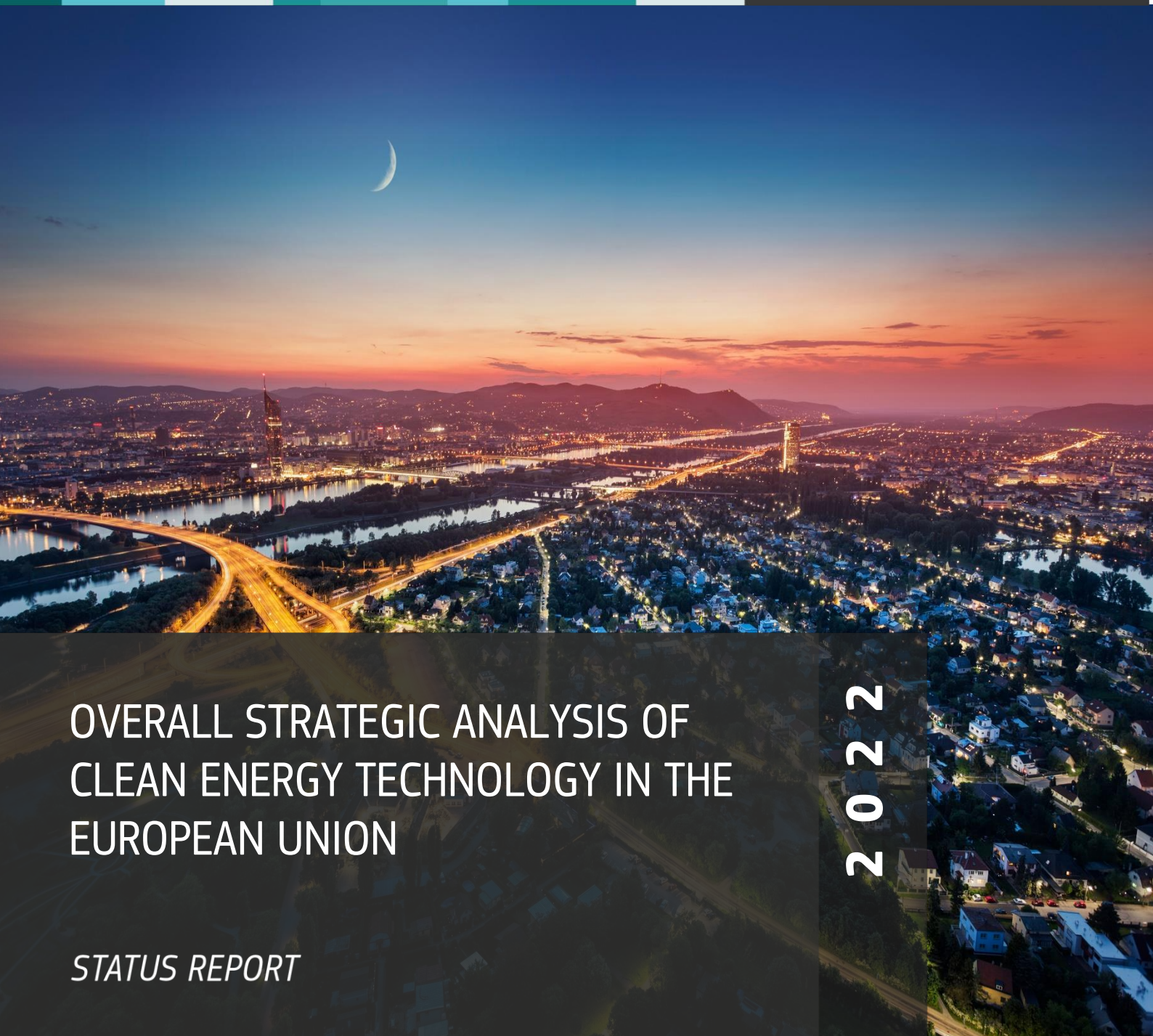




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# CLEAN ENERGY TECHNOLOGY OBSERVATORY



## OVERALL STRATEGIC ANALYSIS OF CLEAN ENERGY TECHNOLOGY IN THE EUROPEAN UNION

*STATUS REPORT*

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## **Foreword**

This report is an output of the Clean Energy Technology Observatory (CETO). CETO's objective is to provide an evidence-based analysis feeding the policy making process and hence increasing the effectiveness of R&I policies for clean energy technologies and solutions. It monitors EU research and innovation activities on clean energy technologies needed for the delivery of the European Green Deal; and assesses the competitiveness of the EU clean energy sector and its positioning in the global energy market. As such, CETO also constitutes the evidence-based analysis underpinning the Annual Progress Report on Competitiveness of Clean Energy Technologies (CPR) under the annual State of the Energy Union Report.

CETO is being implemented by the Joint Research Centre for DG Research and Innovation, in coordination with DG Energy.

## **Acknowledgements**

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## Executive Summary

This report is part of an annual series from the Clean Energy Technology Observatory that address the status of technology development and trends, value chains and markets in the European Union and internationally. The present report aims to provide an overall integrated analysis of the clean energy technology and system integration. It addresses two main aspects: a) data on the overall competitiveness of the EU clean energy sector and b) strategic analysis of critical value chains and sustainability. The following summarises the main findings:

### Energy and Resources Trends

- Energy consumption and energy intensity have been decreasing, the latter at a more rapid pace, indicating more efficient use of energy and decoupling of energy consumption from economic growth. In 2020, the impact of the COVID-19 crisis on the EU economy led to a decrease in energy demand. As a result, both primary and final energy consumption were more than 5% below the EU 2020 target level. With the contribution of increasing renewables in the energy mix, GHG intensities have also decreased; the EU is one of the least emitting major global economies. In 2020, the EU exceeded the target for renewable share in gross final energy consumption by 2%, achieving one of the milestones towards climate neutrality. Nonetheless, in 2021, the economic recovery brought increases in energy consumption, as well as energy and carbon intensity globally, with energy demand higher than 2019 levels and emission increases offsetting the 2020 drop. The trend also affects the EU, albeit to a lesser extent than other economies, so it will be important to put in practice the measures envisaged in policy to maintain a course to energy efficiency, security and climate neutrality.
- During the last decade, EU industrial electricity and gas prices have been higher than in most non-EU G20 countries. Member States with higher import dependence face greater price volatility and higher prices. Beyond interventions on the taxes and levies that may make up part of the cost, increasing the share of renewable energy produced in the EU could mitigate costs and their negative impact on the competitiveness of the EU industry.
- Economic data on the clean energy sector as a whole is available from the Eurostat environmental goods and services accounts and more specifically for renewables from EurObserv'ER. The EU renewable energy sector continued to grow despite the pandemic, outperforming the overall economy in terms of generated turnover and gross value added. While the EU economy contracted by 4% in 2020, gross value added of renewable energy sector increased by 8%, and turnover grew by 9% in 2019-2020, with wind and heat pump value chains being the main drivers. As a whole, the energy sector generates about 4 times more value added per Euro of turnover than the fossil fuel industry. Moreover, it has nearly 70% higher ratio of gross value added to turnover than the overall manufacturing industry in the EU.
- In 2021, the EU production value of most clean energy technologies and solutions broadly increased, reversing the declining trend of 2020. Nevertheless, the simultaneous increase of prices starting in 2021 may give an overly positive picture of production growth. In addition, some technologies experienced an increase of imports to meet the growing demand in the EU.
- Global carbon market inched forward at COP26, but still in 2022 less than 4% of global emissions are covered by a direct carbon price which is in the range of EUR 50-100/tCO<sub>2</sub>. The EU Emissions Trading System (EU ETS), which remains the largest carbon market by traded value, falls within this range, with an average price of EUR 53/tCO<sub>2</sub> in 2021 and of EUR 84/tCO<sub>2</sub> in the first semester of 2022. In 2021 revenue from ETS for the first time surpassed carbon tax revenue globally, increasing its importance for financing low-carbon innovation and the energy transition.

### Human Capital and Skills

- Overall from 2015 to 2020 EU total employment in the renewables has remained at about 1.3 million. The main change has occurred in the distribution of jobs in the various sectors, with heat pumps overtaking solid biofuels and wind energy as the biggest employer in 2020. When energy efficiency and e-mobility are included, clean energy sector employment climbs to 1.8 million (1% of the EU total employment), having expanded on average by 3% annually since 2015. Meanwhile, fossil energy industry employment has declined on average by 2% annually in the last decade.
- The supply chain difficulties and employment shortages observed in the economy during the recovery from the pandemic have also spilled over to the clean energy sector. Nearly 30% of businesses in manufacture of electrical equipment in the EU experienced shortages of labour in 2022. In particular technical skills are in growing demand across the energy industry. The EU is taking action to answer skills related challenges

posed by the digital-green twin transition through its overarching skills policy framework represented by the European Skills Agenda. Also the Clean Energy Industrial Forum (CEIF) commits to stepping up efforts and investments in the development of skills, strengthening reskilling and upskilling programmes. The shortage of materials and equipment is even more pronounced and affected over 70% of electrical equipment manufacturing businesses in the EU. This is also higher than for the overall manufacturing industry (53% affected) in the EU.

- A gender gap continues to prevail in the clean energy sector, and consistent and continuous gender-disaggregated data is largely lacking. For example, women are under-represented in higher education in Science, Technology, Engineering, and Mathematics (STEM) sub-fields that are highly relevant for the energy sector, which remains heavily male dominated. This translates to lower share of patent applications with women inventors (only 20% in all patent classes in 2021 and just over 15% for climate change mitigation technologies), lower share of start-ups founded or co-founded by women (less than 15% in the EU in 2021), and lower amounts of capital invested into women-led companies (only 2% in all-female start-ups and 9% in mixed teams in the EU in 2021), creating a vicious circle. There are however an increasing number of initiatives stimulating women's involvement in innovation, such as the second edition of Women TechEU launched by the EU in 2022 and new gender-balance criterion included under Horizon Europe.

### **Research and Innovation Trends**

- The EU is at forefront in clean energy research and innovation. With 6% of the world population, it is a global leader for 'green' inventions and high-value patents in climate change mitigation technologies. As regards to novel technologies, EU climate-tech start-ups and scale-ups have attracted an increasing amount of venture capital (VC) investments over the last 6 years, accounting for 15% of global climate tech VC investments in 2021, more than a twofold increase (x 2.2) as compared to 2020. 2021 was also the first year where later-stage investments in EU-based climate tech were higher than those in China. However, early-stage investments reached new highs in the US and China in 2021 but peaked in the EU. This remains a good performance in a race where investments are surging around the world and megadeals are driving much of the top line investment growth. Structural barriers and societal challenges<sup>1</sup> are however still holding back EU-based climate tech scale-ups compared to other major economies.
- Public R&I investments in the Member States increased both in terms of absolute spending and as a share of GDP in 2020. However, they still remain below EU 2010 levels in absolute terms and also as a share of GDP compared to other major economies. Nevertheless, EU R&I funds have increased significantly. In 2020, framework programme funds accounted for a third of public investment in the Energy Union R&I priorities, providing a vital boost to research and innovation. Considering both MS and framework programme funding, in 2020, the EU was second in public R&I investment among major economies, both in absolute spending: EUR 6.6 billion (where the US leads with EUR 8 billion) and as share of GDP: 0.046%, behind Japan 0.058% and just ahead of US and KR.

### **Critical Materials and Industry Value Chains**

Availability of the necessary raw materials and smooth functioning of the relevant value chains is essential for the undisrupted deployment of the clean energy technologies, fulfilling the EU energy transition targets. The materials and value chains necessary for each technology have been analysed in the CETO reports on specific technologies. Various materials have been identified as critical and strategic, including steel, cement, copper, rare earths, composite materials, iron alloys, silicon metal, silver, lithium, nickel, graphite, cobalt, etc. Achieving the REPowerEU policy targets would naturally lead to an increase in the demand for raw materials, processed materials, components and assemblies. It is widely recognised that the EU needs to strengthen supply chains and improve its resilience concerning critical materials and components, and the State of the Union address in September 2022 included a proposal for a European Critical Raw Materials Act

### **Sustainability**

Energy systems must be sustainable in terms of their environmental, social and economic performance. As part of the CETO analysis of individual technologies and system integration aspects, data has been gathered in a systematic way on an extensive series of relevant parameters. These qualitative and quantitative analyses of sustainability performance highlight the heterogeneous and limited nature of available information and data. Methodologies used (e.g. PECFR for Life Cycle Assessment) are also not available for all technologies. They

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<sup>1</sup> As analysed in: COM(2020)953 final, Report on Progress of Clean Energy Competitiveness, and COM/2022/332 final, The New Innovation Agenda.



equally highlight that different categories of considerations are relevant depending on the technology for e.g. direct impacts and perceptions. From a life cycle assessment perspective, including for carbon footprints, data can be limited for some technologies and may also not be based on detailed analysis requirements. Specific examples are given for batteries, photovoltaics and wind technologies.

It is recommended that the CETO qualitative analyses should be further expanded and maintained through more detailed studies but focusing on a limited subset of parameters. It may be good to make clear distinctions between economic, social, and environmental considerations. Equally, a split can be made between direct impacts and those associated with value chains.

