 2 of the report are primary and final energy intensity, share of renewable energy sources, import dependency, industrial electricity and gas prices, turnover of the EU sector (clean vs fossil) compared to the rest of the economy, gross value added of renewable energy production, employment of the EU sector compared to the rest of the world including gender statistics, and COVID-19 disruptions.
The indicators in the section 3 of the report are assessed for each technology and in the EU, unless otherwise mentioned. These include the capacity installed (today and in 2050), the cost and/or levelised cost of energy (LCoE), public R&I funding, private R&I funding, patenting trends and the level of scientific publications. The value chain analysis is assessed by the turnover, the gross value added growth, the number of EU companies in the supply chain, the employment in the value chain segment, the energy intensity and labour productivity, and community production. Finally, the global market analysis is assessed through trade considerations, global market leaders vs EU market leaders, and resource efficiency and dependence for segments of the value chain which depend on critical raw materials.

[12] In September, average wholesale electricity prices reached more than EUR 125 per MWh, gas prices reached almost EUR 65 per MWh and EU ETS allowances reached more than EUR 60 per tCO2.

primarily driven by a global demand for gas, resulting in the increase of electricity prices. In addition, electricity prices also increased because of seasonal weather conditions (low water and low wind over this summer). This has resulted in lower production of renewables in Europe. The European carbon prices have also risen sharply in 2021[13], albeit much less than the gas price. The effect of the gas price on the electricity price is nine times bigger than the effect of the carbon increase[14].

These factors translated into the increase of wholesale and retail electricity prices in most of the major economies of the world since the second half of 2020. The high wholesale electricity prices have reached all EU Member States, although some of them have been hit harder, depending in particular on the share of fossil fuels for generating electricity. The speed at which the increase in wholesale gas prices translates into retail prices also depends on the retail contract terms (i.e. contract length, fixed or variable prices, etc.). The European Commission is concerned about the negative impact of the price rise on households and businesses. Having listened to Member States and the European Parliament, the Commission has presented a Communication to enact and support appropriate measures to mitigate the impact of temporary energy price rises and further strengthen resilience against future shocks[15].

The increase in wholesale electricity prices may convey a signal of the improved competitiveness of renewables. This may incentivise increased investment in the sector, which on the long run, will help to reduce electricity prices given their lower production costs/operating expenditures, their exclusion from carbon pricing, and expected decreasing capital cost. The current price hike in the European energy sector also shows the need to reduce the EU's dependency on imported fossil fuels. Looking ahead, the new climate and energy targets will yield new investment needs. Over the next ten years, annual additional investments of EUR 390 billion will be needed compared to the annual amounts invested over the last ten years[16]. A significant acceleration of deployment is needed to achieve the current 2030 renewable energy target of 32%, and an even greater acceleration will be needed to meet the newly proposed 40% target of the July package to deliver on the European Green Deal. As permitting delays constitute a major barrier for the transition to a decarbonised energy system, delaying deployment and investments into clean energy infrastructures and technologies by many years, the Commission will issue guidance in 2022 on accelerating permitting processes for renewable energies and continue working closely with national administrations to identify and exchange on good practice. Urgent simplification and streamlining of permitting procedures is needed to create a common market for renewables that facilitates efficient and cost-effective deployment as well as investor certainty, also in view of the massive investments needed.

An integrated and well-functioning EU energy market would be the most cost-effective way to ensure secure and affordable energy supplies to all types of customers. It keeps prices in check by creating competition and allowing consumers to choose energy suppliers. The Communication on energy prices[17] proposes short-term measures such as Member States'

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[13] Coal power still has a 14% share in the EU.

[14] From January 2021 to September 2021, the ETS price has increased by about 30 EUR / tCO2, which translates into a cost increase of about 10 EUR / MWh for electricity produced from gas (assuming a 50% efficiency) and about 25 EUR / MWh for electricity produced from coal (assuming a 40% efficiency). This is clearly outweighed by the observed increase of the gas price of about 45 EUR / MWh over the same period, which translates into additional electricity production cost of about 90 EUR / MWh.

[15] COM(2021) 660 *Tackling rising energy prices: a toolbox for action and support*

[16] COM(2021) 557 final, Table 7, MIX Scenario, page 133.

[17] COM(2021) 660 final, *Tackling rising energy prices: a toolbox for action and support*

emergency income support to households, state aid for companies, and targeted tax reductions. In the medium term, the Commission proposes inter alia to support investments in renewable energy and energy efficiency; examine possible measures on energy storage and purchasing of gas reserves. While there is of yet no clear evidence that alternative market framework would provide cheaper prices and better incentives, the Commission has also tasked the Agency of Cooperation for Energy Regulators (ACER) to assess the benefits and drawbacks of the current electricity market design and propose recommendations by April 2022.

To this end, the EU strives to further develop interconnectors between Member States, ensuring that as much as possible of interconnectors' capacity is available for trade. It monitors the implementation of the existing acquis (e.g. network codes) and proposed additional tools to ensure liquid markets, such as, for example, the revision of the Renewable Energy Directive, including further promotion of corporate Power Purchase Agreements, as well as the proposal for the revision of the Energy Efficiency Directive, putting energy efficiency first at the heart of our economy.

2.1.2 Impact of Covid-19 and recovery

While the European Green Deal policy framework will drive demand for clean energy technologies, their supply, development and competitiveness is certainly put to the test by the COVID-19 pandemic. The implementation of the energy and climate policies depends on the availability of renewable technologies, undisrupted value chains, retained competitiveness of companies and their skilled workforce. On the one hand, the economic impact of a pandemic threaten to be a major set-back for the competitiveness of the clean energy technologies. On the other hand economic recovery policy also provides an opportunity to refocus and enhance investment to the clean energy sector, thanks to the NextGenerationEU facility.

Renewables have in fact been less affected worldwide by the Covid-19 pandemic than other energy sources[18]. Only biofuels for transportation were impacted more severely as consumption declined due to a combination of reduced travel and low oil prices[19]. Falling capital costs enabled an unprecedented number of solar and wind energy plants to be installed globally[20]. As a result, while electricity generation from coal, natural gas and nuclear decreased, renewables overtook fossil fuels for the first time as the EU's main power source for the year 2020 (renewables 38% of EU electricity, versus 37% fossil fuels and 25% nuclear)[21].

To recover from the Covid-19 pandemic, the Recovery and Resilience Facility (RRF) Regulation is a first in its kind for the EU as a performance-based programme, proposed by the Commission as part of the NextGenerationEU package. Funding is available for Member States based on their comprehensive Recovery and Resilience Plans (RRP) and is unlocked through achievement of measurable milestones and targets. It requires Member States to allocate at least 37% of their total allocation under the Recovery and Resilience Facility to the climate transition in their RRP, and to include measures consistent with the relevant country-specific challenges

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[18] IEA, World Energy Outlook, 2020.

[19] IEA, Energy Technology Perspectives 2020, Special Report on Clean Energy Innovation, 2020.

[20] BloombergNEF, EnergyTransition Investment Trends, Tracking global investment in the low-carbon energy transition, 2021.

[21] Agora Energiewende and Ember, The European Power Sector in 2020: Up-to-Date Analysis on the Electricity Transition, 2021.

and priorities identified in the context of the European Semester and the National Energy and Climate Plans.

The analysis of the 22[22] RRPs approved by the Commission by 5 October 2021[23] shows that EUR 177 billion have been allocated to climate-related investments, representing 40% of the total allocation of these Member States (grants and loans). About 43% of this amount (EUR 76 billion) is dedicated to energy efficiency (27.9%) and renewable energy and network (14.8%)[24], while around EUR 62 billion is dedicated to sustainable mobility (35%).

Research and innovation also represented an important share, as Members States allocated nearly EUR 12.3 billion to investment in R&I in climate change mitigation and adaptation and the circular economy in their Recovery and Resilience Plans[25].

2.1.3 Human capital and value-added

While it is too early to tell how the pandemic as well as recovery funding impacted human capital, latest Eurostat data indicate that clean energy was outperforming the overall economy shortly before the pandemic. In 2018, direct employment in clean energy[26] reached 1.7 million, with an average annual growth of 2%, while employment in the overall economy grew on average by 1% a year. While annual average growth in ’Energy efficiency and management systems’ employment averaged 6% since 2010, direct jobs in ‘Renewable energy’ and ‘Electric mobility’ declined by 3% (2010-2018). This is due to lower renewable energy growth in some Member States, e.g. complex permitting rules and exposure to legal challenges hamper new wind installations in Germany where jobs decline is most prevalent (see also section 3.1). In addition, technological and productivity improvements have lowered labour intensity, particularly in mature markets (e.g. wind, solar). Job growth occurs increasingly in other clean energy applications such as smart meters, smart grids, storage and other products and activities related to energy efficiency and management.

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[22] AT, BE, CY, CZ, DE, DK, EE, EL, ES, FI, FR, HR, IE, IT, LT, LU, LV, MT, PT, RO, SI, SK.

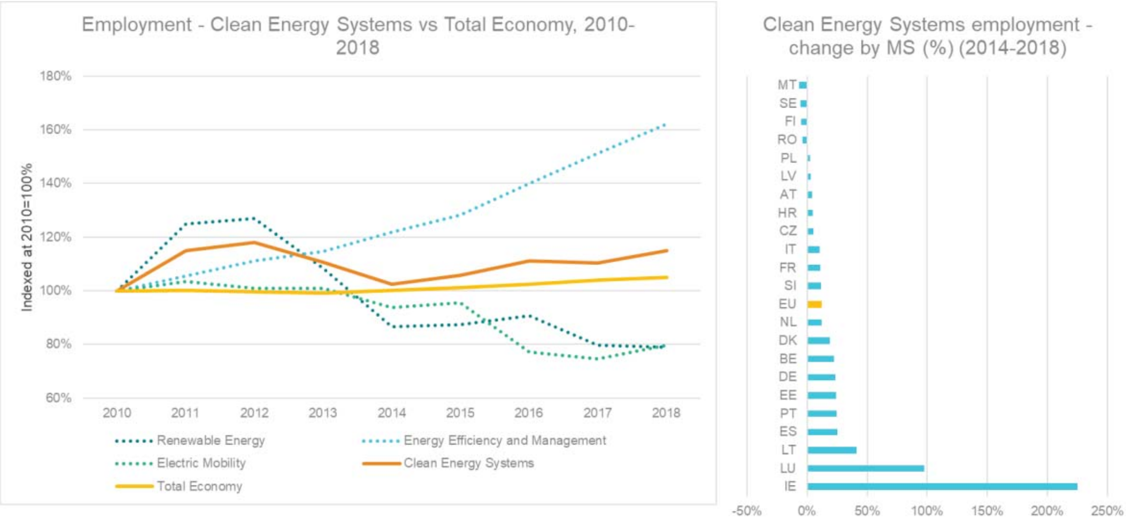
[23] The expenditures reported for the RRF are estimates processed by the Commission based on the information on climate tracking published as part of the Commission’s analyses of the recovery and resilience plans. The data reported cover the 22 national recovery and resilience plans assessed and approved by the Commission by 05 October 2021 and the amount will evolve as more plans are assessed.

[24] Energy efficiency measures cover energy efficiency projects in SMEs or large enterprises, energy renovations in private buildings and public infrastructure and construction of buildings. Clean energy measures cover in particular production of renewables, energy networks and infrastructure as well as hydrogen related investments.

[25] Figure on: Distribution of climate-related investments in MS’ RRPs. Source: Own preliminary assessment of 22 RRPs adopted by the Commission (by 5 October), State of the Energy Union 2021, COM(2021) 950 final.

[26] In comparison to last year CEPA1 is added to better reflect the scope of technologies covered in the report. Thus, employment, gross value added and labour productivity figures in the report are based on Eurostat EGSS the following categories ’CREMA13A’, ’CREMA13B‘ and ’CEPA1’. ’CREMA13A’ includes Production of energy from renewable resources including also manufacturing of technologies needed to produce renewable energy (‘Renewable energy’ – in the graph). CReMA 13B - Heat/energy saving and management includes heat pumps, smart meters, energetic refurbishment activities, insulation materials, and parts of smart grids (‘Energy management’ – in the graph). CEPA1 – Protection of ambient air and climate – includes electric and hybrid cars, buses and other cleaner and more efficient vehicles and charging infrastructure that is essential for the operation of electric vehicles. This includes also components, such as batteries, fuel cells and electric power trains essential for electric vehicles (’Electric mobility’ - in the graph).

Figure 1 Clean energy systems employment vs total economy growth in EU27 2010-2018 and clean energy systems employment change by Member State over 2014-2018



*) Data is missing for Greece, Cyprus, Hungary and Slovakia. EU27 aggregate is estimated. For Finland there was no value for 2014, hence the change is for 2015-2018.

Source: JRC based on Eurostat 'env_ac_egss1'[27]

Similarly, preceding the pandemic, with an average annual growth of 5%[28], the gross value added of the clean energy systems has outperformed the overall economy (3% growth) since 2010. Clean energy represented 1% (EUR 133 billion) of the total value added in the EU in 2018, which is more than double compared to that of fossil fuel extraction and manufacturing sector (EUR 59 billion)[29]. Within the clean energy system, gross value added in 'Renewable energy' (EUR 60 billion) has grown with an average annual growth of 2%, while 'Energy efficiency and management systems' (EUR 67 billion) has grown 9% in the same period. Gross value added in the 'Electric mobility' at EUR 7 billion has grown at less than 1% annually.

'Renewable energy' jobs created, on average, EUR 104 000 of gross value added per employee in 2018, with an average annual growth[30] of 5% since 2010. This is 60% more than in the rest of the economy (EUR 64 000 of gross value added per employee). The value added per employee in 'Energy efficiency and management' is EUR 64 000 and in 'Electric mobility' it

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[27] Clean energy systems include CReMA 13A - Production of energy from renewable resources, which includes both generation of renewable energy and manufacturing of technologies needed to produce renewable energy ('Renewable energy' – in the graph); CReMA 13B - Heat/energy saving and management, which includes heat pumps, smart meters, smart grids, energetic refurbishment of buildings, and storage ('Energy efficiency and management' – in the graph); and CEPA1 - Protection of ambient air and climate, which includes electric vehicles and associated components and the essential infrastructure needed to for the operation of electric vehicles ('Electric mobility' In the graph).

[28] Eurostat 'env_ac_egss2'. Clean energy systems include CReMA 13A - Production of energy from renewable resources, which includes both generation of renewable energy and manufacturing of technologies needed to produce renewable energy ('Renewable energy'); CReMA 13B - Heat/energy saving and management, which includes heat pumps, smart meters, smart grids, energetic refurbishment of buildings, and storage ('Energy efficiency and management'); and CEPA1 - Protection of ambient air and climate, which includes electric vehicles and associated components and the essential infrastructure needed to for the operation of electric vehicles ('Electric mobility').

[29] Data for fossil fuel extraction and manufacturing is from Eurostat Structural Business Statistics. The following codes are considered: B05 (mining of coal and lignite), B06 (extraction of crude petroleum and natural gas), B07.21 (mining uranium and thorium ores), B08.92 (extraction of peat), B09.1 (support activities for petroleum and natural gas extraction), and C19 (manufacture of coke and refined petroleum products).

[30] Compound average growth rate.

is EUR 74 000, growing annually by 3% and 7% respectively during 2015-2018, faster than the rest of the economy at 2%.

Considering the overall resilience of the clean energy sector during the pandemic, the strong performance of human capital in clean energy leading up to the pandemic as well as the EUR 177 billion in climate-related investments planned by Member States in their national RRPs, there is room for cautious optimism that clean energy will continue to be a motor for employment and growth as the EU economy recovers from the pandemic.

2.1.4 Skills

The transformation of the energy system requires re-skilling and up-skilling across all skills levels to deploy and further develop clean energy technologies and solutions across different sectors. Demand for a wide range of occupational categories relevant to the clean energy transition is expected to increase until 2030, including mining (i.e. for critical raw materials), or construction, manufacturing, transport, building and related trades, as well as science and engineering[31]. By 2030, an additional 160 000 jobs could be created in the EU construction sector alone through the EU Renovation Wave[32].

To support the uptake of next-generation skills essential for the EU green transition, the EU launched in 2020 the Pact for Skills[33] where partnerships with industrial ecosystems such as construction and energy intensive industries are being set up through roundtables.

In the case of offshore renewable energy, skills transfer are also possible from the offshore oil and gas sector, as well as from the military sector (e.g. during the exploration of potential project sites) [34].

Women accounted for an average of 32% of the workforce in the renewables sector in 2019[35]. Gender imbalances both in the energy sector workforce as well as in energy related research and innovation activity, are closely – but not exclusively – connected to the women underrepresentation in higher education in some science, technology, engineering, and mathematics (STEM) sub-fields. In the EU, women are overrepresented in tertiary education (54 % across all tertiary education levels and all fields); women are listed in less than 11% of applications, and over 15% for climate change mitigation technologies (CCMT). Yet, sub-fields highly relevant for the energy sector remain strongly male dominated, since in 2019 less than a third of engineering, manufacturing, and construction and less than a fifth of ICT higher education students was female[36].

2.1 Research and innovation trends

Research and innovation plays a key role in shaping the competitive industries of tomorrow. After the 2008 economic crisis, public investments in R&I prioritised by the Energy Union[37,38] went into a decline for half a decade, showing signs of recovery only after 2016 (Figure 2).

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[31] CEDEFOP, Skills forecast: trends and challenges to 2030, 2018.

[32] A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives, COM(2020) 662 final.

[33] European Commission, The Pact for Skills – mobilising all partners to invest in skills, 2020.

[34] D2.1-MATES-Baseline-Report-on-Present-Skill-Gaps.pdf (projectmates.eu)

[35] IRENA, Renewable Energy : A Gender Perspective, 2019.

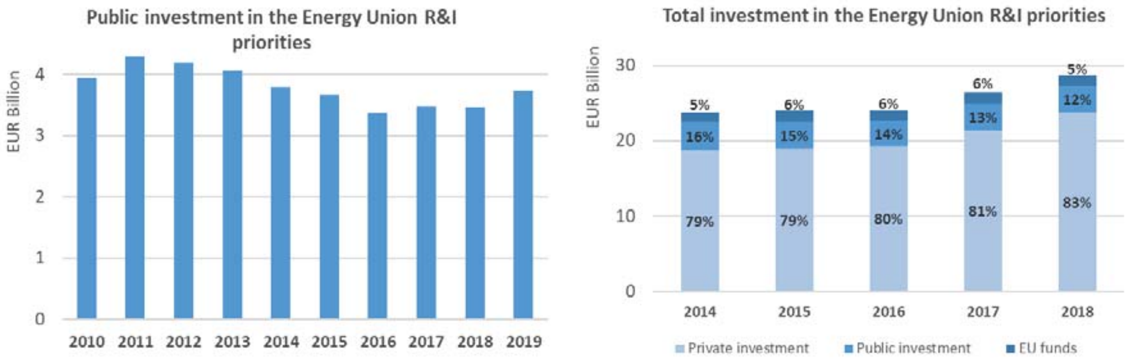
[36] JRC based on Eurostat [EDUC_UOE_ENRT03].

[37] Renewables, smart system, efficient systems, sustainable transport, CCUS and nuclear safety, COM(2015) 80 final.

[38] JRC SETIS https://setis.ec.europa.eu/publications/setis-reseach-and-innovation-data_en.

Since then, EU Member States have invested on average EUR 3.5 billion per year, but spending is still lower than that observed a decade ago. At the global level, the trend is consistent with increased investments in energy in general – and clean energy in particular[39] - however, does not keep pace with increases in GDP or R&I spending in other sectors. Measured as a share of GDP, EU investment rate (0.027%) is currently the lowest of all major global economies, just below the US, though levels seem to be decreasing or stable for all (Figure 3).

Figure 2 Public (left) and total (right) R&I financing of Energy Union R&I priorities in the EU[40].



Source JRC[41] based on IEA[42]and own work.

Although long-term impacts of the pandemic on renewable energy R&I spending remain unclear, early trends indicate general resilience. In global public spending on energy R&I there was continued, but slowed growth in 2020[43]. EU private sector experienced a 7% reduction in overall energy R&I spending during 2020. However spending specifically in renewable energy R&I was more resilient and continued to grow[44].

Essential in maintaining research and innovation investment levels over recent years, EU research funds have been increasing annually, contributing on average EUR 1.5 billion. Combined with an estimated average of EUR 20 billion of private spending[45], the average annual total investment in the Energy Union R&I priorities over recent years (2014-2018) is in the order of EUR 25 billion[46]. Crucial in the recovery context, the world largest R&I programme "Horizon Europe", the Innovation Fund, together with the cohesion policy funding and the "LIFE" programme, are and will be stimulating climate and environmental R&I and market uptake.

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[39] https://www.iea.org/reports/world-energy-investment-2020/rd-and-technology-innovation

[40] Public R&I investment figures for 2020 are only available for a few Member States. Private R&I investment is estimated using patents as a proxy, resulting in a longer time-lag for data availability; 2018 data are provisional.

[41] JRC SETIS https://setis.ec.europa.eu/publications/setis-reseach-and-innovation-data_en

[42] Adapted from the 2021 edition of the IEA energy technology RD&D budgets database.

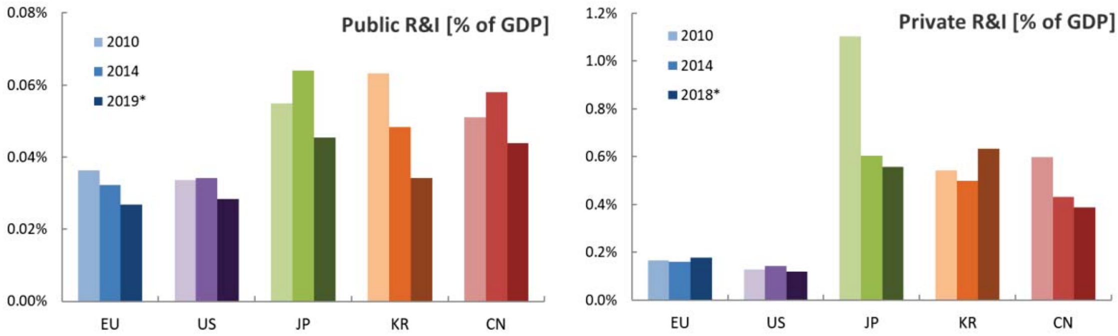
[43] IEA, World Energy Investment, 2021.