At the same time, development is recommended of quantitative modelling for analysis of value chains and of future potential for selected clean energy technologies for selected policy endpoints (autonomy, circularity, climate, environmental, social and economic). This could be done initially for the most dominant clean technologies, building on e.g. examples of more advanced value chain analyses/modelling such as for batteries.

# 1 Introduction

This report is part of an annual series from the Clean Energy Technology Observatory that address the status of technology development and trends, value chains and markets in the European Union and internationally. It aims to provide an overall integrated analysis of the clean energy technology and system integration, to complement the individual technology and system integration reports (listed in Annex 1). As set out in the CETO terms of reference, it addresses two main aspects:

- a) Consolidated data on the competitiveness of the EU clean energy sector, addressing
  - Energy and Resources Trends (including energy intensity, share of renewables, trade balance, electricity, carbon and fuel prices, and turnover)
  - Human Capital and Skills
  - Research and Innovation Trends (investments, patents)
- b) Strategic analysis, addressing:
  - Medium and long-term perspectives for clean energy technology development
  - Critical industrial value chain relationships
  - Sustainability (status for environmental, social, economic and governance aspects, integrated assessment needs and roadmap for further assessments)
  - Impact of Recovery and Resilience Plans (RRPs)
  - SWOT analysis for global competitiveness, technology independence and sustainability

The report makes use of the analysis performed for the European climate Neutral Industry Competitiveness Scoreboard (CINDECS)<sup>2</sup> and the work reported in the Annual Single Market Report 2021 regarding EU Industrial Ecosystems<sup>3</sup>. **Table 2** shows the relationships between the CETO technologies and system integration topics and these related activities.

Concerning part b), for this first annual report focus is restricted to critical materials and industrial value chains, to sustainability and the SWOT analysis. The status of clean energy technology investments in the RRP is summarised in section 2.2.3 – at this stage it is premature to assess specific impacts.

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<sup>2</sup> Kuokkanen, A., Georgakaki, A., Mountraki, A., Letout, S., Telsnig, T., Kapetaki, Z., Quaranta, E., Czako, V. and Pasimeni, F., European Climate Neutral Industry Competitiveness Scoreboard (CINDECS) - Annual Report 2021, EUR 31183 EN, Publications Office of the European Union, Luxembourg, 2022, ISBN 978-92-76-55804-0, doi:10.2760/5869, JRC129336

<sup>3</sup> European Commission SWD(2021)351 Updating the 2020 New Industrial Strategy: Building a Stronger single Market for Europe's Recovery.

**Table 1.** Coverage of clean energy technologies in CETO, CINDECS and by the EU Industrial Ecosystems.

<b><i>CETO technology and system integration areas</i></b>	<b><i>Relevant CINDECS topics<sup>4</sup></i></b>	<b><i>Most Relevant EU Industrial Ecosystems</i></b>
Advanced biofuels		Renewable energy
Batteries	Batteries (Li-ion)	Mobility, Transport, Automotive
Bioenergy (solid biomass and biogas for heat and power and for intermediate carriers)		Renewable energy
Carbon Capture Utilisation and Storage	Decarbonisation of cement through CCS	Energy Intensive Industries
Concentrated Solar Power and Heat	-	Renewable energy
Geothermal heat and power	-	Renewable energy
Heat Pumps	Heat pumps	Renewable energy
Hydropower & Pumped Hydropower Storage	Hydropower	Renewable energy
Novel Electricity and Heat Storage technologies	-	
Ocean energy	Offshore operations for RE installations	Renewable energy
Photovoltaics	Solar PV panels	Renewable energy
Renewable Fuels of non-biological origin (other)	Ammonia as a fuel	Renewable energy
Renewable Hydrogen	-	
Solar Fuels (direct)	-	Renewable energy
Wind (offshore and onshore)	Wind rotors Offshore operations for RE installations	Renewable energy
Building-related clean energy technologies	Pre-fabricated buildings Superinsulation materials Building envelope technologies Cooling and air conditioning	Construction
Digital infrastructure for smart energy system	EV charging infrastructure	Digital
Industrial and District Heat & Cold Management	Heating and cooling network	Energy Intensive Industries
Off-grid energy systems (including islands)		Digital
Transmission and Distribution related technologies	EMS for grids	Digital Electronics
Smart Cities	EV charging infrastructure	
Innovative energy carriers and energy supply for transport		Mobility-transport-automotive

Source: JRC

<sup>4</sup> CINDECS also includes topics on fuel cells and on electric powertrains not included in CETO

## 2 Overall competitiveness of the EU clean energy sector

### 2.1 Energy and resource trends

When looking at recent developments in the clean energy technology sector, it is relevant to report on some overarching indicators that are dependent on the progress of the sector but can also equally affect its prosperity as they impact the competitiveness of the EU industry and economy as a whole (Figure 1). Energy consumption and energy intensity have been decreasing, the latter at a more rapid pace, indicating more efficient use of energy and decoupling of energy consumption from economic growth. In 2020, the impact of the COVID-19 crisis on the EU economy led to a decrease in energy demand. As a result, both primary and final energy consumption were more than 5% below the EU 2020 target level. With the contribution of increasing renewables in the energy mix, GHG intensities have also decreased; the EU is one of the least emitting, per GDP, among major global economies<sup>5</sup>.

In 2020, the EU exceeded the target for renewable share in gross final energy consumption by 2%, achieving one of the milestones towards climate neutrality. Nonetheless, in 2021, the economic recovery brought increases in energy consumption, as well as energy and carbon intensity globally, with energy demand higher than 2019 levels and emission increases offsetting the 2020 drop<sup>6,7</sup>. This is also the case for the EU, albeit to a lesser extent than other economies. JRC data confirms that, in 2021 fossil fuel CO<sub>2</sub> emissions in the EU increased, but only to half the level of the reduction between 2019 and 2020<sup>7</sup>. Going forward, it will be important to put in practice the measures envisaged in policy to maintain a course to energy efficiency, security and climate neutrality.

Despite the achievements in reducing energy consumption and intensity, in 2019, the EU net (energy) import dependency was at a 30-year high. In 2020, imports of energy products decreased and import dependency returned to just below 2005 levels. Russia's unprovoked aggression in Ukraine, highlighted the need to reduce import dependency in general, and end the EU's reliance on Russian fossil fuels in particular (Figure 2). This year, the country-specific recommendations adopted in the context of the European Semester include guidance on reducing the dependency on fossil fuels, in line with the REPowerEU priorities and the European Green Deal.

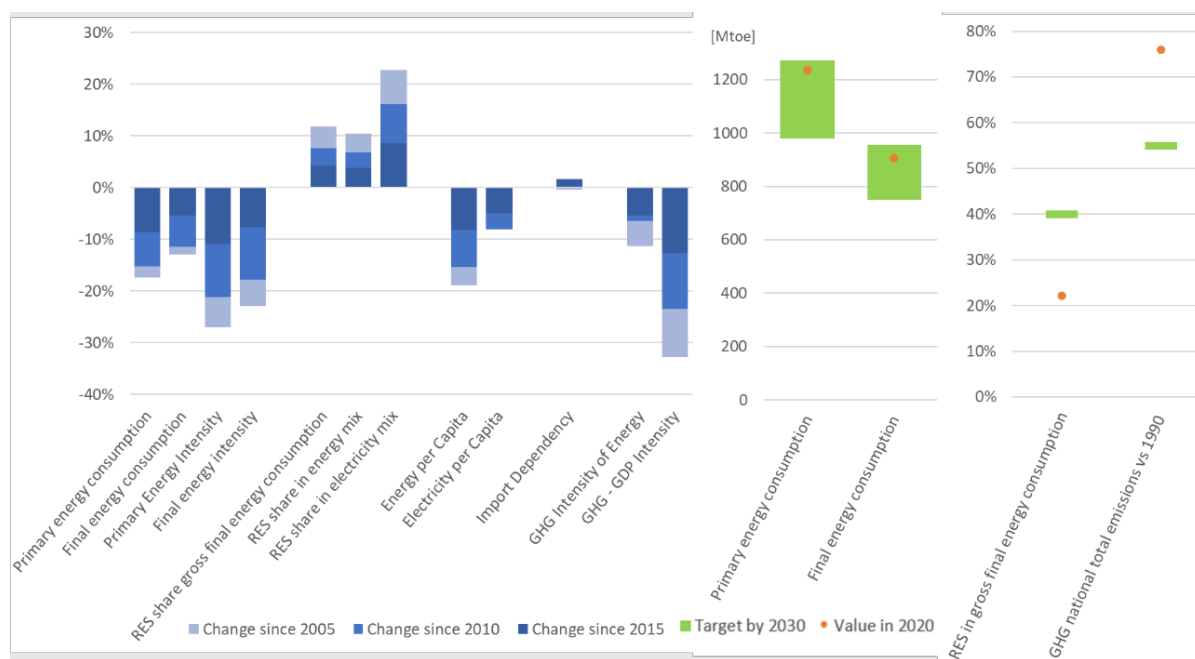
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<sup>5</sup> The European Round Table for Industry (ERT), European Competitiveness and Industry Benchmarking Report 2022

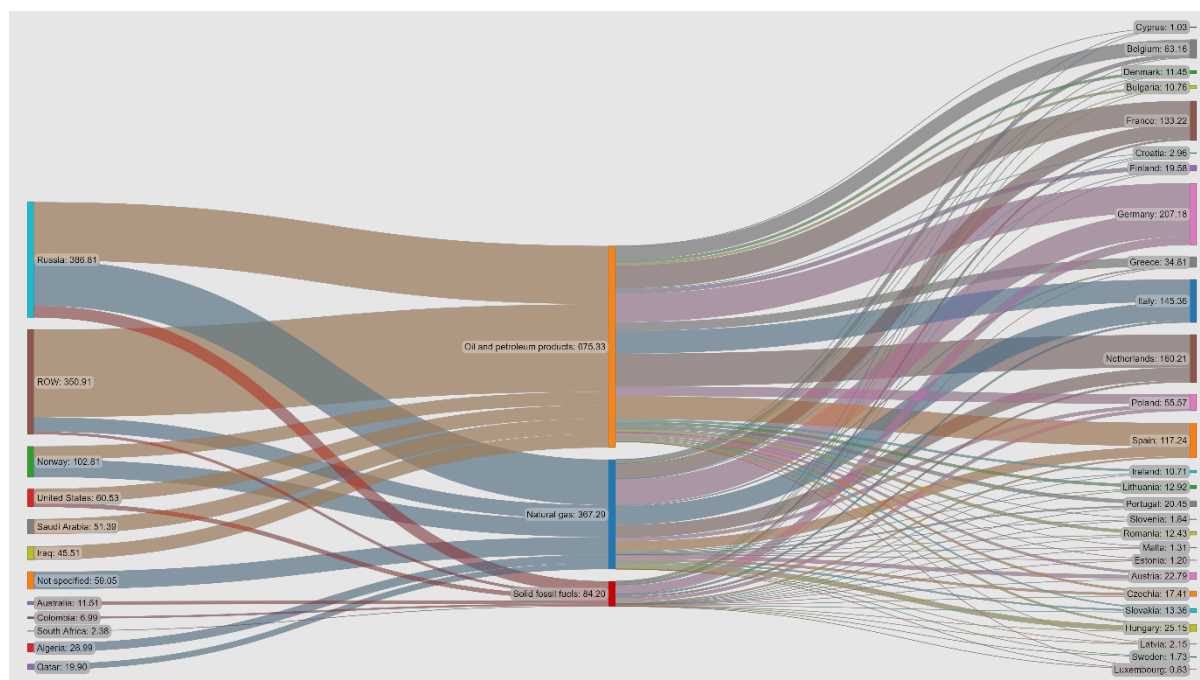
<sup>6</sup> Enerdata – Global Energy and Climate Trends 2022 Edition

<sup>7</sup> Crippa M., Guizzardi D., Banja M., Solazzo E., Muntean M., Schaaf E., Pagani F., Monforti-Ferrario F., Olivier, J.G.J., Quadrelli, R., Risquez Martin, A., Taghavi-Moharamli, P., Grassi, G., Rossi, S., Oom, D., Branco, A., San-Miguel, J., Vignati, E. CO<sub>2</sub> emissions of all world countries – JRC/IEA/PBL 2022 Report, Publications Office of the European Union, Luxembourg, 2022, doi:10.2760/07904, JRC130363

**Figure 1:** Evolution of main indicators for energy consumption, GHG intensity and renewable contribution to the energy system, along with the 2020 value and 2030 targets.



**Figure 2:** Imports of oil and petroleum products, natural gas, and solid fossil fuels to the EU, by source, and importing Member State (this is not necessarily the end-user as there may be transformations and re-exports within the EU), 2019.