[44] IEA, World Energy Investment, 2021.

[45] Private investment estimates have been revised upwards, due to changes in classification and the underlying data.

[46] The increased total compared to last year's reporting is due to the revision of the private investment estimates.

Figure 3: Public (left) and private (right) R&I financing in Energy Union R&I priorities as a share of GDP in major economies



*public R&I data for Italy (in EU total) refer to 2018 ; private R&I data for 2018 are provisional

Source JRC[47] based on IEA[48], MI[49], own work.

In 2019, total public investment in Energy Union R&I priorities from all EU Member States was still 5% lower than in 2010 but had increased by 2% compared to 2015. About a quarter of the Member States have consistently increased spending overall throughout the 10-year period, with an equivalent number showing a decrease. For the remaining, the trend coincides with the EU total, or information on R&I spending is not available[50]. While there is a clear need to improve monitoring of R&I investment, there is also increased momentum and engagement from Member States in view of the reporting foreseen in the Energy Union Governance Regulation in 2023. This goes beyond public R&I investment, to also stepping up efforts at national level to monitor R&I investments from the private sector. The Strategic Energy Technology Plan (SET Plan) is the main European tool to align policies and funding on clean energy technologies R&I at EU and national level and to leverage private investments.

Private investment in the Energy Union R&I priorities in the EU is estimated at 0.18% of GDP (Figure 3), above the US but lower than other major competing economies (Japan, Korea, China). This represents 12% of the business expenditure on R&D, which is above the 6% estimated for the US, but about half of the share observed for major Asian economies.

The declining[51] patenting trend in clean energy technologies[52] (since 2012) seems to be reversing, with annual filing levels in the EU, and globally, returning to those observed a decade ago. The EU has a greater share of ‘green’ inventions in climate change mitigation technologies in overall patent filings compared to other major economies (and the world average), indicating greater focus and specialisation of inventive activity in this field. The EU is second only to Japan in high-value inventions[53], mainly due to Japan’s advantage in transport technologies; however, the EU leads when it comes to renewables and energy efficiency (Figure 4). The EU also continues to host a quarter of the top 100 companies in high-value patents in clean energy

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[47] JRC SETIS https://setis.ec.europa.eu/publications/setis-reseach-and-innovation-data_en.

[48] Adapted from the 2021 edition of the IEA energy technology RD&D budgets database.

[49] Mission Innovation Tracking Progress http://mission-innovation.net/our-work/tracking-progress/.

[50] These Member States include Bulgaria, Greece, Croatia, Latvia, Luxembourg and Slovenia.

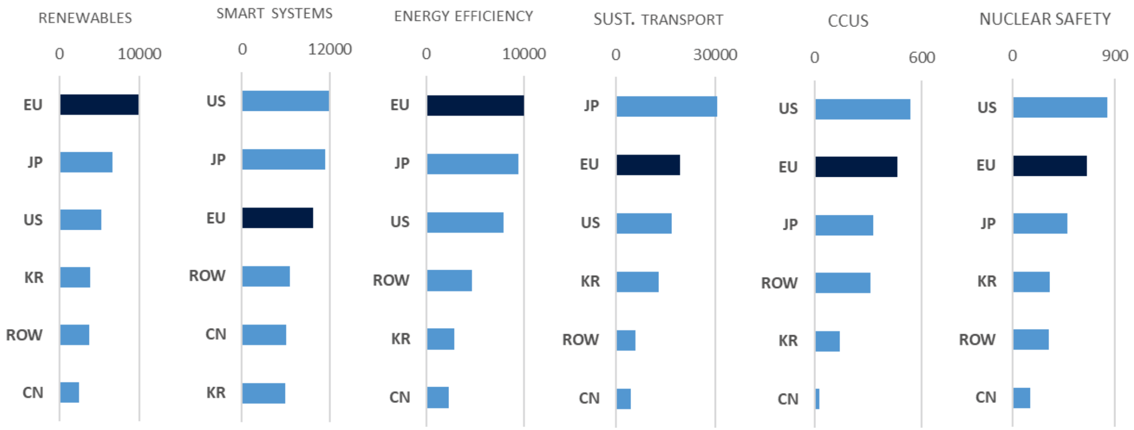
[51] With the exception of China, where local applications keep increasing, without seeking international protection. (See also: Are Patents Indicative of Chinese Innovation? https://chinapower.csis.org/patents).

[52] Low-carbon energy technologies under the Energy Union’s R&I priorities. This is the overall trend; there were exceptions for certain technologies (e.g. batteries) which kept increasing throughout the period. The same applies for broad ‘green’ patenting activity in Climate Change Mitigation technologies.

[53] High-value patent families (inventions) are those containing applications to more than one office i.e. those seeking protection in more than one country / market.

over the last 5 years. Nonetheless, there is an increasing (global) unease about the impact of state- or subsidy- backed technology domination, closed markets and different intellectual protection rules and policies on innovation and competitiveness in the sector, especially as manifested by China. Despite those concerns, over a quarter of the clean energy inventions protected internationally over the last 5 years by EU applicants have also targeted the Chinese market. In terms of collaborations, beyond the alliances built within Europe due to geographical proximity and EU collaborative programmes, EU firms tend to collaborate most with US counterparts[54]. EU Member States generate 33% of co-inventions through intra-EU connections, 29% with the USA and only 6% with China.

Figure 4: EU positioning in high-value patents in the Energy Union R&I priorities (2005-2018)



Source JRC[55] based on European Patent Office Patstat

2.2 The clean technologies funding landscape in the EU

The role of venture capital

Together with the adoption of more mature generation technologies (e.g. solar photovoltaics and wind), the development and scale-up of novel technologies (e.g. long and short-duration energy storage, renewable hydrogen production and use in hard to abate sectors, carbon capture use and storage), and in particular the so-called climate tech[56], will play a crucial role to achieve carbon neutrality by 2050.

Since the 2015 Paris Climate Change Conference, climate tech have gained a significant momentum, and they are becoming highly attractive for venture capital (VC) investments, that are at the forefront of innovation. As climate tech involve long lead times to reach maturity, require a significant amount of capital throughout the start-ups' funding lifecycle as well as

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[54] JRC118983 Grassano, N., Hernández, H., Tübke, A., Amoroso, S., Dosso, M., Georgakaki, A. and Pasimeni, F.: The 2020 EU Industrial R&D Investment Scoreboard.

[55] JRC SETIS https://setis.ec.europa.eu/publications/setis-reseach-and-innovation-data_en

[56] 'Climate tech' encompasses a broad set of sectors which tackle the challenge of decarbonising the global economy, with the aim of reaching net zero emissions before 2050. This includes low-to-negative carbon approaches to cut key sectoral sources of emissions across energy, built environment, mobility, heavy industry, and food and land use; plus cross-cutting areas, such as carbon capture and storage, or enabling better carbon management, such as through transparency and accounting.

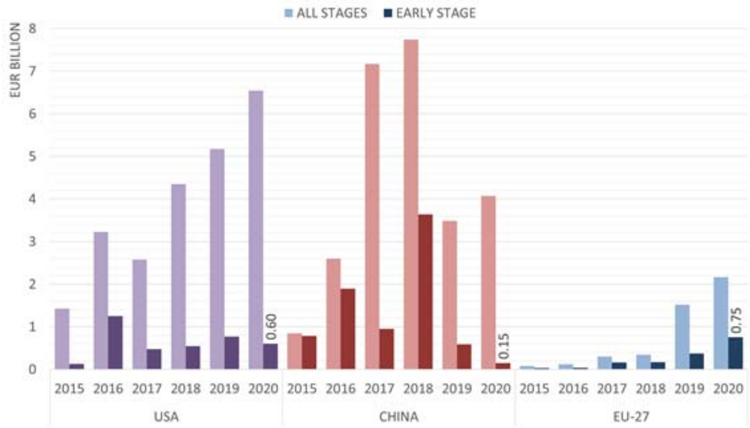
high investments in R&I[57], government action to de-risk the development, and the implementation at scale of new technologies to further stimulate private sector participation is key.

Worldwide, the climate tech domain has also proved to be resilient to the COVID-19 outbreak[58] and has remained attractive to the venture capital investments, in spite of a downward overall investment dynamic and the redirection of significant VC funding to pandemic-related industries such as pharmaceuticals and healthcare[59].

In the climate tech domain, global VC funding reached EUR 14 billion in 2020[60], increasing more than 1250% since 2010. Within this, VC investments in EU-based climate tech start-ups and scale-ups have been 11 times higher over the past 5 years than they were between 2009 and 2014, reaching about EUR 2.2 billion in 2020.

In 2020, EU firms received 16% of global VC funding in the climate tech domain (compared to only 8% of overall VC funding in all domains)[61]. At the same time, 2020 was the first year where early-stage investments in EU start-ups were higher than those in the US and China (Figure 5).

Figure 5: Venture Capital investments in Climate Tech start-ups and scale-up



Source: JRC elaboration based on PitchBook data.

However, EU-based climate tech start-ups still trail their counterparts in their ability to scale and total investments in those still range far behind the US (43%). Over the past 5 years, they

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[57] Giving rise to the notion of Deep Green start-ups: cutting edge technologies focused on addressing environmental challenges (e.g. green battery manufacturing, electric aircraft). Deep Green are at the intersection between Climate Tech and Deep Tech, defining the latter as companies building on scientific discovery in engineering, mathematics, physics, and medicine. Characterised by long R&D cycles and untested business models.

[58] IEA, World Energy Investment 2020.

[59] Bellucci, A., Borisov, A., Gucciardi, G. and Zazzaro, A., The reallocation effects of COVID-19: Evidence from Venture Capital investments around The World, EUR 30494 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76- 27082-9, doi:10.2760/985244, JRC122165.

[60] Accounting for: i) between 4 to 6% of total VC funding according to JRC elaboration based on PitchBook data and ii) PwC data based on Dealroom data.

[61] JRC elaboration based on Pitchbook data 2021.

only benefited from 6.9% of all later stage investments in climate tech start-ups, far behind the US (44%) and China (40%)[62].

The energy domain accounted for 8.2% of global climate tech VC investment between 2013 and 2019[63]. Europe (EU and UK) is investing a larger share of VC in energy solutions (23.5%) compared to the US (9.4%) and China (less than 1%), mostly in the development of core technologies for renewable energy generation (predominantly PV cells) and energy storage (batteries) to support their proliferation[64].

Barriers and opportunities in the VC ecosystem

Both the overall climate tech VC funding dynamics in the EU and the attraction of VC investors for EU energy companies are related to the number of overarching policy goals in the climate and energy areas established at EU and Member State level, together with tools supporting climate tech (e.g. fund of funds, grants and financial instruments equity and debt co-investment, R&D).