<sup>8</sup> EU energy statistical pocketbook and country datasheets [https://energy.ec.europa.eu/data-and-analysis/eu-energy-statistical-pocketbook-and-country-datasheets\\_en](https://energy.ec.europa.eu/data-and-analysis/eu-energy-statistical-pocketbook-and-country-datasheets_en); Eurostat (nrg\_ind\_eff), (nrg\_ind\_ren)

<sup>9</sup> Eurostat tables [nrg\_ti\_gas], [nrg\_ti\_sff], [nrg\_ti\_oil]. Graph build with sankeymatic.com. 2019 values are representative of previous years, 2020 is an outlier; the second supplier of natural gas is "not specified" but it is very likely Russia (mostly to Germany and Austria); Cyprus does not import natural gas, a nominal value is added to construct the diagram; idem for Malta on solid fossil fuels

### 2.1.1 Production and trade

In 2021, the EU production value of most clean energy technologies and solutions experienced a widely positive increase, a reversing trend compared to the 2020 decline. The EU production of batteries had a staggering year with production value quadrupling with respect to 2020 values as more capacity came online. The heat pump, wind and solar PV production registered a 30% growth in 2021: for heat pumps it was a record year, wind bounced back to pre-pandemic level, whilst solar PV reversed the declining trend seen since 2011. The production of biofuels, mainly biodiesel, grew by 40%, and increased widely across Member States, while production of bioenergy, such as pellets, starch residues and wood chips, increased by 5%. The production of hydrogen<sup>10</sup> grew by nearly 50% as the Netherlands more than doubled its production in 2021.

Nevertheless, the simultaneous increase of prices starting in 2021 may give an overly positive picture of production growth. In addition, some technologies experienced an increase of imports to meet the growing demand in the EU. In 2021, imports for wind energy and heat pumps doubled, while imports of solar PV also increased by 40%. Nonetheless, extra-EU exports in a number of technologies, such as batteries and wind also increased significantly, by 74% and 42% respectively, in contrast to biofuel exports, which continued to shrink. Heat pumps had the most significant relative increase in trade deficit (EUR 390 million in 2021 vs EUR 40 million in 2020), followed by biofuels (EUR 2.3 billion in 2021 vs EUR 1.4 billion in 2020) and solar PV (EUR 9.2 billion in 2021 vs EUR 6.1 billion in 2020). The increasing domestic battery production is far from keeping up with expanding demand, also resulting to an increased trade deficit (EUR 5.3 billion in 2021 vs EUR 4.2 billion in 2020). In contrast, the EU maintained positive trade balance in wind energy technology (EUR 2.6 billion in 2021 vs EUR 2 billion in 2020). Finally, while the volume of imported hydrogen<sup>11</sup> doubled, exports also increased, resulting in the EU maintaining a slightly positive trade balance.

### 2.1.2 Costs and prices

As stated in previous competitiveness reports<sup>12</sup>, during the last decade, EU industrial electricity and gas prices have been higher than in most non-EU G20 countries. Member States with higher import dependence face greater price volatility and higher prices. Beyond interventions on the taxes and levies that may make up part of the cost, increasing the share of renewable energy produced in the EU could mitigate costs and the impact on the competitiveness of the EU industry. Figure 3 provides a snapshot of levelized costs of electricity (LCOE) calculations for the year 2021 for a range of representative conditions<sup>13</sup> across the EU. The results indicate that in 2021 technology fleets with low variable costs (incl. variable operational costs and fuel costs) have been highly cost competitive. This finding is most robust for solar- and wind-powered generation with LCOE in the range of 40 to 60 Euro per MWh, highlights the high cost-competitiveness of clean energy technologies. Furthermore, the Combined Cycle Gas Turbine (CCGT) fleet appears more competitive on average in 2021 than coal-fired generation thanks to significantly higher capacity factors resulting from preferred dispatch in the first three quarters of 2021 and a fuel switch only factoring in towards the fourth quarter of 2021<sup>14</sup>. During the first quarter of 2022, the rise of gas prices continued to support the gas-to-coal switching, despite the increase in carbon prices. However, the high coal prices in the beginning of the second quarter of 2022 started to close the gap and recent announcement by some Member States to increase the use of coal-fired plants have led to expectations of further price rises for coal in the coming months.

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<sup>10</sup> Referring to all hydrogen, irrespective of production route.

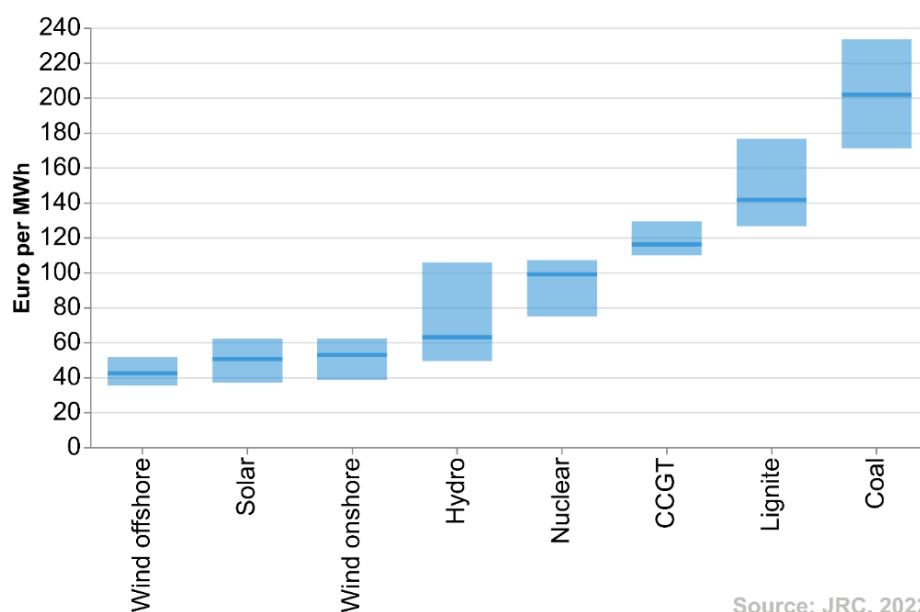
<sup>11</sup> Referring to all hydrogen, irrespective of production route.

<sup>12</sup> Report from the Commission to the European Parliament and the Council on 'Progress on Competitiveness of clean energy technologies' (first edition: COM (2020) 953 final; second edition: COM(2021) 952 final).

<sup>13</sup> Data points shown for first to third inter-quartile range to filter for outliers.

<sup>14</sup> The modelled capacity factors could overestimate actual fuel switching and thus differences in capacity factors to some extent (see section 2.1 in <https://publications.jrc.ec.europa.eu/repository/handle/JRC127862>).

**Figure 3:** Snapshot of technology-fleet specific levelised costs of electricity (LCOE) for the year 2021. The light blue bars display a range across the EU27 and the solid blue lines denote median.



Source: JRC METIS model simulation, 2022<sup>15</sup>

Source: JRC, 2022

### 2.1.3 Raw materials, supply chains, commodity prices

The implementation of the Green Deal and REPowerEU set an ambitious vision for the EU to phase out fossil fuels by accelerating the green energy transition and intensifying the roll out of technologies, such as wind and solar PV. This increased demand for clean energy technology deployment will also increase the demand for resources, such as metals and minerals necessary for these technologies. Examples include wind (permanent magnets using rare-earth elements), solar PV (Si-metal, Ag, Ge, Ga, In, Cd), batteries (Co, Li, graphite, Mn, Ni)<sup>16</sup>. Worldwide, the IEA forecasts that the total minerals demand due to the declared renewables rollout is set to double or even quadruple by 2040<sup>17</sup>, while global demand for certain processed raw materials for batteries is expected to increase up to 20 times by 2040.

The COVID-19 pandemic and the energy crisis exacerbated by the Russian invasion in Ukraine led to supply chains disruption and price increases for those resources and minerals with strategic applications for the twin green and digital transition including e.g. titanium metal, palladium, aluminium, nickel, magnesium, silicon, noble gases and rare earths. Surging raw material prices can affect the cost competitiveness of clean energy technologies and thus have a negative impact on their roll-out. The price of commodities like lithium and cobalt more than doubled in 2021, while those for copper and aluminium also increased by around 25% to 40%<sup>18</sup>. In the same year, the trend of cost reductions for wind turbines and PV modules was reversed; both increased by 9% and 16% respectively, compared to 2020, while similar increases are expected for batteries<sup>19</sup>.

An emerging challenge is to avoid exchanging fossil fuel dependency to resource dependency on exported raw materials and technological expertise for their processing and components manufacturing. For instance, China, has a near monopoly on mining and processing certain REE, combined with a strong market position within certain clean energy technologies production chain. In terms of resource dependency, the challenge is threefold. Firstly, the EU faces an increased competition for gaining access to critical raw materials as the other countries

<sup>15</sup> Kanellopoulos, K., De Felice, M., Busch, S. and Koolen, D., Simulating the electricity price hike in 2021, EUR 30965 EN, Publications Office of the European Union, Luxembourg, 2022

Computation based on annualised costs for the year 2021. Capex and Opex based on the 2020 PRIMES reference scenario, annualised by technical lifetimes and weighted average cost of capital. Annualised costs are levelised using capacity factors derived from the METIS model. Variable costs are based on 2021 commodity prices, variable OPEX and the dispatch in the METIS simulation.

<sup>16</sup> Critical Raw Materials for Strategic Technologies and Sectors in the EU - A Foresight Study, <https://ec.europa.eu/docsroom/documents/42882>

<sup>17</sup> IEA, The Role of Critical Minerals in Clean Energy Transitions, Revised Version in May, 2022.

<sup>18</sup> IEA, [Critical minerals threaten a decades-long trend of cost declines for clean energy technologies](#), 2022,

<sup>19</sup> IEA, The Role of Critical Minerals in Clean Energy Transitions, Revised Version in May, 2022.

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step up efforts to build up capacity, potentially also restricting exports. Half of the 30 Critical Raw Materials listed by the EU<sup>20</sup> are imported in more than 80% per volume.

Circularity and secondary raw material are often seen as a way to mitigate supply risk of materials, also considering that recycling is a formal risk reducing factor in the criticality calculation<sup>21</sup>. Boosting the supply of secondary materials through recycling is an important part of the EU raw materials initiative<sup>22</sup> and the 2020 circular economy action plan (CEAP<sup>23</sup>). Recycling's contribution to meeting demand is overall generally low: secondary raw materials generally represent a small share of manufacturing inputs. Only in a few cases, especially of base metals, does the availability of secondary materials approach or surpass one third of current demand (e.g. rhenium, tungsten, iron, tin and zinc), and only in one case does it reach above 50% (lead). Recycling is extremely low (both in terms of the fraction recycled and of absolute value) for most of the speciality metals. The contribution of secondary raw materials to meeting manufacturing needs heavily depends on the evolution of demand, and other factors currently limit their availability, including: economic or technical feasibility, collection rates, lifetime of products or losses in manufacturing or use<sup>24</sup>.

Secondary raw materials alone will not be sufficient to address the high demand in the transition to green and digital economy, due to dramatically rising demand, and limited availability of secondary raw materials. This is for example the case for raw materials for batteries<sup>25</sup> and this is why they are some ambitious recycled content targets in the Battery regulation proposal, in particular for lithium, cobalt and copper. The contribution of resource efficiency and of recycling is very likely to increase in the future. Innovative design for recyclability of products will also play an important role.

Although there is theoretical potential to cover between 5 and 55% of Europe's 2030 needs by extraction of raw materials from European grounds, a boost in domestic mining capabilities might encounter obstacles due to permitting procedures and environmental concerns.

The REPowerEU plan identifies a number of measures to strike a balance between domestic sourcing and diversified resource imports. It highlights the need to promote resource efficiency and circularity together with establishing and strengthening the cooperation on raw materials value chains with chosen partners, while ensuring a high level of environmental protection in resource exploitation<sup>26</sup>. The Action Plan on Critical Raw Materials<sup>27</sup>, Global Gateway initiative<sup>28</sup> and reformulation of Trade and Sustainable Development approach regarding EU's trade agreements<sup>29</sup> also address the diversification and sustainability of supply, while the European Raw Materials Alliance will strengthen domestic sourcing of minerals, with the potential to prioritise mining projects in regions where the skills and know-how are already present<sup>30</sup>. In addition, a strategic approach to innovation can have a crucial role, to increase technology performance and circularity, and decrease their cost and material needs while also providing alternatives for material sourcing and substitution. The Circular Economy Action Plan<sup>31</sup>, the Action Plan on Raw Materials<sup>32</sup>, and participation in international initiatives such as the Materials for Energy<sup>33</sup>, will identify investment needs and guide and accelerate R&I efforts on recycling measures, raw materials efficiency and alternatives, and novelty mining technologies. In March 2022 the European Council's Versailles declaration<sup>34</sup> called for a step up of action to reduce dependencies and reinforce

<sup>20</sup> COM(2020) 474 final, Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability.

<sup>21</sup> Blengini, G.A., et al., EU methodology for critical raw materials assessment: Policy needs and proposed solutions for incremental improvements, Resource Policy, Volume 53, September 2017, Pages 12-19  
<https://www.sciencedirect.com/science/article/pii/S0301420717300223?via%3Dihub>

<sup>22</sup> See [https://single-market-economy.ec.europa.eu/sectors/raw-materials/policy-and-strategy-raw-materials\\_en](https://single-market-economy.ec.europa.eu/sectors/raw-materials/policy-and-strategy-raw-materials_en)

<sup>23</sup> See [https://environment.ec.europa.eu/strategy/circular-economy-action-plan\\_en](https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en)

<sup>24</sup> Raw Materials Scoreboard 2021, Indicator 15: <https://rmis.jrc.ec.europa.eu/?page=scoreboard2021#/ind/15>, ISBN 978-92-76-23795-2.