Structural barriers are still holding back the EU-based Climate Tech scale-ups compared to US and China, such as the EU's market and regulatory fragmentation that hinders growth and lead to different maturity of VC ecosystems. The difficulty in translating a strong EU research performance into innovation, the need of a clear pathway from early-stage funding to growth-stage investment, the need to develop international partnerships and cross-border funds, and the lack of patient capital can also be listed among the main challenges that must be addressed.

To this end, the Horizon Europe pillar III on "Innovative Europe" aims at supporting the development of disruptive and market-creating innovations through the European Innovation Council (EIC), as the one-stop shop to help innovators create markets, leverage private finance and scale-up their companies. Horizon Europe also supports the European Innovation Ecosystems initiative and the European Institute of Innovation and Technology (EIT). For example, EIT InnoEnergy has a portfolio of more than 250 innovative start-ups and scale-ups set to save 1.1 gigatonnes of CO2e – equivalent to one-third of Europe's 2030 carbon emissions reduction target – and EUR 9.1 billion in annual energy costs by the end of the decade[65]). The InvestEU programme as well as cohesion policy also support access to and availability of finance primarily for SMEs, but also mid-caps and other enterprises. Moreover, the European Investment Bank (EIB), and the European Investment Fund (EIF), effectively support the deep-tech development that Europe needs to achieve its sustainability goals.

Moreover, additional funding programmes, such as the Innovation Fund, the Modernisation Fund, and the Social Climate Fund, help to convey revenues from climate-related policies in support of the energy transition.

Filling the scale-up gap between EU and other major economies also requires mobilisation of private investors to participate more actively in the European VC market and in the funding of climate tech and deep climate tech start-ups[66]. As an example, the pilot EUR 100 million joint

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[62] JRC elaboration based on PitchBook data 2021.

[63] Pwc, The State of Climate Tech 2020. The next frontier for venture capital, 2020.

[64] Pwc, The State of Climate Tech 2020. The next frontier for venture capital, 2020.

[65] EIT InnoEnergy, Impact Report 2020.

[66] Deep Tech start-ups build on scientific knowledge and are characterised by long R&D cycles and untested business models. Deep Climate tech start-ups are companies using cutting edge technology to address environmental challenges.

fund established by the European Commission, the European Investment Bank (EIB) and Breakthrough Energy Ventures Europe (BEV-E) allows for the blending of institutional (risk-averse) with a VC (less risk-averse) investment approaches[67]. The EIB played a role in attracting private investment in Northvolt - the Swedish green battery company founded in 2016 - that is building the first European commercial-scale battery plant in Sweden and raised EUR 1.4 billion in financing in June 2020. EIT InnoEnergy supported the company to put together a consortium of investors and access EIB funding: the EUR 350 million loan from EIB is accompanied by EUR 886 million from private investors.

The EU taxonomy for sustainable activities provides a framework to facilitate durable investments and defines environmentally sustainable economic activities. The 2020 European Industrial Strategy package, including the EU Start-up Nation Standard within the SME Strategy, indicates that the EC will deploy new initiatives to boost the scale of VC funds, increase private investment and facilitate the cross-border expansion and scale-up of SMEs. The 2021 European Sustainable Finance Strategy aims at providing the right tools and incentives to access transition finance stressing the importance to support SMEs. The Digital Innovation and Scale-up initiative focuses on the early stage and the scale-up of innovative start-ups and deep tech SMEs in the Central, Eastern and South Eastern Europe region. Other mechanisms to increase the take-up and scale-up of innovative solutions include the Connecting Europe Facility and the cohesion policy funds.

Streamlining these mechanisms in the right way and making use of synergies across instruments can lead to a further flourishing of EU climate tech start-ups, enhancing and accelerating VC funds' support across all sectors, thus strengthening the link between technological innovation and implementation.

3. FOCUS ON KEY CLEAN ENERGY TECHNOLOGIES AND SOLUTIONS

The following section assesses the competitiveness of selected technologies relevant in the context of the package of legislative proposals adopted by the European Commission in July 2021 to deliver on the European Green Deal.

This report focuses first on wind and solar power that are projected to show the higher relative growth up to 2030. The analysis then looks into electricity storage technologies, such as batteries and renewable hydrogen, given their critical importance for increasing the overall flexibility of the energy system, while optimizing the market integration of renewable electricity. In the context of electrification of our societies, the study investigates the competitiveness of heat pumps, given their high value in helping decarbonise the buildings sector. The report also looks at the renewable fuels, which are needed to facilitate the decarbonisation of certain transport modes. Finally, smart grids are analysed as a horizontal technology which will facilitate the combination of different technologies. Each technology is firstly assessed through its current situation and outlook, then through an analysis of its value chain, and finally through an analysis of its global market.

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[67] The European Commission, European Investment Bank and Breakthrough Energy Ventures establish a new EUR 100 million fund to support clean energy investments (eib.org)

3.1 Offshore and onshore wind

Technology Analysis

In 2020, the EU installed 10.5 GW of wind power capacity (both onshore and offshore), bringing its cumulative wind power capacity to 178.7 GW[68]. Offshore wind energy alone has surged from 1.6 GW cumulative capacity in 2010 to 14.6 GW in 2020[69]. Current national targets as expressed in the NECPs suggest that the offshore renewable energy targets for 2030 (at least 60 GW) can be achieved. Most of the offshore wind installations deployed until 2030 will be in the North Sea (47 GW), yet substantial capacities can be expected in other sea basins particularly in the Baltic Sea (21.6 GW), the Atlantic Ocean (11.1 GW), the Mediterranean Sea (2.7 GW), and the Black Sea (0.3 GW). The move to new sea basins will require further developments of floating technology and the development of port infrastructure. Building the future offshore grid around hybrid projects[70], in cases where they can reduce costs and use of maritime space will also be important to step up offshore wind deployment.

Following current projections on the future costs of bottom-fixed offshore wind, levelised costs of electricity (LCoE) in the range of EUR 30-60 per MWh are expected by 2050 (similar to onshore installations)[71].

For onshore wind, a reduced annual addition observed since 2018, originates from moderate deployments in Germany due to complex permitting rules and potential exposure to legal challenges. The age structure of the EU onshore and offshore wind fleet indicates that repowering will play a crucial role in the coming years. Replacing wind turbines at end of life with new turbines, or lifetime extension through upgrading some of the components presents an opportunity for modernising the assets, using the resource at the best wind sites and may improve social acceptance, as existing turbine locations remain in use, preserving local jobs and revenues for local municipalities. However, the decommissioning and renewal of current wind energy installations represents a challenge in terms of resource efficiency, supply of raw materials and waste production, because many components of the current wind turbines cannot be reused or recycled yet. Circularity of wind mills still requires R&I and deployment efforts. Wind asset owners’ choice between decommissioning and the different repowering options is influenced by electricity prices, support schemes and permitting procedures. The current share of total electricity generation for onshore wind is 13.7% (2020). The 2030 Climate Plan scenarios project a production of 847 TWh of onshore wind in 2030 (share of total electricity generation: 27.3%), and 2 259 TWh in 2050 (share: 32.9%)[72].

Over the last decade, private R&I spending in wind technology held a constant level between EUR 1.6 billion and EUR 1.9 billion per year[73]. It topped public R&D investments tenfold during this period.

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[68] JRC based on GWEC, 2021.

[69] JRC based on GWEC, 2021.

[70] A so-called offshore hybrid asset has dual functionality, combining transport of offshore wind energy to shore (for consumption) and interconnectors. See Recital 66 of Regulation 2019/943 on the internal market for electricity, as well as COM(2020) 741 final., page 14.

[71] Beiter P., Cooperman A., Lantz E., Stehly T., Shields M., Wiser R., Telsnig T., Kitzing L., Berkhout V., Kikuchi Y. (2021) Wind power costs driven by innovation and experience with further reductions on the horizon, WIREs Energy Environ. 2021.

[72] EC CTP-MIX.

[73] WindEurope, 2021.

With 57% of the share in the period 2015-2017, the EU is a global leader in high value patents in wind energy technologies. Shares of other major economies include the US with 18%, Japan with 11%, China with 5%, and Korea with 1%[74]. Top global high value patent countries between 2015 and 2017 were Denmark, Germany, US, Japan, and China. Major EU Original Equipment Manufacturers (OEMs) file most of the high value patents, yet experiencing a decrease since 2012, due to strong performance in high-value patents by major companies from the US (e.g. General Electric) and Japan (e.g. Mitsubishi Heavy Industries, Hitachi). EU Research organisations active in wind energy are among the most recognised in the field. In terms of citation impact, 9 organisations within the Top 20 are in the EU.

Value Chain Analysis

Wind based energy production is a strategic industry for Europe. It is estimated that this sector offers between 240 000 and 300 000 jobs[75]. Most European manufacturing facilities are in the country of the company's headquarter or countries with increased wind energy deployment. 48% of active companies in the wind sector are headquartered in the EU. 214 operational manufacturing facilities are located in the EU (26 % of all global facilities)[76]. In 2018 the wind energy value chain in the EU produced a turnover of EUR 36 billion[77].

The EU wind sector has shown its ability to innovate. The EU is leading in the parts of the value chain dealing with sensing and monitoring systems for onshore wind turbines, including research and production. Also, the EU wind industry has high manufacturing capabilities in components with a high value in wind turbine cost (towers, gearboxes and blades), as well as in components with synergies to other industrial sectors (generators, power converters and control systems).

However, efforts are still needed to improve the circularity of the wind energy components. We also need research on the cumulative impacts of offshore wind in ocean ecosystems.

Global Market Analysis

Among the top 10 Original Equipment Manufacturers (OEMs) in 2018, European OEMs led with 43% of market share, followed by the Chinese (32 %) and North American (10 %) companies. The European OEMs in the wind energy sector held a leading position in the last few years. In 2020, they were surpassed for the first time by Chinese OEMs (EU: 28%; China: 42%)[78], which can be explained by a surge in new installations in the Chinese wind market following China's shift from Feed-in-Tariffs towards a tender-based support scheme.

The EU has had a positive trade balance in wind energy related equipments in the last 20 years. Yet there is some stagnation in the growth of this indicator[79]. This is in part a consequence that other economies are catching up on the EU's early mover advantage, but also partially due to third country policies aimed at protecting their domestic market or forcing EU companies to localise production capacity (e.g. through local content requirements). To illustrate, exports of

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[74] JRC based on European Patent Office Patstat.

[75] WindEurope, 2021.

[76] WindEurope, 2021.

[77] JRC, commissioned by DG GROW, European climate-neutral industry competitiveness scoreboard (CIndECS) (Draft, 2021). IEA codes: 32 Wind Energy.

[78] When analysing the Top10 OEMs in terms of market share. GWEC, Global Offshore Wind Report 2020, 2020.

[79] JRC based on Eurostat (Comext).

wind generating sets to China have fallen drastically since 2007 after the introduction of a supportive policy framework for their domestic industry, and have not recovered. On the opposite, 21% of Chinese wind-related exports in 2018 were destined for the EU market, representing just under 10% of the EU market.

Since 2016, earnings before interest and taxes (EBIT) margins of EU OEMs are declining due to high competition in turbine orders particularly in the period 2017-2018 and increased material costs for main turbine components. Despite the record year in 2020 installations[80], these factors were further intensified through the impact of Covid-19 which created logistic challenges for all manufacturers.