<sup>25</sup> Bobba, S., Mathieux, F., Blengini, G.A., How will second-use of batteries affect stocks and flows in the EU? A model for traction Li-ion batteries, Resources, Conservation and Recycling, Volume 145, June 2019, Pages 279-291,  
<https://www.sciencedirect.com/science/article/pii/S0921344919300795?via%253Dihub>

<sup>26</sup> COM(2022) 230 final REPowerEU Plan.

<sup>27</sup> COM(2020) 474 final, Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability.

<sup>28</sup> JOIN(2021) 30 final, The Global Gateway.

<sup>29</sup> COM(2022) 409 final The power of trade partnerships: together for green and just economic growth.

<sup>30</sup> European Commission, Directorate-General for Energy, Guevara Opinska, L., Gérard, F., Hoogland, O., et al., Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis : final report, Publications Office of the European Union, 2021, <https://data.europa.eu/doi/10.2833/946002>

<sup>31</sup> COM(2020) 98 final A new Circular Economy Action Plan.

<sup>32</sup> COM(2020) 474 final, Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability.

<sup>33</sup> Mission Innovation, Innovation Platform, The Materials for Energy (M4E)

<sup>34</sup> European Council, Versailles Declaration, <https://www.consilium.europa.eu/media/54773/20220311-versailles-declaration-en.pdf>, 11.3.2022.

resilience of critical raw materials supply chains by means of diversification of supply through strategic partnerships; exploring strategic stockpiling and increasing resource efficiency and circularity. Commission President von der Leyen's State of the European Union address in September 2022 included a proposal for a European Critical Raw Materials Act, with the aim *"to identify the policy actions needed to develop strategic projects to strengthen EU supply chains while maintaining a sustainable level playing field"*<sup>35</sup>.

## 2.1.4 Carbon Pricing

The Staff Working Document<sup>36</sup> accompanying the 2021 Competitiveness Progress Report looked at carbon pricing applied across the biggest economies through emissions trading systems and taxes. Since then, COP26 in Glasgow has agreed the rules for cooperative approaches (international carbon market and non-market mechanisms) under the Article 6 of the Paris Agreement. By 2022, if all planned carbon pricing initiatives around the globe are implemented, 23% of global greenhouse gas emissions will be covered, up from less than 15% in 2020<sup>37</sup>. However, less than 4% of global emissions in 2022 are covered by a direct carbon price of around EUR 50-100/tCO<sub>2</sub>, which is deemed to be the minimum range to maintain global temperature increase to 2°C<sup>38</sup>. The EU Emissions Trading System (EU ETS), which remains the largest carbon market by traded value, falls within this range, with an average price of EUR 53/tCO<sub>2</sub> in 2021 and of EUR 84/tCO<sub>2</sub> in the first semester of 2022. For comparison, allowances in the Chinese ETS, which is the largest carbon market by emissions<sup>39</sup>, are priced around EUR 5-10/tCO<sub>2</sub><sup>40</sup>, with prices increasing at the end of 2021.

In the EU, the Commission has proposed<sup>41</sup> to extend the EU ETS to the maritime sector, and in parallel, to create a separate upstream emissions trading system covering the sectors of road transport and buildings. The new system would provide an additional signal on top of the Effort Sharing Regulation targets<sup>42</sup>. With these proposals enacted, emissions trading would cover some 75% of EU emissions, which at the moment stands at 36%<sup>43</sup>, incentivising further reduction of fossil fuel consumption, improvement in energy efficiency, and energy savings. As fuel suppliers are likely to pass on some of their carbon costs to consumers buying transport and heating fuels, the Commission has also presented a proposal for a Social Climate Fund<sup>44</sup>, which would mitigate social and distribution impacts on the most vulnerable households, micro-enterprises and transport users.

### *Higher carbon prices and volatility*

Carbon prices rose also in other jurisdictions which implement emissions trading, such as UK, California (WCI initiative), New Zealand, and Republic of Korea. In the EU, ETS prices rose steadily in 2021 in response to the more ambitious EU climate policy and increasing gas prices globally. With the impact of the geopolitical instability due to the Russian invasion of Ukraine, prices have decreased slightly, averaging at around EUR 80 t/CO<sub>2</sub> in the first semester of 2022.

ETS rising prices had prompted questions from stakeholders about the possible role of speculation behind this trend. The report by the European Securities and Markets Authority (ESMA)<sup>45</sup> countered these concerns. Whilst the market has drawn in a growing number of participants, compliance and other, non-financial entities dominate, trading mostly in derivatives. Meanwhile, hedge funds and financial investors, which might be associated with speculative behaviour, were found to be active in the market only to a marginal 8% extent. ETS prices continue to be driven by supply (e.g., gradually decreasing cap and supply of free allowances) and demand (e.g., expectations of future availability of allowances), factors that are inherent to the market design. As the EU ETS becomes more prominent, however, the ESMA report suggested ways of reinforcing the system and increasing transparency.

<sup>35</sup> [https://single-market-economy.ec.europa.eu/news/commission-seeks-views-future-european-critical-raw-materials-act-2022-09-30\\_en](https://single-market-economy.ec.europa.eu/news/commission-seeks-views-future-european-critical-raw-materials-act-2022-09-30_en)

<sup>36</sup> SWD(2021) 307 final, Progress on competitiveness of clean energy technologies.

<sup>37</sup> The World Bank. 2022. "State and Trends of Carbon Pricing 2022" (May), World Bank, Washington, DC. DOI:10.1596/978-1-4648-1895-0.

<sup>38</sup> Value defined according to the Report of the High-Level Commission on Carbon Prices (2017). More recent analysis, also due to the evolution of the geopolitical instability points to carbon prices in the range of EUR 50-250 /tCO<sub>2</sub>.

<sup>39</sup> It covers so far only power sector emissions, which is equivalent to over 30% of China's total GHG emissions.

<sup>40</sup> ICAP, 2022. Emissions Trading Worldwide: Status Report 2022. Berlin: International Carbon Action Partnership.

<sup>41</sup> See COM(2021) 551 final, as part of the revision of Directive 2003/87/EC

<sup>42</sup> COM(2021) 555 final

<sup>43</sup> COM(2021) 962 final, Brussels 26.10.2021.

<sup>44</sup> COM(2021) 568 final

<sup>45</sup> Esma - final report on emission allowances and associated derivatives (ESMA70-445-38)

Higher carbon prices improve price signal needed to incentivise investments in low-carbon solutions such as green hydrogen and CCUS for decarbonisation of energy-intensive sectors, such as steel, cement and chemicals. For these sectors, REPowerEU proposes, in addition to dedicated funding windows in the Innovation Fund, to roll out carbon contracts for difference that will also support green hydrogen production for decarbonisation of industry. The Commission has also proposed a Carbon Border Adjustment Mechanism<sup>46</sup> to address the increased risk of carbon leakage in energy-intensive industries due to EU's more ambitious climate targets.

### *EU ETS revenues*

Based on World Bank estimates<sup>47</sup>, for the first time in 2021, revenues from emissions trading systems, at 67% of total revenue (up from 49% in 2020), surpassed carbon tax revenues globally. In the EU alone, ETS revenues reached EUR 31 billion<sup>48</sup> in 2021, nearly twice as much as in 2020. On average EU MSs spent over 70% of this on domestic and international climate-related action in 2020. EU ETS revenues are channelled also to the Innovation Fund that will invest around EUR 38 billion<sup>49</sup> in commercial demonstration of innovative low-carbon technologies in 2020-2030. The second biggest by revenue, Californian ETS system<sup>50</sup>, uses most of its revenue on reducing greenhouse gas emissions and part of it towards direct support of disadvantaged and low-income communities. This increases its importance in financing low-carbon innovation and green transition, but also in addressing the impacts of the energy price crisis and mitigating energy poverty. With this, the Commission proposed that Member States commit all auction revenues (from the EU ETS and the new system for road transport and buildings) to climate and energy projects.

## **2.1.5 Energy poverty**

Energy poverty has become a challenge recognised across the EU as it is a widespread condition affecting millions of households in the continent. The term describes the inability to access the socially and materially adequate level of energy services. Across EU on average Energy poverty levels have been on a decreasing trend since 2012 with unemployed, elderly, women and low-income households being exposed the most to the phenomenon.<sup>51</sup> However, the most recent data from 2020 (first pandemic year) indicate the reverse of this trend as energy poverty started to rise again.<sup>52</sup> As since, the increase on the energy prices continued and inflation soars we expect further rise for 2021 and 2022 on energy poverty indexes.

Building on recent communications regarding energy poverty<sup>53</sup> and rising energy prices<sup>54</sup>, the European Commission is setting up an Energy Poverty and Vulnerable Consumers Coordination Group [(EU) 2022/589 of 6 April] with Member States and energy regulators to enable an exchange best practices and better focus measures to address energy poverty – in step with related EU policies such as energy efficiency and the Renovation Wave.

## **2.2 Research and innovation trends**

### **2.2.1 Public R&I spending**

The previous Competitiveness Progress reports highlighted that, while public R&I spending in the Energy Union R&I priorities has been steadily increasing since 2016, it still has not recovered to the levels seen before the financial crisis. What is more, it has not been keeping pace with increases in GDP or increases in R&I investment in other sectors.

For 2020, most EU Member States show an increase in respective public R&I, with investments of more than EUR 4 billion reported this far, and final figures expected to be comparable with pre-crisis values in absolute terms. It is estimated that in 2021 public budgets in Europe continued increasing<sup>55</sup>. Nonetheless, measured as

<sup>46</sup> COM(2021) 564 final

<sup>47</sup> The World Bank. 2022. "State and Trends of Carbon Pricing 2022" (May), DOI:10.1596/978-1-4648-1895-0.

<sup>48</sup> EU ETS account for around 41% of the global carbon pricing revenue of USD 84 billion in 2021, according to the World Bank. According to ICAP EU ETS revenues in 2021 amounted to EUR 31 billion.

<sup>49</sup> Depending on the carbon price.

<sup>50</sup> The 2021 revenue was approximately 10% of EU ETS revenue based on International Carbon Action Partnership (2022).

<sup>51</sup> Koukouloufikis, G. and Uihlein, A., Energy poverty, transport poverty and living conditions - An analysis of EU data and socioeconomic indicators, EUR 31000 EN, Publications Office of the European Union, Luxembourg, 2022, ISBN 978-92-76-48396-0, doi:10.2760/198712, JRC128084

<sup>52</sup> Eurostat [ILC\_MDES01] Inability to keep home adequately warm.

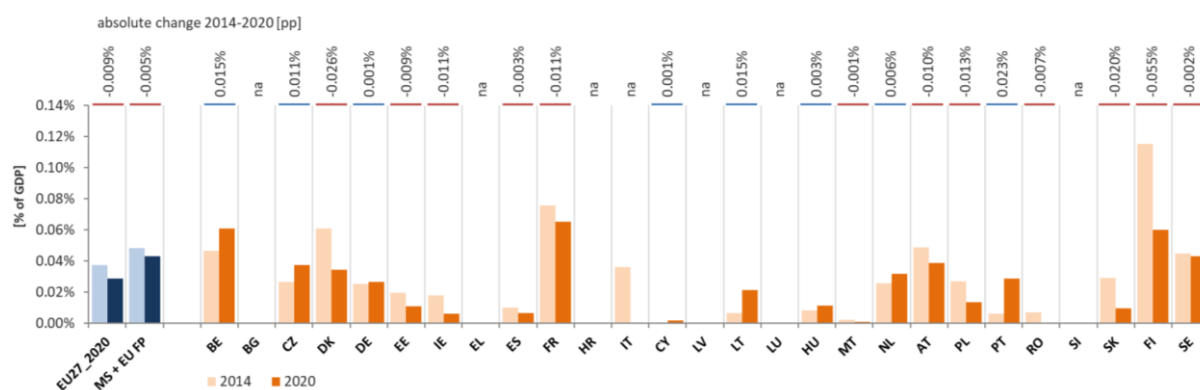
<sup>53</sup> Recommendation on Energy poverty [(EU) 2020/1563

<sup>54</sup> Tackling rising energy prices: a toolbox for action and support (COM (2021) 660

<sup>55</sup> IEA, World Energy Investment 2022

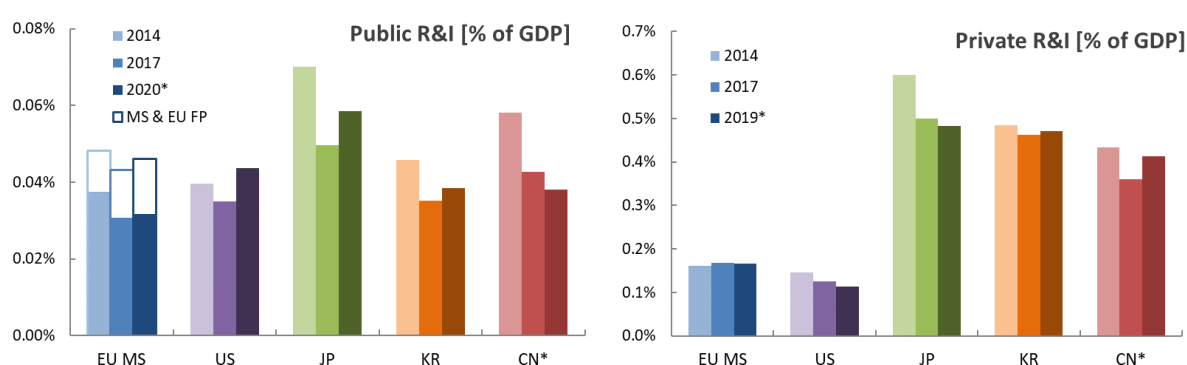
a share of the GDP, investment in public R&I, at Member States and EU level, remains below the levels observed prior to 2016 (Figure 4). Already in 2020, Horizon 2020 funds supporting Energy Union R&I priorities added EUR 2 billion to what was contributed by the Member States national programmes. This provided a vital boost to research and innovation in the EU. While national contributions alone remain low among major economies, if Member States and Horizon 2020 funds are added together, the EU ranked second in public R&I investment among major economies in 2020 (**Figure 5**)<sup>56</sup>, both in absolute spending (EUR 6.6 billion, the US leads with EUR 8 billion); and as share of GDP (0.046%, behind Japan 0.058% and just ahead of US and KR<sup>57</sup>).