Many of the critical raw materials for wind generators are imported from China[81] and more generally face concentration of the upstream supply chains. Potential future material supply challenges would pose a potential risk to EU wind energy production industry. Environmental concerns have also been raised, related to the composite blades of installations reaching their end of life as these are still difficult to recycle. In line with the Commission's 2020 Action Plan on Critical Raw Materials[82], actions are underway to diversify the supply of critical raw materials from both primary and secondary sources and improve resource efficiency and circularity while promoting responsible sourcing worldwide. Circularity, including re-use, recycling, and substitution are moreover priority areas of innovation to abate these risks while improving the overall sustainability of the sector and are included in the 2021-2022 Work Programme of Horizon Europe. The European wind industry has also committed to reusing, recycling or recovering 100% of decommissioned blades, and is aiming to develop a roadmap for further accelerating wind turbine blade circularity[83].

The EU has commercialised 42% of the global offshore wind market, with a cumulative installed capacity of 14.6 GW in 2020. Within the next decade, it is expected that Europe will maintain its leadership position in annual growth of offshore wind. Yet China, Asia Pacific and North America are expected to develop a significant market share (i.e. installed capacity) of the offshore wind segment[84] in the coming years. With respect to onshore wind, China will remain the largest market (average annual market share of about 50% in the period 2020-2025) followed by Europe (18%), North America (14%) and Asia (excluding China) (8%).

European offshore manufacturing at ports (6-8 GW/year current estimated production capacity) will need to grow substantially to serve annual capacity additions up to an estimated 16 GW to satisfy the demand in the period 2030-2050[85].

3.2 Solar Photovoltaic (PV)

Technology Analysis

Solar photovoltaics emerges as a very large and innovative industry, growing with unexpected speed. This is the combined result of an accelerated technology development, deployment

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[80] Global Wind Energy Council, Global Wind Report, 2021.

[81] European Commission, Critical Raw Materials in strategic technologies and sectors – a foresight study, 2020.

[82] COM (2020) 474 final. Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability.

[83] Wind industry calls for Europe-wide ban on landfilling turbine blades | WindEurope.

[84] GWEC, Global Offshore Wind Report 2020, 2020.

[85] JRC Wind manufacturer database,2021, and WindEurope, 2020.

policies and implementation of large-scale manufacturing facilities with low costs, mostly in Asia. The technology is central to future climate neutral electricity generation systems.

More than 3.1 TW of photovoltaic power capacity are projected to be installed - globally - in 2030 and about 14 TW in 2050. The investment required in the 2020-2050 period for the additional solar power capacity is estimated at about USD 4.2 trillion[86]. In the EU, 0.4 TW of solar photovoltaic capacity is projected to be installed by 2030 (estimated to reach almost 160 GW by 2021) and 1 TW by 2050[87,88]. Scenarios from the industry itself project even larger penetration[89].

The residential systems, predominant five years ago in the EU, are now second (25.4%), after the utility scale segment (30.5%), in terms of share of installed capacity. After peak investments in 2011, the EU total public investment in photovoltaic research development and demonstration has declined and is now below the level it was at the beginning of the decade[90].

Over the last year, the EU has slipped from second in high value inventions (after Japan) to third (after Japan and Korea)[91]. If the current trend continues, Chinese "high value" inventions will soon also surpass the EU. In terms of viability of EU manufacturing, cell, and module design, particularly, tend to become increasingly complex, requiring further investments to remain at the cutting edge.

Value Chain Analysis

The EU is a global leader in several parts of the photovoltaic value chain: research and development, polysilicon production, equipment and machinery for PV manufacturing[92].

The EU hosts one of the leading polysilicon manufacturers. Furthermore, EU companies are more competitive in the downstream part of the value chain with key roles in the monitoring and control, and balance of system segments, especially inverter and solar trackers manufacturing. European companies have also maintained a leading position in the deployment segment.

On the other hand, the EU has lost its market share in solar cells and module manufacturing. In case of a revival of an European silicon solar cell and module manufacturing industry, which looks not too unrealistic, given the current number of possible projects, the dependence on some critical raw materials like boron, gallium, germanium and indium would need attention at the supply chain. A recent study[93] shows that the EU has the best performance in terms of the energy produced compared to that used in manufacturing and operating photovoltaic systems, followed by China and the US. Similarly the EU also has the lowest carbon intensity for the energy produced by PV systems, followed by USA and then China. The EU also has the highest energy return on carbon, while China has the worst performance, and the US are in the middle[94].

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[86] EC CTP-MIX.

[87] IEA, WEO 2020 Sustainable Development Scenario.

[88] International Renewable Energy Agency (IRENA), World Energy Transitions Outlook: 1.5°C Pathway, 2019.

[89] https://www.solarpowereurope.org/wp-content/uploads/2020/04/SolarPower-Europe-LUT_100-percent-Renewable-Europe_mr.pdf?cf_id=11789

[90] JRC 2021, based on IEA data.

[91] JRC 2021, based on EPO Patstat.

[92] BNEF, Solar PV Trade and Manufacturing, A Deep Dive, 2021.

[93] F. Liu and J.C.J.M. van den Berg, Energy Policy 138 (2020) 111234.

[94] F. Liu and J.C.J.M. van den Berg, Energy Policy 138 (2020) 111234.

This latter indicator reflects the carbon intensity of the production cycle of the electricity used in the manufacturing processes.

In 2018, 109 000 direct and indirect jobs in photovoltaics are reported in the EU, with a 42% increase between 2015 and 2018[95]. The preliminary results of a more recent study indicates about 123 000 direct and 164 000 indirect full-time jobs in the EU PV industry, in 2020, for a total of 287 000 jobs[96].

From the job skills perspective, the photovoltaic sector employs a highly educated work force in the areas of R&D, polysilicon and wafer production and cells and module manufacturing. EPC (engineering, procurement and construction), O&M (operation and maintenance), decommissioning and recycling are also demanding activities in terms of skills required.

Global Market Analysis

With the increase of PV system installations, the trade deficit for the EU for the import of solar modules has started to increase again since 2016, after it had declined between 2011 and 2016, due to a shrinking deployment of PV systems. It has grown to more than EUR 5.7 billion in 2019. This imbalance reflects the volume of the imports, as the exports have not changed dramatically over the years. EU solar photovoltaic imports are strongly dependent from Chinese and other Asian companies[97].

The polysilicon, ingots, and wafer production together with the solar cells and modules manufacturing currently have a global value of about EUR 57.8 billion. The EU’s share (12.8%) corresponds to EUR 7.4 billion. This share is mostly due to the polysilicon production. Almost all of the growth in manufacturing of photovoltaic cells and modules has taken place outside the EU[98]. With market demand accelerating in Europe and around the world, and new production technologies emerging, European manufacturers are showing a renewed interest in setting up production capacity within the EU based on the latest technologies. In that respect, the European Commission’s updated European Industrial Strategy[99] welcomed efforts of the industry-led European Solar Initiative to scale up manufacturing of solar photovoltaics. Several projects are already taking off in the EU for manufacturing wafers, solar cells and modules. The European Commission will publish a communication on solar energy in 2022.

The role of prosumers and energy communities

The take up and production of renewable energy such as solar photovoltaic but also energy efficiency can be strengthened by energy communities which allow consumers to take an active role in the energy market. Today, at least two million European citizens collectively engage in more than 8 400 energy communities, having realized a minimum of 13000 projects since 2000[100]. Current total renewable capacities installed by energy communities in Europe can be estimated at least as high as 6.3 GW, contributing typically about 1-2% to the nationally

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[95] JRC 2021, based on EurObserv'ER data.

[96] Solar Power Europe, Solar PV job market study for the European Union, 2021.

[97] JRC Report: EU energy technology trade - https://publications.jrc.ec.europa.eu/repository/handle/JRC107048

[98] JRC PV Snapshot 2021.

[99] Updating the 2020 New Industrial Strategy: Building a stronger Single Market for Europe’s recovery, COM(2021) 350 final.

[100] Schwanitz, V. J., Wierling, A., Zeiss, J. P., von Beck, C., Koren, I. K., Marcroft, T., … Dufner, S. (2021, August 22). The contribution of collective prosumers to the energy transition in Europe - Preliminary estimates at European and country-level from the COMETS inventory. https://doi.org/10.31235/osf.io/2ymuh.

installed capacities, the top contribution is as high as 7% in the case of Belgium. The lion's share of installed capacities is taken by solar PV, followed by onshore wind. A conservative estimate of the total invested finances amounts to at least EUR 2.6 billion[101].

Today, energy communities are organized in various legal forms. Areas of activities, technology portfolios, size, and membership structures differ. Currently, energy communities raise technology awareness and acceptance, promote energy efficiency, produce and distribute renewable-based electricity and heat, provide services around e-mobility, and run energy consulting services. They experiment innovatively with business models and self-sufficiency concepts for the benefit of local communities. The continuation and extension of energy communities in Europe depends on favourable legislation and financial incentives as well as on the competitiveness of technologies that are accessible to citizens.

Whilst the EU policy frameworks aim to trigger the development of energy communities across the EU[102], including across borders, much will depend on how Member States will implement the enabling framework for these types of models[103]. The National Energy and Climate Plans (NECP) framework already has a requirement for Member States to report on renewable energy communities, however only a few Member States included quantitative targets and concrete measures for the development of energy communities in their NECPs. In order to boost the development of energy communities in the sense of the EU Directive, the Commission is in the process of setting up an Energy Community Repository which will contribute to the dissemination of best practices and provide technical assistance for the development of concrete energy community initiatives across the EU.

Similarly as for energy communities, the EU framework will support the uptake of self-consumption (i.e. prosumers), with the requirement to enable individual and collective self-consumption and the exemption from network tariffs. Again, much will depend on the design of the legal framework, applicable network tariffs and taxes, and single points of information to stimulate collective self-consumption in multi-level apartment buildings - and beyond, if Member States decide to do so. Legal constraints and unfavourable taxation can pose serious barriers to the uptake of self-consumption.

3.3 Heat pumps for building applications

Technology Analysis

Heat pumps for building applications[104] are mature, commercially available products. They can be classified according to the source from which they extract renewable energy (air, water or ground), the heat transfer fluid they use (air or water), their purpose (space cooling / heating, domestic water heating) and the market segments targeted (residential, light commercial and heat networks).

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[101] Ibid.

[102] Including in making financial support available such as through cohesion policy

[103] Consisting of the Renewable Energy Directive II and the Electricity Market Directive. Both Directives set the conditions for Member States to include options for cross-border implementation of energy communities in their national transpositions.

[104] Industrial heat pumps are not in the scope of this report.

Heat generation by heat pumps has been growing at 11.5% per year over the last 5 years in the EU, reaching 250 TWh in 2020[105]. This trend is to increase because electrification of heating will be a key contributor to the building sector path to climate neutrality.

Heat pumps are very efficient; their typical seasonal coefficient of performance of 3 means that for each kWh of electricity consumed, 3 kWh of heat are generated[106]. Consequently, the operation of a heat pump for building heating may only be cost effective compared to gas boilers, if the electricity to gas price ratio is not higher than 3. This ratio varies greatly, from 1.5 to 5.5 between Member States[107], often due to higher taxes and charges on electricity with respect to fossil fuels and the lack of internalisation of the external cost of greenhouse gas emissions in the gas/oil prices. These issues are addressed by the policy package presented in July 2021 to deliver on the European Green Deal, specifically by the amendment proposals for the Energy Taxation Directive and the introduction of a new emissions trading for the building and road transport sectors.

The heat pumps sector is characterized by a global and competitive market, where innovation is of key importance. The adaptations to evolving EU climate and environmental regulations and strategies are competing with the improvement of products performances and costs in the small, medium or large enterprises of the EU, where R&D capacities are limited. Nevertheless, they offer opportunities for industry to propose innovative products.

Over the 2011-2021 period, out of the highly cited scientific publications on heat pump technology, more than 37% belong to the EU, followed by China (23%) and the USA (20%). The EU is also leading in inventions in the ‘mainly-heating heat pumps for buildings applications’: over the period 2015-2017, 42% of high-value inventions were filed in the EU, followed by Japan (20%), US (8%), South Korea (7%) and China (4%)[108].

Building on this knowledge and innovation base, the EU research institutions and industry have the capacity to propose innovations. Over the period 2014-2020, heat pump projects for building applications represented a total funding of EUR 146.8 million under Horizon 2020, the EU R&I programme. The largest share was dedicated to the integration of heat pumps with other renewables (60.9%), compared to the development of heat pumps for residential applications (6.5%) and for district heating applications (32.6%).

Value Chain Analysis

According to EurObserver[109], the turnover of heat pumps in EU amounted to EUR 26.6 billion in 2018, growing by 18% compared to 2017. In parallel, the direct and indirect jobs amounted to 222 400 in 2018, growing by 17% versus 2017. These data include all types of heat pumps, including air-to-air heat pumps used only for cooling or for heating and cooling, which represented 86% of the units sold in 2019.

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[105] European Heat Pump Association database.

[106] The coefficient can be lower or higher depending on climate zone, heat source nature and temperature.

[107] Energy prices and costs in Europe, COM(2020) 951 final.

[108] JRC, based on EPO Patstat, CPC codes: Y02B 10/40, 30/12, 30/13, 30/52.

[109] EurObserver, The state of renewable energies in Europe, 2019.

From the skills perspective, the heat pump sector employs a well-educated work force in the areas of R&D, components and heat pump manufacturing, thermo-technical engineers and geologists, installers (including drillers) and service & maintenance.

Global Market Analysis

Asia and America are dominating exports in the residential air conditioning market[110] of air-to-air heat pumps. The unbalance is less pronounced when considering reversible air conditioners[111]: Asian countries are still leading, followed by European countries. When considering 'mainly-heating heat pumps'[112], EU countries are leading exports, followed by Asia. However, over the last 5 years, the EU market growth of 'mainly-heating heat pumps' has been captured by the imports from Asia, growing at an average annual rate of 21% from 2015 to 2020. Therefore, the trade balance has been degrading from a surplus of EUR 249 million in 2015 to a deficit of EUR 40 million in 2020.

Based on projections from the EU long-term strategy[113], sales of heat pumps are expected to increase rapidly until 2030 in the EU for electrification in the building heating sector, followed by a slower penetration growth thereafter. The faster penetration in the EU front runner market is an opportunity for the EU industry to grow and develop competitive production until 2030, then to seize the sustained growth globally, as projected by the IEA[114].

The high costs in Europe are partly attributable to a high level of fragmentation and nationally focused markets. In some cases, national laws differ, notably on product approval requirements and permitting rules. Better marketing and distribution networks in the EU and outside, and potentially more cooperation with partners with relevant competences, would contribute to increase the competitiveness of EU companies. Nevertheless, recognising the significant role of heat pumps in the energy system integration, the Commission announced to further promote the use of heat pumps in its Renovation wave Communication[115]. The Commission will also seek to increase the role of heat pumps in the flexibility of the energy systems, for example with the development of a network code on demand-side flexibility.

3.4 Batteries

Technology Analysis

This report focuses on lithium ion (Li-ion) battery technology, given its importance to electro-mobility, which dominates demand for batteries related to clean energy transition[116]. In the wider energy system, stationary batteries will be critical as an energy storage mean, enabling high contribution to the energy from intermittent renewable sources in the electricity mix. In addition, the interaction of electric vehicles with the electricity grid has great potential to be exploited).

In 2020, Electric Vehicles (EVs) became cost competitive in more than 50% of the total European automotive market, based on the total cost of ownership. Li-ion EV battery average

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[110] UN-COMTRADE 8415 'air conditioning machines'.
[111] UN-COMTRADE 841581 'air conditioning machines incl. a valve for reversal "reversible heat pumps'.
[112] UN-COMTRADE 841861 'heat pumps, excluding air conditioning machines of heading 8415'.
[113] In-depth analysis in support of Long Term Strategy COM(2018) 773 final.
[114] IEA, Net zero by 2050, May 2021.
[115] A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives, COM(2020) 662 final.
[116] Avicenne energy, EU battery demand and supply (2019-2030) in a global context, 2021.

pack prices have fallen 89% in real terms since 2010 to USD 137 per kWh (EUR 115 per kWh) in 2020. By 2023, average pack prices are projected to be USD 101 per kWh and by 2027 purchase price of EVs are expected to be less than conventional cars[117].

Average battery energy density of EVs is rising at 7% per year[118], while average battery pack size across electric light-duty vehicles (electric only and hybrid) increased from 37 kWh in 2018 to 44 kWh in 2020, the battery for pure electric cars in most countries is in the 50-70 kWh range[119]. Trends in growing car size threaten energy efficiency gains and availability of critical raw materials.

Deployment of battery technology in the EU has reached historic highs, with 2020 EV sales of 10.5% of the car market (an increase from 3% in 2019)[120], yet there is a strong disparity within the EU, with EV sales ranging from 0.5% in Cyprus to 32% in Sweden. The number of EVs on the road doubled to more than two million in the EU in course of 2020, an equivalent of more than 60 GWh storage capacity. By 2030, over 50 million EVs are expected on EU roads[121].

The nascent stationary battery market in the EU grew roughly to 1.3 GWh in 2020, with a cumulative installed capacity of roughly 4.3 GWh (mostly Li-ion batteries)[122]. Promoting self-consumption has gained Germany two-thirds of the European residential battery storage market (2.3 GWh)[123]. By 2030 stationary batteries may store nearly as much as pumped hydro storage today, measured in energy throughput Li-ion batteries can efficiently provide storage for up to 5 hours, while emerging technologies, including flow batteries, can better cater for longer storage durations.

In view of additional cost elements, system cost of grid scale Li-ion applications is between EUR 300 and EUR 400 per kWh, while the cost of home storage systems is roughly double. Reducing battery energy system cost to half the current price is key for mass deployment throughout Europe[124].

Two multi-billion Important Projects of Common European Interest (IPCEI)[125] involving 12 Member States and dozens of companies and research organisations display increasing priority of batteries in R&I funding. The EU, in turn, has earmarked EUR 925 million for the Batteries Partnership under Horizon Europe over the 2021-2027 period.

Value Chain Analysis

Despite rising interest in mining projects in Europe, especially in lithium and natural graphite as far as the minerals of relevance for batteries are concerned, supply of both primary and secondary battery raw materials requires major upscaling to keep up with the rising demands for battery materials[126]. The EU is highly dependent on international trade for supply of cobalt,

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[117] BloombergNEF, Electric Vehicle Outlook 2021, 2021.

[118] BloombergNEF, Electric Vehicle Outlook 2021, 2021.

[119] IEA, Global EV outlook 2020, 2021.

[120] Transport and Environment, CO2 targets propel Europe to 1st place in e-mobility race, 2021.

[121] Central MIX scenario of the Fit for 55 proposals.

[122] EASE, EMMES 5.0 market data and forecasts electrical energy storage, 2021.

[123] Solar Power Europe, European market outlook for residential battery storage 2020-2024, 2020.

[124] Batteries Europe, WG on stationary integration, 2021.

[125] IP/21/226: https://ec.europa.eu/commission/presscorner/detail/en/IP_21_226.

[126] Aperio Intelligence Ltd. – commissioned by Eurobattery Minerals, Critical materials and e-mobility, 2021.

lithium and graphite and those materials are on the EU list of critical raw materials[127]. Although the supply of nickel is more diversified, the EU relies on imports of the high-purity material necessary for battery production with a share of ~56%. Future anode and cathode materials such as silicon, titanium and niobium are also on the EU list of critical raw materials[128].

Other than cobalt refining (second after China), the EU generally holds a weak position in battery related materials refining. While the EU has strong players in cathode materials field, the EU is still a net importer of cathode materials from Asia. Battery cell production capacity is projected to approach 400 GWh and largely satisfy domestic demand by 2025[129].

As of 2021, EU subsidiaries of foreign, mostly Korean companies, encompassed 44 GWh Li-ion cell production capacity[130]. In the meantime, 10 EU headquartered companies will start Li-ion cell production in the coming years. Leading world producers are also establishing factories in the EU. Li-ion cell production capacities are growing in the EU, amounting to 6% of global capacity as of 2021[131], up from 3 % in 2018. European producers maintain a strong position in Li-ion niche applications, but continue to depend on Asian companies for battery-cell-production equipment[132].

The EU has its strongest role in final products. All EU automotive companies embraced the switch to e-mobility, one even aiming to sell 1 million electric cars in 2021. EU has a number of recyclers, but with limited capacities. Currently, batteries are mostly sent to Asia at end of life[133]. Once the supportive framework of the new Battery Regulation[134] is in place, Europe can become the leader in the circular economy of batteries – from mining to recycling. A growing value chain requires more effort in education and training, as 800.000 direct jobs and from 3 to 4 million jobs in total will be created by 2025[135]. To this end, the EU has launched the EBA250 Academy.

Global Market Analysis

China controls 80% of the world's battery raw material refining capacity, 77% of cell production capacity and 60% of battery component manufacturing capacity[136]. EU trade deficit in Li-ion batteries was EUR 3.6 billion in 2018 and EUR 4.2 billion in 2019. Most of the battery cells were still imported in 2020 and all leading battery producers were non-European (but several of which having manufacturing in the EU). In 2020, Li-ion battery global market roughly amounted to USD 40-47 billion[137]. With investment projects under way, by 2025, the EU is set to become the second largest battery cell producer in the world, behind China.[138]

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[127] European Commission, Internal Market, Industry, Entrepreneurship and SMEs https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

[128] European Commission, Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis, 8 October 2021.

[129] IP/21/1142: https://ec.europa.eu/commission/presscorner/detail/en/speech_21_1142

[130] EBA 250.

[131] EBA250; US Department of Energy, National blueprint for lithium batteries 2021-2030, 2021.

[132] Decisive Market Insights, Lithium battery manufacturing equipment market report, 2021.

[133] EBA250.

[134] COM(2020) 798/3 final.

[135] IP/21/1142: https://ec.europa.eu/commission/presscorner/detail/en/speech_21_1142

[136] Marian Willuhn, National lithium-ion battery supply chains ranked, PV Magazine, 16 September 2020.

[137] Avicenne energy, EU battery demand and supply (2019-2030) in a global context, 2021.