**Figure 4:** Public R&I investments in EU MS as a share of GDP since the start of Horizon 2020.



Source: JRC based on IEA<sup>58</sup> and own work<sup>59</sup>.

**Figure 5:** Public and private R&I investments in major economies as a share of GDP



\*public R&I data for China and Italy (in EU total) refer to 2019 ; private R&I data for 2019 are provisional

Source: JRC based on IEA<sup>60</sup>, MI<sup>61</sup>, own work<sup>62</sup>.

<sup>56</sup> The graph overlaps the first two categories of Figure 4 for the EU. The values in the two figures are slightly different, as **Error! Reference source not found.** includes an estimate for Italy.

<sup>57</sup> These figures include MS and EU Framework Programme funds. Last year's report referred to MS funds alone, which are also shown in **Error! Reference source not found.** and remain below other major economies as a share of GDP.

<sup>58</sup> Adapted from the 2022 edition of the IEA energy technology RD&D budgets database.

<sup>59</sup> JRC SETIS [https://setis.ec.europa.eu/publications/setis-research-and-innovation-data\\_en](https://setis.ec.europa.eu/publications/setis-research-and-innovation-data_en)

<sup>60</sup> Adapted from the 2022 edition of the IEA energy technology RD&D budgets database.

<sup>61</sup> Mission Innovation Country Highlights, 6th MI Ministerial 2021

<sup>62</sup> JRC SETIS [https://setis.ec.europa.eu/publications/setis-research-and-innovation-data\\_en](https://setis.ec.europa.eu/publications/setis-research-and-innovation-data_en)

## 2.2.2 Private R&I spending

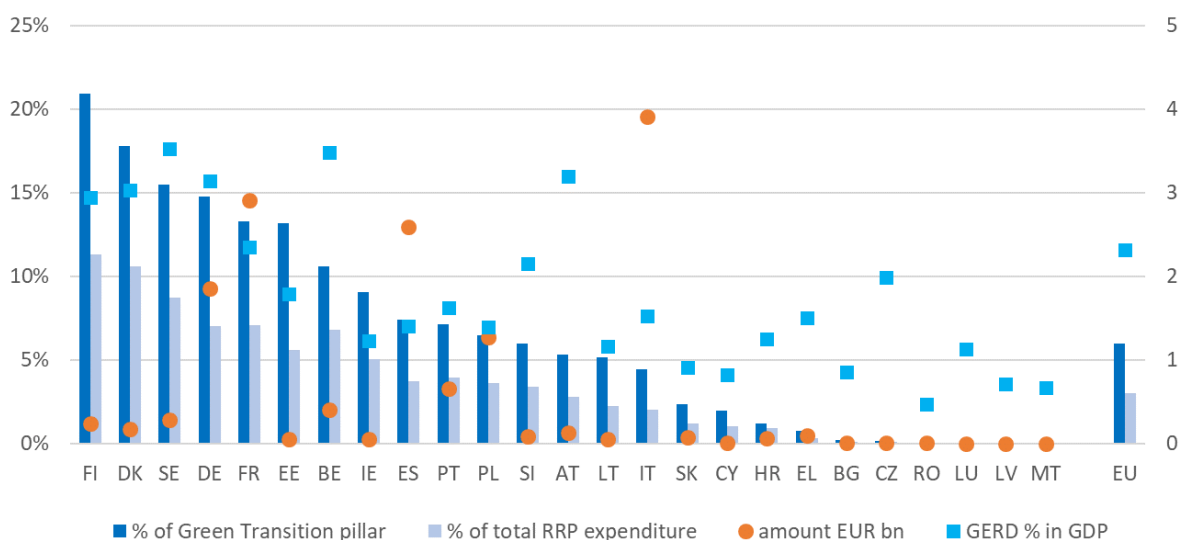
According to global assessments, the corporate sector invests at least three times as much in clean energy R&I as government budgets<sup>63</sup>. Investment by the EU business sector accounts for 80% of the R&I spending in Energy Union R&I priorities. In 2019, the estimated respective private R&I investment was at 0.17% of GDP (**Figure 5**, right-hand side), which also amounts to 11% of the total R&D spending of the business and enterprise sector. Since 2014, the estimates for the EU, the US and Japan show comparable amounts in absolute terms in the respective R&I topics (between EUR 18-22 billion per year). However, in terms of GDP the EU expenditure is above the US, but lower than other major competing economies (Japan, Korea and China).

## 2.2.3 Research, Innovation and the Recovery and Resilience Plans

The reforms and investments proposed by Member States in their Recovery and Resilience Plans (RRPs) have exceeded the climate expenditure target (at least 37% of the RRP's expenditure)<sup>64</sup>. In the 26<sup>65</sup> RRP's approved by the Council by 8 September 2022, measures worth EUR 198 billion are dedicated to the climate transition, representing 40% of the total allocation of these Member States (grants and loans).

The approved RRP's include measures related to research and innovation for a total budget of EUR 47 billion<sup>66</sup>. The Member States have thus far allocated EUR 14.9 billion in their RRP's to R&D&I in green activities. For the most part propensity to allocate a large share to R&D&I, aligns with the R&D intensity of Member States, indicating a similar weight or importance for this activity in the context of the RRP as in their usual government spending (Figure 6). The measures typically aim to reduce the fragmentation of the research system, increase the attractiveness of research careers in public institutions, reduce administrative burden, support knowledge and technology transfer, and improve coordination on R&I policies between different levels of governance<sup>67</sup>.

**Figure 6:** R&D&I in green activities in the RRP's as a share (left axis) and absolute amount (right axis). The R&D intensity vs GDP (right axis) is also given for comparison.



Source: JRC based on ECFIN data

<sup>63</sup> IEA, 2020. Tracking clean energy innovation - A framework for using indicators to inform policy

<sup>64</sup> The progress on the implementation of the Recovery and Resilience Plans can be followed live on the Recovery and Resilience Scoreboard, an online platform set up by the European Commission in December 2021.

<sup>65</sup> AT, BE, BG, CY, CZ, DE, DK, EE, EL, ES, FI, FR, HR, IE, IT, LT, LU, LV, MT, PL, PT, RO, SE, SI, SK.

<sup>66</sup> The figures are based on the pillar tagging methodology for the Recovery and Resilience Scoreboard and correspond to the measures allocated to the policy areas 'R&D&I in green activities', 'digital-related measures in R&D&I' and 'R&D&I' as primary or secondary policy areas. For more information, the Recovery and Resilience Scoreboard is available at: [https://ec.europa.eu/economy\\_finance/recovery-and-resilience-scoreboard/](https://ec.europa.eu/economy_finance/recovery-and-resilience-scoreboard/)

<sup>67</sup> European Commission. Recovery and Resilience Scoreboard, Thematic Analysis, Research and Innovation, April 2022

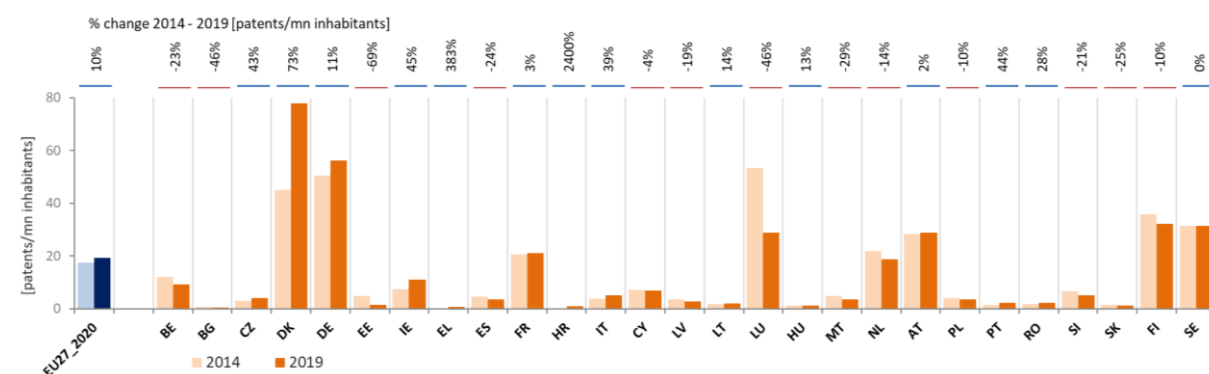


## 2.2.4 Patenting Activity

Half of the Member states have increased their patenting activity since the start of Horizon 2020, including green innovation champions such as Germany and Denmark perform strongly both in absolute numbers and in the share of green patents in their overall innovation portfolio, as indicated in the previous competitiveness progress report. This means that, on average patents per million inhabitant in the EU have increased by 10% in the same period (**Figure 7**), and maintains its good positioning in patents protected internationally, as highlighted in previous reports. Overall, it remains second to Japan in high-value patents relevant to the Energy Union R&I priorities but is a clear leader in renewables and shares the lead with Japan in Energy Efficiency due to the EU specialisation in materials and technologies for buildings. The EU also shows specialisation in renewable fuels, batteries and e-mobility and carbon capture, storage and utilisation technologies.

The previous competitiveness reports included concerns 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. In light of Russia's aggression against Ukraine, both the EPO<sup>68</sup> and the USPTO<sup>69</sup> have decided to freeze co-operation with the patent offices of the Federation of Russia and of Belarus, as well the Eurasian Patent Organisation. Revised Russian legislation<sup>70</sup> that – if enacted – could provide local actors with the ability to use foreign patents without the consent of the patent holders and without paying royalties, further undermines the importance of respecting IP rights and would make it difficult for foreign companies to resume operations in that market. To address IP challenges, there is a need to change the paradigm of knowledge valorisation and focus on broader intellectual assets, beyond protected IP. A new ERA for Research and Innovation<sup>71</sup> calls to update and develop Guiding Principles for knowledge valorisation and a Code of Practice for the smart use of intellectual property (IP). This draft code of practice, providing advice to stakeholders on challenges related to intellectual assets in the current R&I context, was co-created by a community of practice launched by the Commission and is expected by the end of 2022<sup>72</sup>.

**Figure 7:** Patents per million inhabitants in the Energy Union R&I priorities per EU MS since the start of Horizon 2020.



Source: JRC based on EPO Patstat<sup>73</sup>.

## 2.2.5 Scientific Publications

In contrast to previous years (2016-2019), in 2020, there was a slight decrease in scientific publications addressing low carbon energy technologies globally. The EU scientific output also followed this trend, albeit with a more modest increase in the previous period and more pronounced decline in 2020 compared to the global average. The EU contributed just over 16% of the scientific articles worldwide, but was over two times

<sup>68</sup> EPO press release, [Standing together for peace in Europe](#), Munich, 1 March 2022

<sup>69</sup> USPTO statement on [engagement with Russia, the Eurasian Patent Organization, and Belarus](#), March 22, 2022

<sup>70</sup> Decree of the Government of the Russian Federation dated 6 March 2022 No. 299 "On Amending item 2 of the Methodology of calculation of compensation's amount to be paid to patent owner resulted in decision to use invention, utility model or industrial design without patent owner's consent, and procedure of its payment"

<sup>71</sup> COM(2020) 628 final

<sup>72</sup> A new guide is already available on the valorisation of results from Horizon Europe <https://data.europa.eu/doi/10.2826/437645>

<sup>73</sup> JRC SETIS [https://setis.ec.europa.eu/publications/setis-research-and-innovation-data\\_en](https://setis.ec.europa.eu/publications/setis-research-and-innovation-data_en)

above the global average in terms in publications per population<sup>74,75</sup>. Nonetheless, the EU specialisation in clean energy research has been decreasing between 2016 and 2020, as scientific output is more intensive in fields such as psychology and cognitive sciences, economics and business, and clinical medicine, at the expense of e.g. information and communication technologies, and engineering. This is consistent with the observation that, after an initial advantage, high-income economies no longer dominate topics related to clean energy and innovation<sup>76</sup>. Nonetheless, EU scientists collaborate and publish internationally well above the global average, and show a higher level of collaboration between the public and private sectors. Notably, four EU funding mechanisms are among the top 20 acknowledged in supporting clean energy science in the period 2016-2020, Horizon 2020, listed among the top 10<sup>77</sup>.

## 2.2.6 Coordinating R&I efforts in the EU and global context

Launched in 2007, the Strategic Energy Technology Plan (SET Plan) constituted a first step to establish an energy technology policy for Europe. The overall objective of the SET Plan is to provide a common vision, goals and coordination in accelerating the development and deployment of efficient and cost-competitive low-carbon technologies, and to enhance the EU's geo-political resilience and security of energy supply. Under its umbrella, the SET Plan is gathering experts from governments, industry, and research institutes in the EU and Associated Countries to develop research and innovation roadmaps for key energy technologies.

The SET Plan was updated in 2015, proposing 10 Actions supported by a new structure with European Technology and Innovation Platforms (ETIPs) developing Strategic Research and Innovation Agenda's, and 14 corresponding Implementation Working Groups (IWG) to accelerate the energy system transformation. The SET Plan played a central role in implementing the Research, Innovation & Competitiveness dimension of the Energy Union, and in guiding national energy research strategies, as reflected in the National Energy and Climate Plans. Thus, the role of the SET Plan is crucial in coordinating national R&I agendas on low-carbon energy.

One of the key recent contributions of the SET Plan actors towards European cross-sectoral cooperation is the establishment of the European Clean Energy Transition Partnership (CETP)<sup>78</sup>. Emanating from the SET Plan implementation plans, many of the working groups (e.g. Solar PV, Wind, Geothermal, Positive energy districts, Energy systems, Energy efficiency in industry and buildings and others) have been successfully involved in the strategic design of the topics within the CETP, including co-authoring input papers and contributing to the development of the Strategic Research and Innovation Agenda (SRIA). The collaboration under the CETP is expected to boost and accelerate energy transition in all its dimensions. In addition, it will enable joint R&I programmes from regional to national and global level, co-supported by industry, public organisations, research and citizens' organisations to make Europe a frontrunner in energy innovation.

In a rapidly changing policy context, the SET Plan must align the EU, national and industrial research & innovation objectives with the European Green Deal, Fit for 55, REPowerEU, and the new European Research Area (ERA) Agenda. To this end, by the end of 2022, the Commission is preparing a new SET Plan Communication. The renewed SET Plan will aim to tackle the following pressing needs:

- increase the performance and cost efficiency of clean energy technologies as well as the efficiency and resilience of clean energy value chains, including at industrial manufacturing level;
- accelerate the development and the deployment of clean energy technologies;
- define an overall strategy to exploit synergies between R&I strategies and the innovation landscape at national, European and international level, and limited synergies between the various instruments for financial support for R&I at national and EU level;
- pay more attention to cross-cutting issues, such as environmental needs (sustainability, circularity, best use of resources) and social needs (health, safety, security, availability and affordability of energy, public engagement);

<sup>74</sup> European Commission (2022), Publications as a measure of innovation performance: Selection and assessment of publication indicators. Report in progress under tendered study 2018/RTD/g1/OP/PP-07481-2018 authored by Provencal, S; Khayat, P., and Campbell, D., Science Metrix.

<sup>75</sup> The study focused on SET Plan key actions: No 1 in Renewables, Smart Solutions for Consumers, Smart, Resilient and Secure Energy System, Energy Efficiency in Buildings, Energy Efficiency in Industry, Batteries and e-Mobility, Renewable Fuels and Bioenergy, Carbon Capture Utilisation and Storage, Nuclear Safety

<sup>76</sup> UNESCO (2021) UNESCO Science Report: the Race Against Time for Smarter Development. S. Schneegans, T. Straza and J. Lewis (eds). UNESCO Publishing: Paris.

































<sup>77</sup> Elsevier (2021) Pathways to Net Zero: The Impact of Clean Energy Research, Elsevier Analytical Services

<sup>78</sup> <https://cetpartnership.eu/>

- consider challenges to the energy transition which have emerged since the creation of the SET Plan, such as the availability of critical materials, digitalisation, technology dependence and resilience, amongst others;
- address the increasing role of enabling technologies or fuels, such as energy storage, smart grids and hydrogen;
- reinforce the Research, Innovation and Competitiveness chapters in the National Energy and Climate Plans.

The Communication on 'EU external energy engagement in a changing world' envisages the intensification of international cooperation and the development of partnerships supporting the green transition on crucial topics, such as green hydrogen globally, access to raw materials, or innovations. To advance international cooperation on energy innovation and technology, the EC continues its engagement in Mission Innovation (MI) and the Clean Energy Ministerial. After successful first five years, MI 2.0 was launched with a new set of 'Missions'. The EU co-leads the Missions on clean hydrogen and urban transition (Table 2). In addition the EC is part of the MI Secretariat and Technical Advisory Groups, which support all MI Missions.

**Table 2:** EU participation in Mission Innovation 2.0

Missions	Co-Lead	Core Group	Support Group
Zero-emission shipping			
Clean hydrogen		  	
Green powered future			   
Carbon dioxide removal			
Urban transitions		 	
Net Zero industries		  	
Integrated biorefineries			
<b>Innovation Platform Collaborate</b>			
International Sustainable Aviation Fuels		  	
Materials for Energy		  	
Affordable Heating and Cooling of Buildings		  	

Source: JRC based on MI

## 2.2.7 Venture Capital Investments in Climate Tech Firms and Clean Energy Technologies

EU climate tech<sup>79</sup> start-ups and scale-ups have attracted an increasing amount of venture capital (VC) investment<sup>80</sup> over the last 6 years. Worldwide, VC investments in the climate tech domain (start-ups and scale-ups) reached EUR 40.5 billion in 2021<sup>81</sup>, an increase of 100 % compared to 2020 (EUR 20.2 billion).

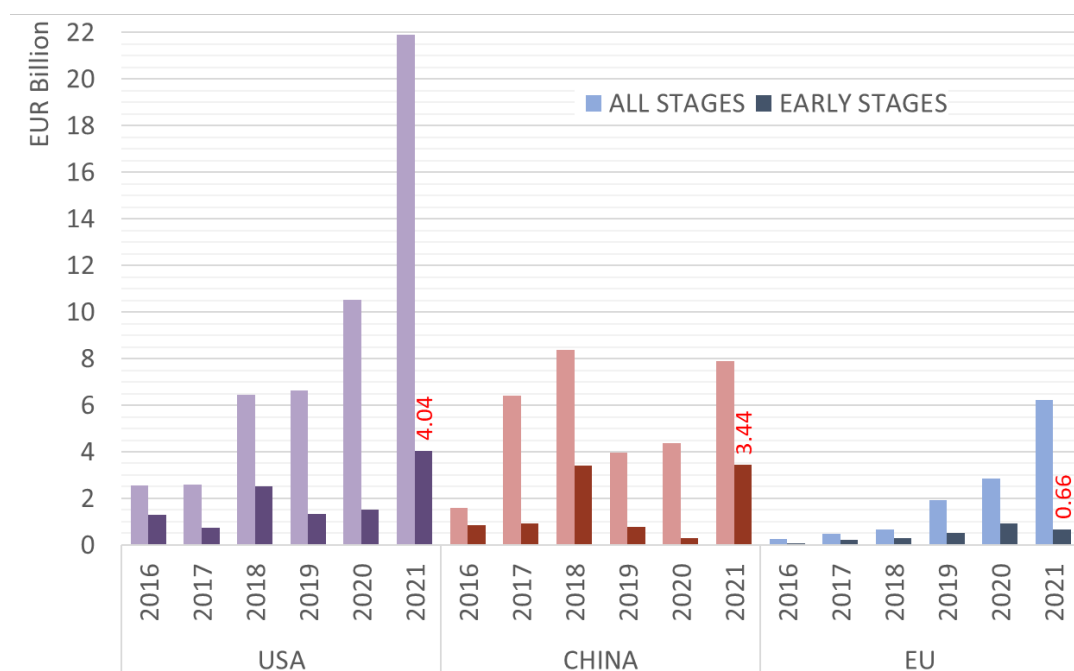
In 2021, EU climate tech firms attracted EUR 6.2 billion of VC investments, more than a twofold increase (x 2.2) as compared to 2020. The EU currently accounts for 15 % of global climate tech investments and showed impressive resilience during the Covid pandemic with higher levels of investments already in 2020 and new all-time highs in 2021. With an outstanding growth of its later stages investments, the EU also reported, for the first time, a higher value of later stage investments than China. Early stage investments in EU climate tech firms however peaked in 2020, whereas they reached new highs in the US and China in 2021 [Figure 8].

<sup>79</sup> PitchBook's Climate Tech vertical is a selection of 2 760 companies that are developing technologies intended to help mitigate or adapt to the effects of climate change. The majority of companies in this vertical are focused on mitigating rising emissions through decarbonisation technologies and processes. Applications within this industry vertical include renewable energy generation, long duration energy storage, the electrification of transportation, agricultural innovations, industrial process improvements, and mining technologies, among others.

<sup>80</sup> Venture capital deals are defined as early stage deals (including pre-seed, accelerator/incubator, angel, seed, series A and B occurring within 5 years of the company's founding date) and later stage deals (usually series B to series Z+ rounds and/or occurring more than 5 years after the company's founding date, undisclosed series and private equity growth / expansion).

<sup>81</sup> Accounting for 5.2 % of total VC funding in 2021 according to JRC elaboration based on PitchBook data (as compared to 4.6 % in 2020).

**Figure 8** - Venture capital investments in climate-tech start-ups and scale-ups



Source: JRC elaboration based on PitchBook data

Worldwide, the energy sector accounted for 22% of VC investments in climate tech firms in 2021, with clean energy generation<sup>82</sup> and grid technologies<sup>83</sup> taking 13.2 % and 8.7 % of global VC investments respectively. This positions the energy sector (22 %) behind transport and mobility (46 %) and for the first time, ahead of food and land use (19.6 %), but also above its historical share (the energy accounted for 16 % of the VC investments in climate tech firms since 2016).

Investments in electric vehicles (EV), EV battery technologies and e-mobility have historically been the main drivers of climate tech VC investments. The share of transport and mobility however peaked in 2018, largely due to a shift away from companies developing micro-mobility solutions<sup>84</sup>. In the EU however, its share continued to grow with investments in several application segments and some of EU's largest deals<sup>85</sup> (**Figure 9**). As a consequence and despite increasing VC investments in the EU, the US has – since 2016 – invested a higher share in the energy sector (20.2 %) compared to the EU (17.3 %) and China (less than 4.1%).

In the energy sector global VC investments in climate tech firms surged in 2021, amounting to EUR 8.8 billion worldwide. With levels more than three times higher (x 3.8) than in 2020, investments in clean energy generation technologies were the main driver of this growth. Pushed by some large investments in nuclear fusion in the US and wind in China, they increased much faster than those for grid technologies (x 2.4) and climate tech VC investments in general.

In the EU, VC investments in energy firms also increased significantly in 2021 (x 1.6 as compared to 2020, amounting to EUR 887 million in 2021), confirming the sustained growth seen over the past 4 years. Despite this good performance, the overall EU share halved in 2021. With 10 % of VC investments in energy firms, the EU ranks 3<sup>rd</sup> far behind the US (62 %) and China (13.3 %), both of which enjoyed outstanding 2021 investment levels, driven by megadeals in clean energy generation. [**Figure 10**]

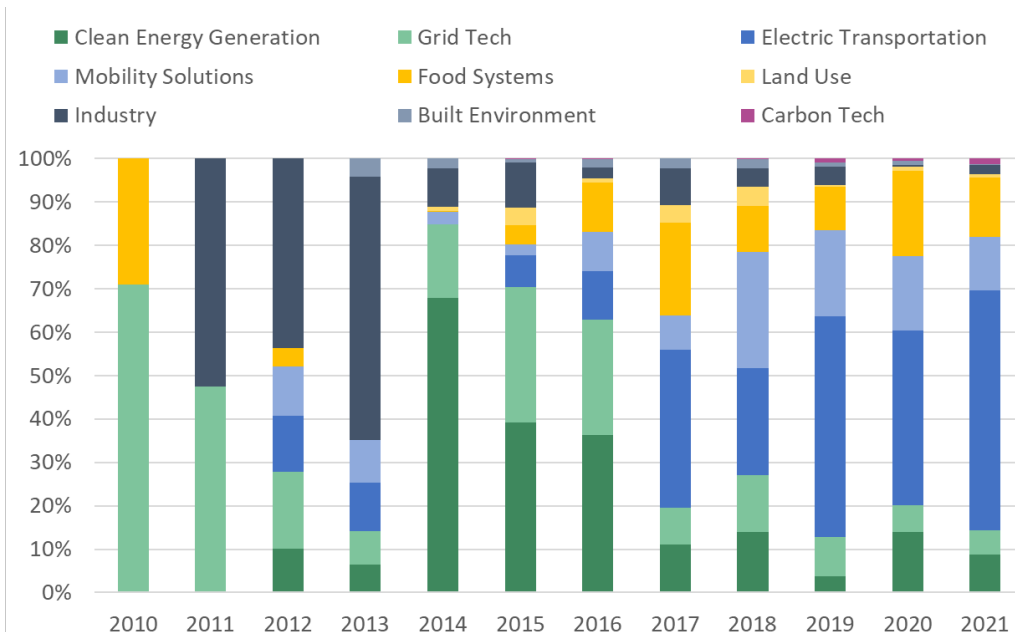
<sup>82</sup> Including solar, wind, nuclear, waste-to-energy, ocean & hydro and geo-thermal energy.