[138] Fraunhofer ISI, Li-ion Battery cell production capacity to be built up, April 2021; Benchmark Minerals, Li-ion battery cell capacity by region, 2021.

The EU only had a slight trade deficit in electric cars in 2020, while exports grew faster than imports[139]. Simultaneously, EU automotive companies expand their production facilities in Asia and the US competing with companies there. The EU also has strong players in the stationary storage market: e.g. including global leaders in grid-scale applications and residential storage market.

In electric bus production and deployment, the EU is lagging far behind China which has already electrified 60% of its bus fleet. Only 1 714 electric buses were sold in EU in 2020[140] compared to 61 000 in China[141].

3.5 Renewable hydrogen production through electrolysis

Technology Analysis

Renewable hydrogen obtained through water electrolysis (also called Renewable Fuels of Non Biological Origin) has the potential to decarbonize hard-to-electrify and hard-to-abate sectors such as industry and heavy-duty transport, and to contribute to energy services such as seasonal storage. The main technology challenge includes the energy efficiency losses associated with converting renewable power into hydrogen, as every unit of renewable hydrogen produced requires 1.5 unit of renewable electricity. This requires massive amounts of renewable energy, mainly wind and solar, as well as the costs of renewable power to decline to make it competitive with fossil-based hydrogen.

The current EU industrial demand for hydrogen of about 7.7 million tonnes per year[142] is largely produced from fossil fuels. Hydrogen produced from water electrolysis is estimated to be less than 1% of the overall production[143]. The EU's current 2030 objective is to install 40 GW of electrolysers, to produce up to 10 million tonnes of renewable hydrogen per year[144]. By 2050, electrolyser capacity forecasts for the European market range from 511 GW[145] to 1 000 GW[146].

Some key performance indicators (KPIs) for water electrolysers are summarized below for different technologies: Alkaline, Polymer Electrolyte Membrane (PEM), Anion Exchange Membrane (AEM), and Solid Oxide (SO) Electrolysers. Anion Exchange Membranes do not have the same level of maturity as the other technologies (still in development but available for limited commercial use). Solid Oxide Electrolysis is starting to be deployed for demonstrations. Alkaline and Polymer Electrolyte Membrane (PEM) are fully commercial technologies.

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[139] Eurostat, 2021. Data retrieved: https://ec.europa.eu/eurostat/web/products-eurostat-news/-/ddn-20210524-1

[140] ACEA, Medium and heavy busses (over 3.5t) new registrations by fuel type in the EU, 2020.

[141] https://insideevs.com/news/481987/ev-buses-sales-2020-china-byd-yutong/

[142] Fuel Cell Observatory: https://www.fchobservatory.eu/observatory/technology-and-market/hydrogen-demand

[143] In addition, 2%-4% is estimated to come from Chlor-Alkali Electrolysis.

[144] A hydrogen strategy for a climate-neutral Europe, COM(2020) 301 final.

[145] A Clean Planet for all. A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy, COM(2018) 773 final.

[146] Kanellopoulos, K., Blanco Reano, H., The potential role of H2 production in a sustainable future power system - An analysis with METIS of a decarbonised system powered by renewables in 2050, EUR 29695 EN,Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-76-00820-0, doi:10.2760/540707, JRC115958.

Table 1 Key Performance Indicators for the four main water electrolysis technologies in 2020 and projected in 2030. Stack degradation is defined as percentage efficiency loss when run at nominal capacity.

	2020				2030			
	Alkaline	PEM	AEM	SO	Alkaline	PEM	AEM	SO
Characteristic Temperature [°C]	70-90*	50-80*	40-60*	700-850*	-	-	-	-
Cell Pressure [bar]	<30*	<70*	<35*	<10*	-	-	-	-
Efficiency (system) [kWh/kgH2]	50	55	57*	40	48	50	<50*	37
Degradation [%/1 000h]	0.12	0.19	-	1.9	0.1	0.12	-	0.5
Capital Cost Range [€/kW - based on 100 MW production]	600	900	-	2700	400	500	-	972

Source: Addendum to the Multi - Annual Work Plan 2014 – 2020, FCH JU, 2018 and for parameters labelled with '', DG ENERGY (European Commission) elaboration based on IRENA data from the "Green Hydrogen Cost Reduction" report", 2020.*

The Fuel Cell and Hydrogen Joint Undertaking (FCH JU) invested about EUR 150.5 million since 2008 in Electrolyser technologies development (EUR 74.7 million for research actions and EUR 75.9 million for Innovation Actions). The main beneficiary countries have been Germany, France and the UK with about EUR 31, 25 and 18 million respectively. The Horizon 2020 Green Deal Call made circa EUR 90 million funding available for three project consortia to develop and operate 100 MW electrolysers in real life environments. While Japan has been patenting consistently in this technical area for many years, in other regions (in particular China) the number of inventions related to electrolysers has steadily increased in recent years. For electrolysers, Europe (including UK) files proportionally higher numbers of International Patent Families (patent applications filed and published at several international patent offices) than other leading economies[147].

Value chain analysis

It is difficult to have accurate information on renewable and low-carbon hydrogen related value chains and their predicted growth, but the work of the European Clean Hydrogen Alliance with its over 1 500 members points to a very dynamic and rapidly developing sector. To date, the European Clean Hydrogen Alliance has already collected information on projects for about 60 GW of electrolyser by 2030, out of which the large majority are to be powered by renewable electricity.

The electrolysis market shows strong potential for development. An overview of the manufacturers of medium to large scale electrolysis systems, reporting only manufacturers of commercial systems and not considering manufacturers of laboratory-scale electrolysers, shows that Europe has a strong international position for both alkaline and PEM electrolysis and a very strong position for SO electrolysis, while the only AEM manufacturer is also located in the EU[148]. The large-scale deployment of these electrolysers will depend inter alia on the availability of renewable and low carbon electricity required for the production of renewable and low carbon hydrogen, as well as other factors such as increasing the number of operational hours of electrolysers and reduction of electricity prices.

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[147] JRC based on European Patent Office, EPO Patstat data, 2020 and https://iea.blob.core.windows.net/assets/b327e6b8-9e5e-451d-b6f4-cbba6b1d90d8/Patents_and_the_energy_transition.pdf.

[148] A. Buttler, H. Spliethoff, Renewable and Sustainable Energy Reviews 82 (2018) 2440–2454 updated with IRENA Green Hydrogen Cost Reduction, 2020.

Global Market Analysis

The EU has established a technological lead in electrolysis and associated technologies but so far still has a relatively small production of electrolysers that, however, is expected to grow significantly in the coming years. Around 30 raw materials are needed for producing fuel cells, electrolysers and hydrogen storage technologies. Of these materials, 13 materials are deemed critical for the EU economy according to the 2020 Critical Raw Materials list (electrolysers not included in the assessment)[149]. In particular PEM electrolysis, requires the use of noble metal catalysts like iridium for the anode and platinum for the cathode, both of which are mainly sourced from South Africa; while SO electrolyser require rare earth metals, which are mainly coming from China.

3.6 Smart grids (distribution grid automation, smart metering, Home Energy Management Systems and smart EV charging)

The take-up of smart grid technologies is expected to remain a robust trend during this decade and beyond, in close correlation with electrification, decentralisation and the need for improved grid reliability and operating efficiency and increasing investments to upgrade aging grid infrastructure. Technologies such as smart metering, automation or electrification of mobility will each contribute with around 8% of the estimated investment in EU and UK in power distribution grids until 2030[150]. It is widely anticipated that markets for associated digital services will also continue to grow. This section analyses four areas of digital technologies and services that are particularly important for the EU's ambitions in relation to buildings and mobility, namely distribution grid automation, Home Energy Management Systems (HEMS), smart meters, and smart charging.

Technology analysis

Distribution automation and smart metering can rely on mature, market-ready devices and software, whose deployment has been ongoing for a decade. For instance, by the end of 2020, almost 150 million smart meters were installed in the EU, Norway, Switzerland and UK (49% average penetration rate). This number is expected to grow to almost 215 million by 2025 (69% penetration rate)[151] with the second wave technology focussing more on decentralization and services to consumers.

On the other hand, HEMS and smart charging are in early take-up, with still many promising research projects running in the EU and elsewhere advancing the state of the art of the technology and influencing this early growth. Standardisation, interoperability and cyber security are common challenges across the board for all technologies and risk slowing the up-take in an often fragmented market.

Value chain analysis

The value chain of the four technologies is made of a combination of hardware, software and services providers. This contributes to the fragmentation of EU value chains among many players, especially in the area of HEMS and smart charging. The distribution automation and smart metering value chains, on the other hand, are more concentrated. In distribution

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[149] CRMs_for_Strategic_Technologies_and_Sectors_in_the_EU_2020.pdf (europa.eu).

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

[151] ESMIG, based on figures from Berg Insight Report, June 2020.

automation, some European companies are present in the full value chain and are significant global players or market leaders, while smart metering value chains are typically dominated by regional players.

Overall, over 50 companies, mostly European, are somehow active in the HEMS market[152], some of which have a strong legacy in energy. More recently, aggregators and tech companies have appeared in this market, focusing their business models solely around HEMS and sometimes offering products or services to major companies, avoiding these ones to cover the whole HEMS production chain.

The three key insights gained with regards to the supply chain of EV charging infrastructure[153] are: (i) the 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 market and value chain are not fully mature yet as vendors develop, design, and manufacture mainly in-house, with some contract manufacturing. But as the adoption of Distributed Energy Resources (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 especially in the slow-charging part that will be bigger than the fast-charging one according to the IEA in its latest Global EV Outlook[154].

It is worth mentioning that with the increasing importance of the software in smart grid related technologies, the business model is partially aligning with that of the pure software industry and evolving more towards a services market, with much of the revenues coming in after the initial deployment[155].

Global market analysis

All four markets are growing at around 10% CAGR (Compound Annual Growth Rate), with charging infrastructure at 26%[156]. Distribution automation, the biggest global market among the four 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. The Smart Meter market was estimated at USD 21.3 billion in 2019 and projected to grow to USD 38-39 billion in 2027 (due to growth mainly in Asia). The global HEMS market 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%. The booming EV market will create enormous opportunities for the HEMS market, as this will become one of the most important electric loads in the home.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 and management systems, 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[157].

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[152] Delta-EE, Accelerating the energy transition with Home Energy Management, New Energy Whitepaper, February 2020.

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

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

[155] 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.

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

[157] See the accompanying Staff Working Document for further data.

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, Cohesion policy, European Innovation Fund, Recovery and Resilience facility), the EU aims to lead the way in deploying smart grids. This, together with the existence of long established EU companies providing grids technologies will support having European market leaders and solid technology manufacturers in all four technology domains. At the same time, as the global market analysis reveals strong developments in the US, as well as in Asia Pacific (China, Japan, South Korea) too, European companies will have to face tough competition along the way to 2030.