<sup>83</sup> Including long-duration energy storage, grid management, analytics, battery technology, smart grid and clean hydrogen production.

<sup>84</sup> Light electric vehicles addressing the “last-mile” problem in the urban transport sector.

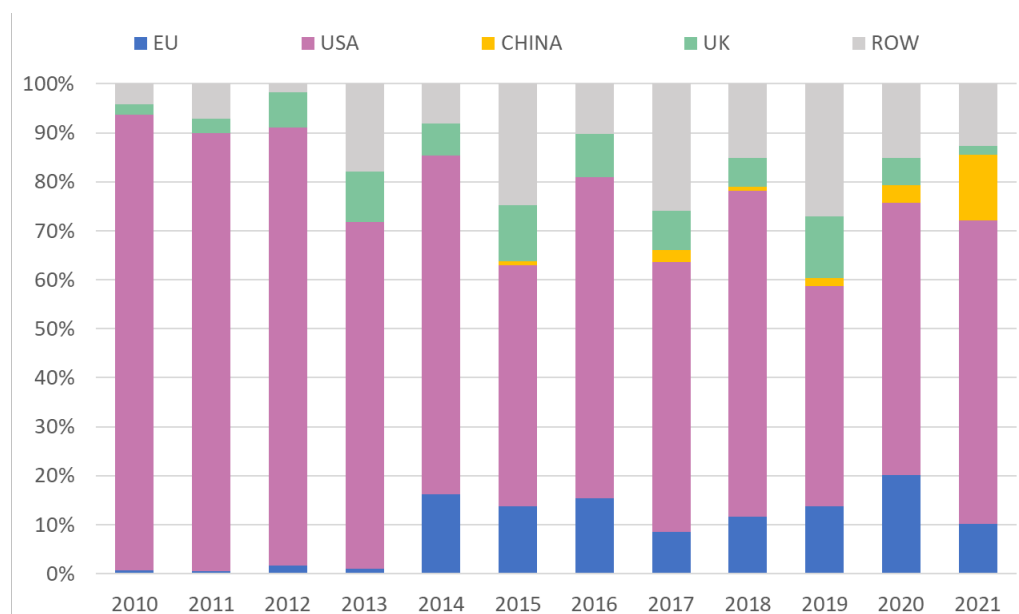
<sup>85</sup> Including EV battery technologies (Northvolt, Lithium werks), aircraft (Lilium, Volovopter), Electric Vehicles (Rimac Automobili, Einride) and micro-mobility (TIER, Voi, VanMoof).

**Figure 9 - Share of VC investments in EU Climate Tech firms, by application segment.**



Source: JRC elaboration based on PitchBook data

**Figure 10 - Share of VC investments in Energy Climate Tech firms, by firm location.**



Source: JRC elaboration based on PitchBook data

Nuclear technologies accounted for half of the 2021 global VC investments in energy generation technologies (i.e. EUR 2.8 billion and 7 % of global Climate tech VC investments in 2021), corresponding to an impressive ten-fold increase compared to investment levels in previous years. Several competing North American scale-ups<sup>86</sup> have attracted large investments in 2021, aiming in particular at the development of commercial demonstrators for the production of nuclear fusion energy. In 2021, VC investments in identified EU Climate Tech firms developing nuclear technologies only amounted to EUR 5.5 million.

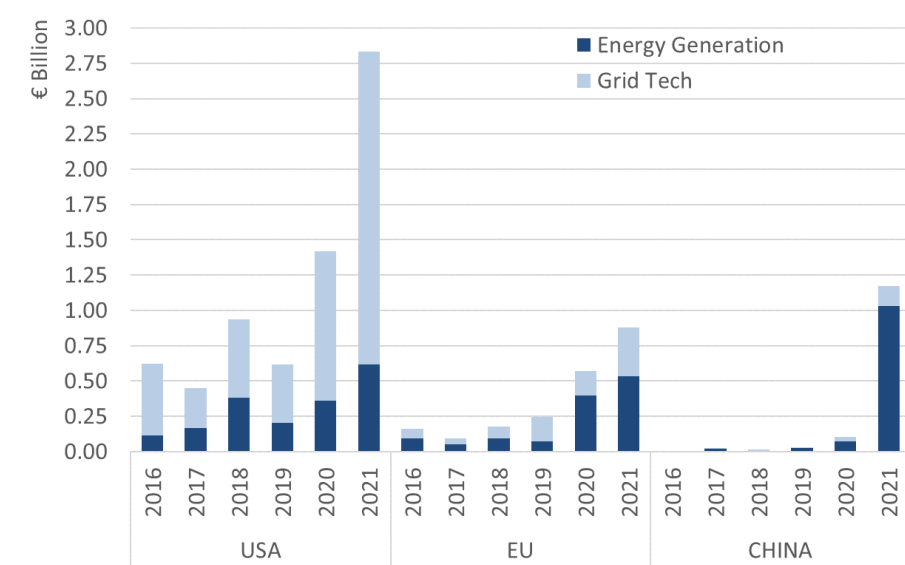
<sup>86</sup> This includes in particular a € 1.5 billion mega deal in US company Commonwealth Fusion Systems as well as large deals in Helion Energy (US), TAE technologies (US) and General Fusion (CA) developing solutions for the commercial production of nuclear fusion energy, and to a lesser extent, in NuScale (US) developing Small Nuclear Reactor solutions (fission).

If nuclear technologies are omitted from the analysis, the EU accounts for 15 % of VC investments in climate tech firms in the Energy sector (clean energy generation, 9 % and Grid Tech, 6 %), behind the US (47.5 %) and China (19.5 %).

VC investments in EU firms developing clean energy generation technologies other than nuclear continued to grow in 2021 (x 1.3). The main driver was investments in solar supported by late stage deals Germany and the Netherlands<sup>87</sup>. Although the EU was on par with the US in 2020 to lead on both early and late stage investments, in 2021 it ranked 3<sup>rd</sup>, losing momentum with decreasing early stage investments and a lower increase in late stage investments. Early stage investments in solar, which were largely predominant in the EU and higher than in the US in 2020, decreased in 2021, both in the EU and in the US. The US took the lead back in 2021 with increasing early and later stage investments in geothermal and waste-to-energy technologies. While VC investments in Chinese energy generation firms have been historically lower than in the US and EU, a mega expansion deal in a developer of wind and related smart technologies<sup>88</sup> put China in a lead position in 2021. This confirms the success of Chinese high-growth companies in rapidly attracting large scale-up and expansion investments, as repeatedly seen in the transport sector over the past years. **[Figure 11]**

VC investments in EU firms developing grid technologies doubled in 2021 (x 2 as compared to 2020), driven by long-duration energy storage (x 7.8) and clean hydrogen production (x 5.8) with larger late stage deals in Germany and France<sup>89</sup> respectively. VC investments in EU firms developing Grid Management & Analytics solutions however peaked in 2019 and even halved in 2021. With higher investment levels, in particular in battery technologies that were somewhat over -looked in the EU, the US maintained a leading position, far ahead of the EU and China. **[Figure 11]**

**Figure 11 – VC investments in Energy Climate Tech firms, by location and segment (excluding nuclear technologies)**



Source: JRC elaboration based on PitchBook data

Climate Tech ventures developing digital technologies<sup>90</sup> account for a significant share of the investments in energy ventures realised since 2016 but to a lesser extent than in the early 2010s. While they represented two third of investments in energy ventures before 2016 (both in the EU and the US), digital technologies only account for 29 % of the investments realised in the US since 2016 but still for more than half (54 %) of investments in EU firms.

With fluctuating investments over the past years, the US exhibits a different trend than the EU where investments in digital ventures in the Energy sector have steadily increased, reaching levels almost comparable

<sup>87</sup> Including solar installation companies Enpal (DE) and Zola Electric (NL).

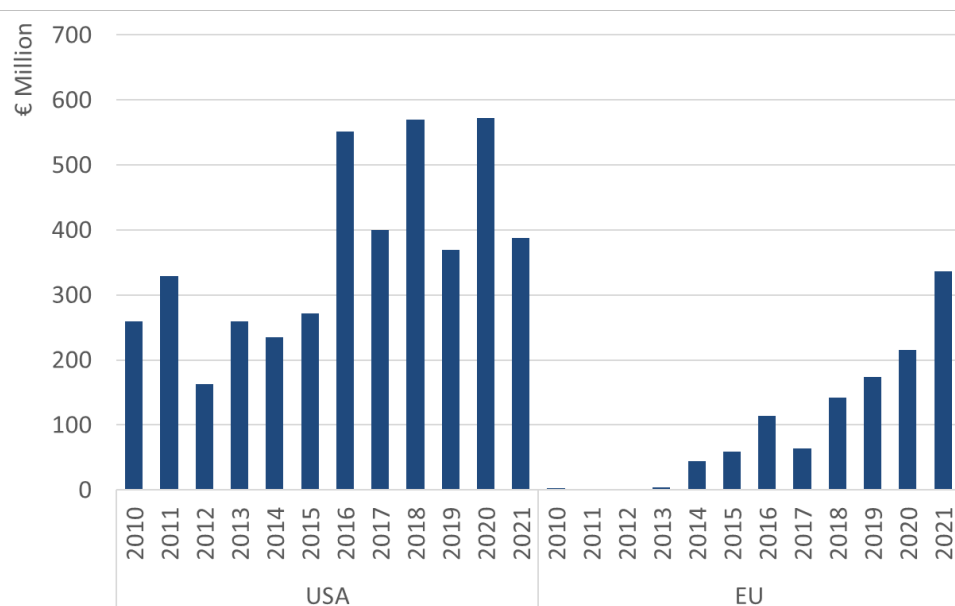
<sup>88</sup> Chinese company ENVISION ENERGY raised € 860.4 million of development capital (PE growth/expansion) in a single deal in 2021.

<sup>89</sup> Including German companies Skeleton Technologies and Hydrogenious LOHC Technologies (long-duration energy storage) and French companies Lhyfe and EODev (clean hydrogen production).

<sup>90</sup> i.e. belonging to the following PitchBook industry verticals: Artificial Intelligence & Machine Learning, Big Data, Cryptocurrency/Blockchain, E-Commerce, FinTech, Internet of Things, Mobile, Mobile Commerce and SaaS.

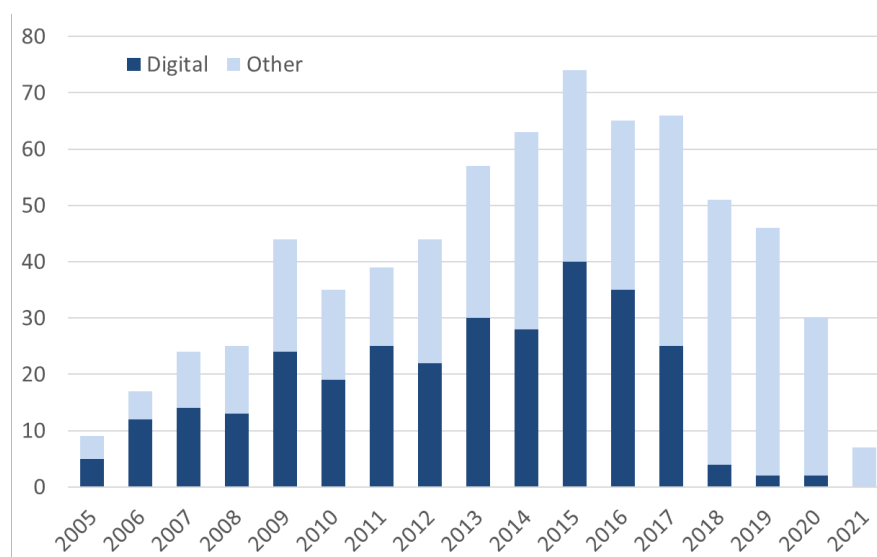
to the US. The creation of new digital Climate Tech ventures in the energy sector has however peaked in 2015, following the overall trend of energy start-up creation, and the share of digital start-ups in new ventures has considerably dropped in 2018. While digital energy investments in Chinese Climate Tech firms have been historically low, the mega 2021 deal in the Chinese wind sector will contribute to improve its position in smart energy management software and internet of things (IoT) in particular. [Figure 12, Figure 13]

**Figure 12** - VC investments in digital Climate Tech firms in the Energy sector, by firm location



Source: JRC elaboration based on PitchBook data

**Figure 13** - Number of new Climate Tech firms created by year in the Energy domain and share of new digital ventures



Source: JRC elaboration based on PitchBook data

Over the past 3 years, larger deals in the Transport and Mobility domain have permanently impacted the EU Climate Tech funding landscape. It demonstrated that where the EU manages to foster the development of high-growth potential firms, it also manages to attract the interest of investors and increasingly competitive level of investments.

Looking at clean energy firms<sup>91</sup> across all sectors confirms the progress achieved in reducing the funding gap with the leading investment hubs that are the US and China, as compared to the first half of the previous decade. It also highlights their better performance of EU clean energy firms in attracting early and later stage investments – one of EU's main weakness – than EU VC firms in general. Indeed, the EU attracted:

- 10.8 % of all recent (2016-21) early stage investments in clean energy firms, against the 37.2 % and 45.6 % received by the USA and China, respectively and against the 5.3 % previously received by the EU (2010-15).
- 14.3 % of all recent (2016-21) later stage investments in clean energy firms, against the 47.5 % and 29.2 % received by the USA and China, respectively and against the 4.1 % previously received by the EU (2010-15).
- 7.2 % of all recent (2016-21) early stage investments and 8.7 % of all recent (2016-21) later stage investments in EU VC firms.