3.7 Renewable Fuels for Aviation and Shipping

Technology Analysis

Renewable fuels, including advanced biofuels[158] and renewable synthetic fuels[159], are the only commercialised solution to decarbonise the aviation and shipping sectors in the near-term[160]. Renewable fuels are projected to supply 5% (i.e. 2.3 Mtoe) of total EU jet fuel consumption by 2030 and 63% (i.e. 28 Mtoe) by 2050[161]. Announced total annual capacity of renewable aviation fuels in the EU is about 1.7 million tonnes by 2025, making up 0.05% of total EU aviation fuel. By comparison, US installed capacity is twice as large (3.6 million tonnes) and roughly 60% of global capacity[162]. The share of renewable maritime fuels is negligible today but it is projected to reach 8.6% of the total fuel mix by 2030 and 88% by 2050[163].

Commercialisation and scaling up of renewable fuels are hindered by high capital expenditures (CAPEX), reaching as much as EUR 500 million for one plant and 80% of total production costs. In particular, the production costs of renewable fuels are currently estimated at 3 to 6 times the current market price of conventional fuels[164]. Co-processing (or co-hydrotreating in the case of aviation fuels) in existing refineries and other industries is maturing and presents an advantage for lowering capital costs.

The EU contributes significantly to cost reduction of renewable fuels by maintaining a strong global position in R&I investments. Public R&I funding from Member States for biofuels[165], including advanced biofuels, has remained constant at roughly EUR 400 million per year since 2008. In addition, EU funding of renewable fuels increased from EUR 430 million for the period 2012-2016 to 531 EUR million during 2017-2020. Specific dedication of funding to aviation and maritime fuels increased from EUR 84 million to EUR 229 million for the same time periods[166].

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[158] Fuels derived from organic material listed in Annex IX of Directive (EU) 2018/2001. 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. Power-to-gas and liquid capacity in the EU is currently very limited, amounting to only 0.315 Kt/y.

[159] Fuels based on renewable energy, according to Article 2 (36) of Directive (EU) 2018/2001.

[160] IRENA (2021), Reaching Zero with Renewables: Biojet fuels, International Renewable Energy Agency.

[161] Impact assessment report - SWD(2021) 633, pg. 38.

[162] Based on data compiled from internal database of Flightpath 2020.

[163] Impact assessment report - SWD(2021) 635, pg. 53.

[164] Depending on the cost of petroleum jet fuel and the feedstock used to make renewable fuels.

[165] Data reported after 2014 depend on how funding is allocated between biofuels and other bioenergy technologies and lacks the granularity to distinguish between conventional and advanced biofuels.

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

Evidence is limited for private R&I investment but suggests that China-based companies average the highest annual investments (EUR 809 million) in renewable fuels, followed by EU (EUR 652 million) and US (EUR 578 million) companies[167]. However, the largest share of top R&I investing companies are in the EU, followed by China and the US.

Consistent investment may have placed the EU amongst global innovation leaders. Yet evidence suggests falling behind US companies in particular, which have twice as many patents in aviation fuels as EU based companies, and a larger number of leading innovators[168]. Japanese and EU based companies each make up one third of all patents in the maritime sector, but evidence is inconclusive due to inclusion of some technologies beyond renewable fuels and a lack of granularity in the data.

Value Chain Analysis

Overall, renewable fuels in the aviation and maritime sector are not only a strategic element for moving towards a climate-neutral economy, but can also provide an opportunity for growth and employment. The package delivering the European Green Deal is expected to increase demand of renewable fuels for shipping and aviation in the EU. This could contribute up to an annual growth value added of several billion euro by 2030. Considering current liquid biofuel production of 16 Mtoe in the EU employs nearly 230 000 people[169], the respective increase in domestic production could create up to 270 000 additional jobs by 2050[170]. Current biofuel employment also suggests a strong basis of the job skills needed for expansion of the market already exists, but increased job skill training may be required for a potential doubling by 2050.

EU value chains benefit from diverse expertise in various production pathways and feedstocks as well as synergies from increasing number of joint ventures between renewable fuel companies, oil and gas companies and ports and airports, demonstrating preparedness for expansion of renewable fuel markets to aviation and shipping.

Advanced biofuels are mainly based on non-recyclable waste and residues, which is a more sustainable option, with less impacts on land use and biodiversity, than food and feed biofuels. The choice of biomass feedstock may have implications for sustainability, production costs and potential supply bottlenecks. Particularly when scaling up advanced biofuels, maturity of alternative production pathways based on diverse feedstocks, other than wastes, will be necessary to avoid bottlenecks.

Global Market Analysis

The market for renewable fuels in aviation and shipping is currently very limited. New policies in the package delivering the European Green Deal[171] are expected to largely increase demand and expand these markets within this and then following decades. The strong global market

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[167] JRC SETIS 2021.

[168] JRC SETIS research and innovation data: https://setis.ec.europa.eu/publications/setis-reseach-and-innovation-data_en

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

[170] Based on projected renewable fuel production and employment figures in Impact assessment report - SWD(2021) 633 and Impact assessment report – SWD(2021) 635.

[171] Particularly: COM(2021) 562 final, COM(2021) 561 final and COM(2021) 557 final.

position of the EU in road transport biofuels[172], as well as concentration of leading advanced biofuel producers, suggest a good start position to fill these new markets. Yet, with dedicated initiatives[173] and twice the installed capacity of the EU[174], and US production of sustainable aviation fuel may also compete for EU markets.

Due to the dependence of power-to-liquid on low-cost renewable electricity, production of synthetic fuels could require larger dependence on Middle East and North Africa (MENA) region. On the other hand, the synergies with existing fuel manufacturing facilities in the EU (integration with refineries, re-use of production and ancillary infrastructures, availability of skilled employees, availability of CO2 for capture and reuse and other factors) offer the potential of economically competitive production of synthetic fuels in the EU.

Importance of Breakthrough Technologies – Example of solar fuels

The need for alternatives to liquid fossil fuels drives research and innovation to develop cost-efficient renewable fuels with high energy density and ample feedstock availability. While advanced biofuels and synthetic fuels mature and some even reach commercialisation, solar fuels are still low Technology Readiness Level (TRL) technologies, at conceptual or experimental phase. However, by 2050 scaled investment could enable this example of breakthrough technologies to increase the availability of cost-effective, high energy density fuels while reducing feedstock and resource pressure.

By 2050, in addition to rapidly deploying available technologies, reaching net zero emissions will require bringing further technologies to market that are low TRL today[175]. Similarly in the past, through dedicated research and innovation actions it was possible to bring technologies to the market which, thirty years ago, were only low TRL or even just concepts, such as offshore wind, renewable fuels and lithium-ion batteries for EVs.

Solar fuels generation embodies a number of anthropogenic and biologically assisted processes to convert solar energy directly to fuels, chemical products, and materials from sunlight, air (e.g., CO2 and nitrogen), and water. It includes using light energy directly from sunlight, often termed *artificial photosynthesis,* as well as the heat from sunlight to drive high-temperature thermal processes[176].

Particularly photo-electro-chemical (PEC) water splitting is a promising solar-to-hydrogen pathway for hydrogen production, offering the potential for high conversion efficiency at low operating temperatures using cost-effective thin-film and/or particle semiconductor materials.

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[172] The EU is currently a global leader in the production of conventional biofuels with a net trade balance of roughly EUR 4 million.

[173] I.e. Federal Strategy on Alternative Jet Fuels adopted in 2016 and the ongoing work on the Commercial Aviation Alternative Fuels Initiative (CAAFI).

[174] Including planned capacity by 2025. Data compiled from internal database of Flightpath 2020.

[175] IEA, Net-zero by 2050- a roadmap for the global energy sector, 2021.

[176] Mission Innovation, Innovation Challenge 5: Converting Sunlight into Solar Fuels and Chemicals Roadmap 2020–2050, 2021.

With scaled investments, PEC could reach cost-competitiveness with fossil fuels and market introduction by 2040[177].

4. CONCLUSIONS

The Green Deal objectives cannot be achieved without significantly increasing public and private research and innovation in clean energy technologies and more efforts to move from laboratory to market. This will not only provide the new solutions needed to achieve carbon neutrality by 2050 while tackling biodiversity loss, pollution and natural resources depletion, but also further growth and jobs in the EU clean energy sector.

While the private sector itself will have to take the main responsibility for investment, the role of the EU is to put the right regulatory and financial framework conditions in place. This includes stimulating demand through a number of measures included in the Fit-for-55 legislative package. In addition, the Recovery and Resilience Fund, InvestEU, and the new generation of EU programmes under the 2021-2027 EU budget offer a strong stimulus for addressing some of the challenges, by increasing available scale up capital, removing market barriers, and driving policy reforms. While gradually decarbonising the EU energy sector and rolling out clean energy technologies, there is a need to focus on competitiveness, jobs and growth.

This report shows that the EU stays at the forefront of clean energy research. The declining trend in clean energy patents seems to be reversing, with annual filing levels in the EU, and globally, returning to those observed a decade ago. At global level, the EU has a greater share of ‘green’ inventions in climate change mitigation technologies, compared to other major economies. With a positive trade balance and substantial market share, the EU retains a strong position in the wind industry, however it may be at crossroads in multiple other industries. In the PV industry, European manufacturers are showing a renewed interest to invest in the EU based on the latest technologies. Similarly, the EU batteries industry is catching up through a combination of investment in battery production, increased demand in EV combined with the shift of the EU car industry, and focus on recycling to address the raw materials issue. The European heat pump, renewable fuels, smart grids and renewable hydrogen industries are in a good position to benefit from the growing future demand based on policy driven expansion of relevant markets. Their competitive position will depend of their speed of penetration/development, the engagement of planned investments/markets getting ready, as well as a favourable legal framework, and developments of other sectors (e.g. aviation and maritime transport). The deployment of clean energy requires also a sound assessment of the environmental impacts of the technologies, and mitigating measures.

Further efforts are also needed to bridge the gap between innovation and market. EU-based climate tech start-ups still trail their counterparts in their ability to scale, thus challenging the EU from reaping the climate and competitiveness benefits of EU innovation and leading promising ventures to move to US or Asia to reach scale. Despite the fact that many national and local ecosystems exist, the EU’s natural market and regulatory fragmentation hinders growth and lead to different maturity of VC ecosystems, and entrepreneurs face challenges in scaling up breakthrough technologies. Uptake of technologies is also hindered by demand side issues such as permitting, repowering and other structural barriers as well as market distortions from international subventions where European companies operate. Intensified work on

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[177] Artifical Photosynthesis: Potential and Reality, EUR 27987 EN.

European standards addressing digitisation, reliability and sustainability issues is also critical to support the uptake of innovative technologies.

In parallel to fostering research, innovation and market uptake of clean energy solutions, the EU must secure reliable, sustainable and undistorted access to raw materials. Resource efficiency, circularity and sustainable domestic feedstock resourcing will be essential to avoid bottlenecks as demand increases. This, in many cases, requires further R&I. Securing further value chain segments within the EU will require strengthening the innovation funding landscape.

The recent rise in energy prices has made it clear that Europe needs to decrease its energy dependency. The European Green Deal and an increasing share of clean energy will lead the way forward. The European Commission will continue to monitor progress of the clean energy sector and will further develop its methodology and data collection in cooperation with Member States[178] and stakeholders, with the aim to inform policy decisions and contribute to making Europe competitive, resource efficient and carbon neutral by 2050.

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[178] Including via the upcoming Governance Regulation Implementing Act.