VC investments in clean energy firms however remain subject to very large singular deals that, while contributing in reducing the funding gap, do not reflect the core trends of the majority of deals nor constitute a recurring investment base. In the EU or in the US, VC investments remain concentrated and only 11 % of clean energy firms account for 80 % of VC investments realised since 2016. The sole investments in Swedish EV Battery developer Northvolt<sup>92</sup> have a significant impact on the overall VC investment trends in EU Climate Tech firms over the past years. As the company transitioned towards later investment stages, early stage investments in EU Climate Tech firms decreased in 2021 while later stage investments increased to reach for the first time a higher value than reported in China.

Dismissing such singular deals<sup>93</sup> shows that the EU manages to maintain the competitive position it has developed in a context of accelerating VC investments in clean energy firms worldwide [Figure 14]. Over the past three years, the EU recorder more deals of increasingly larger sizes. Beyond specific technologies<sup>94</sup> however, their size and occurrence remain lower than the ones of the largest deals seen in the US in particular.

In 2021, early stage investments in clean energy firms have doubled (x 2.15) both in the US and in the EU and the EU stands second with a 21.6 % share. Investments in EV Battery technology and Industry<sup>95</sup> are driving the growth of early stage investments in the EU while they have decreased in clean energy generation (in particular solar) and grid management solutions.

In 2021, later stage investments increased in the EU (x 1.6) but less faster than in the US (x 2.3). The EU stands 3<sup>rd</sup> with 15.3 % of investments in 2021. Investments in Solar and Long-duration Energy Storage are driving the growth of EU later stage investments. US investments display a faster increase than in the EU in technologies related to Battery recycling and fuel alternatives in particular.

<sup>91</sup> Subset of all companies selected by PB under its Climate Tech vertical that includes technologies specific to energy generation (except Nuclear), grid management and energy storage, electric transportation, fuel alternatives, energy efficiency, industry and CCUS. It excludes solutions related to mobility (shared mobility, autonomous vehicles, smart infrastructures, and micro-mobility), food systems, land use, the built environment and other carbon techs.

<sup>92</sup> With EUR 3.7 billion of cumulated VC investments since 2017 (and an additional EUR 1.05 Billion later stage deal completed in 2022), the case of the Swedish EV Battery developers Northvolt constitutes a singular success which accounts for 30 % of all VC investments in EU Climate Tech firms realised over the 2016-21 period. It demonstrated the capability of an EU high-growth energy firm to leverage corporate and government venture investors and public debt financing to rally institutional investors beyond traditional VC firms (including pension funds and asset managers) and strategic investors, access to commercial debt and further raise the very large levels of venture funding necessary to an accelerated scale-up.

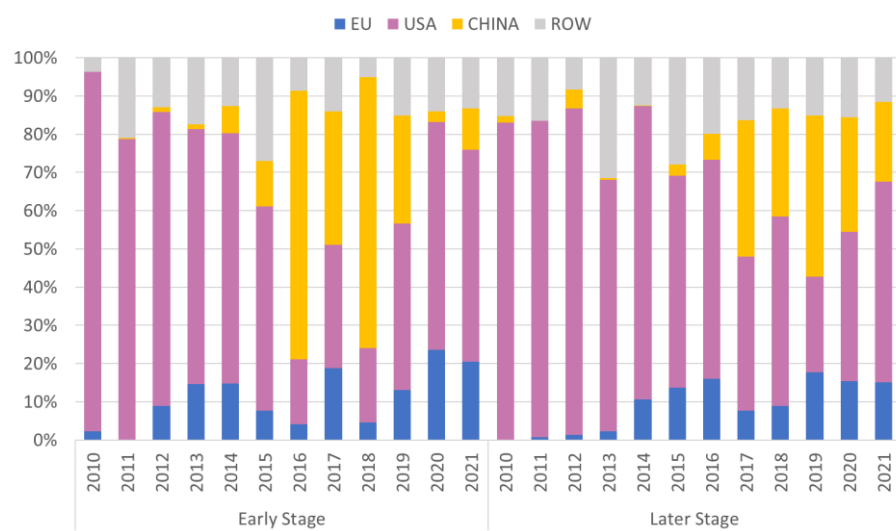
<sup>93</sup> i.e. excluding the few very large deals which value is above the 99th percentile of all clean energy deals for each year and stage (early or late).

<sup>94</sup> e.g. solar where EU investments in German installation services provider Enpal is the largest solar deal recorded in 2021.

<sup>95</sup> In particular in the French Battery manufacturer Vekor and in the Swedish company H2 Green Steel leveraging green Hydrogen to decarbonize the production of steel.



**Figure 14** - Share of VC investments in clean energy firms<sup>91</sup>, by firm location and stage of investments, excluding large singular deals<sup>93</sup>.



Source: JRC elaboration based on PitchBook data

A closer look at firms developing and manufacturing CETO technologies provides further insights on the current situation and challenges faced by the different ecosystems.

### COMPETITIVE VC ECOSYSTEMS

1. **SOLAR:** Worldwide investments in solar PV solution developers increased sharply in 2021, surpassing the highest levels seen in the early 2010s. With an actively funded base of VC companies, the EU has significantly strengthened its competitive position as compared to the 2010-15 period and accounts for 16 % of investments realised since 2016 (both early and late). Despite a continuous growth of investments in EU firms, EU's share peaked in 2020 with the acceleration (in number and average deal size) of later stage investments in China and the US that host a stronger base of VC companies. Early stage investments in the EU peaked in 2020 and remain supported by lower grant funding levels than in the rest of the world.

### STRONG VC COMPANY BASE BUT LOW INVESTMENT LEVELS

2. **HEAT PUMPS:** Global investments in heat pump solution developers have steadily increased since 2016 to an all-time high in 2021. The EU hosts half of the identified VC companies and has repeatedly succeeded in attracting higher levels of later stage investments as of 2015 and holds a competitive position with 43 % of later stages investments over the current 2016-21 period. With a peak in 2017 and decreasing investments since, this position is however challenged by three US firms<sup>96</sup> that attracted much larger deals (both early and late stage) over the past two years and account for 60 % of investments seen since 2016. As a result and due to already low level of investments, the EU only accounts for 10 % of early stages investments realised since 2016.
3. **BIOMASS:** After a soft patch from 2016 to 18, global VC investments in bioenergy ventures are back on a growth path. The EU accounts for a significant share (42 %) of active VC companies over the current 2016-21 period and together, France and Sweden alone challenge the US leadership (22 %). The EU has attracted 24 % early stage investments and 23 % of later stages investments over the current period, strengthening its competitive position. Early stages investments in the EU however remained significantly dependent on grants and with a very limited number of new VC companies since 2016, are almost null in 2020 and 2021. Later stage investment levels, in the EU or elsewhere, however remain low as compared to other technologies.
4. **OCEAN:** With 43 % of identified VC companies, the EU has a strong though ageing company base to develop a leadership. Over the current 2016-21 period, the EU however only accounts for 22 % of early stage investments due to higher levels of investments in the US and the UK and a very limited number of new VC companies over that period. While the EU accounts for a large share of late stage (51 %) investments

<sup>96</sup> US companies Dandelion Energy, Stone Mountain Technologies and Thermolift.

realised since 2016, almost half of those investments have been realised in a single deal back in 2016. The essential of growth and expansion investments is realised in more recent deals in the US and the UK (resp. accounting for 24 % and 18 % of later stages investments over the current period). The remaining investments realised in the EU are scattered in smaller sized deals across several companies that may be insufficient to ensure a competitive scale-up of EU companies.

5. WIND: Driven by a mega expansion deal and higher levels of investments in the scaling up of its onshore wind firms, China is taking a strong lead in the competitive investment race. Despite established bases of VC companies, investments in the US and the EU have decreased as compared to the previous 2010-15 period. A rebound of investments in early onshore ventures (however mostly relying on grants) enables the EU to harness 21 % of investments realised since 2016 and to increase its competitive position. Discarding the Chinese mega expansion deal seen in 2021, the EU maintains its competitive position 14 % of late stage investments in onshore wind. The acceleration of later stage investments in offshore wind firms in the UK and the US however reduces EU's share to 16.5 % and significantly weakens its competitive position in Offshore wind.

### **EMERGING VC ECOSYSTEMS (STILL) AT RISK**

6. CCUS: While global investments have more than doubled in 2021 and reached all-time highs, the EU only accounts for a very low share of early and late stage investments (resp. 2 % and 4 %). The number of identified VC companies located in the EU is very limited and most of them have been created during the 2016-21 period. Five non-EU companies attracted the essential of VC investments since 2010 and benefited from the support of EU corporate VCs across different potential application sectors.
7. HYDROGEN: Worldwide investments in clean hydrogen production firms more than doubled (x 2.3) in 2021. With growing investment levels, the EU has harnessed 43 % of late stage investments realised since 2016 and significantly improved its competitive position as compared to the 2010-15 period. The EU however faces a risk of being out paced as later stages investments in the rest of the world have quadrupled in 2021 alone (amounting to as much as all EU later stages investments realised since 2016). A large share (40 %) of identified EU VC companies has also been founded during the 2016-21 period and investments in early ventures (which rely essentially on grants) have increased much faster in the US than in the EU. As a consequence, the EU only accounts for 19 % of the early stage investments realised since 2016.
8. BATTERY: Worldwide investments in battery technology developers skyrocketed in 2021 (amounting to more than all investments realised since 2010). Both early stage and later stages investments reached all time-highs in 2021, supported by a few mega deals in EV battery manufacturers in Sweden and China<sup>97</sup>. As compared to the 2010-15 period, the EU has significantly strengthened its competitive position and respectively accounts for 17 % and 27 % of early and late stage investments realised since 2016. Almost half (46 %) of identified EU VC companies have however been founded during the 2016-21 period and the share of VC companies located in the EU remains significantly lower than in the US and China. Moreover, while most of EU firms have attracted funding over the current period, investments are very concentrated in the EU and a very limited number of firms has attracted almost all of the investments realised in the EU. While investments in US EV battery manufacturers are lower in 2021, as compared to China or the EU, the US is taking an undisputable lead in Grid applications and recycling technologies.

### **VC ECOSYSTEMS UNFIT TO HARNESS INVESTMENTS**

9. BIOFUELS: In 2021, worldwide investments in biofuel firms are dropping towards all time low since 2010. Only 38 % of all identified VC companies has actually received funding over the period and investments realised since 2016 are lower than those realised over the previous 2010-15 period. With a weak base of venture capital companies (no new venture creation) and with smaller deals than over the past period, the EU only accounts for 7 % of early stage investments and 4 % of later stages investments over the period. A few champions located in the US and CA harness the essential of early stage investments (mostly in the form of grants) and of the later stage investments via large deals.
10. CSP&H: The number of identified VC companies, in particular in the EU, is very limited and the current investment levels seen worldwide are much lower than in the beginning of the previous decade. Following a long period of low activity, recent deals confirm a renewed interest but remain concentrated in a few

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<sup>97</sup> Including in Swedish company Northvolt (€ 2.6 billion, later stage VC) and Chinese (Svolt, € 2.6 billion, early stage VC and China aviation Lithium Battery, € 1.5 billion, PE growth)

companies (mostly US based). The EU only attracted 7 % and 8 % of early (mostly grant) and later stage investments respectively, to the benefit of a single company.

11. HYDROPOWER: The number of identified VC companies, in the EU or the US, is very limited and the EU has not seen the creation of any new venture since 2016. While global investments realised since 2016 have increased as compared to the previous period, they remain among the lowest as compared to other technologies and 2021 displays a sharp drop (both early and late stage). The EU holds a competitive position with 28 % of early stage investments over the 2016-21 period and despite the absence of reported grants (while they constitute the essential of early stage investments in the rest of the world). The level of later stages investments in the EU over the period is very low (9 %) and even null over three of six last years. Later stages investments in the rest of the world constitute the essential (85 %) of all VC investments and are mostly concentrated in the last 4 years and in United States.

## 2.3 Human Capital and Skills

### 2.3.1 Employment in clean energy

EU total employment in renewable energy sector totalled 1.3 million in 2020<sup>98</sup>. Overall, since 2015, EU total employment in the renewable energy sector has remained at about 1.3 million. The main change has occurred in the composition of jobs. In 2020, heat pumps overtook solid biofuels<sup>99</sup> and wind energy, as the biggest employer, accounting for 24% of all jobs in renewables. Solid biofuels and wind each contribute about one fifth of the total jobs.

The biggest growth of jobs from 2019 to 2020 (at over 25%<sup>100,101</sup>), was seen in heat pumps and wind energy sector<sup>1</sup>. The other renewables remained stable or slightly declined. Favourable policy and market conditions have led to booming sales of heat pumps<sup>102</sup> especially in Poland, Denmark, Hungary, Germany and the Netherlands<sup>103</sup>, and the positive job creation development is likely to continue with REPowerEU plans to accelerate decarbonisation of buildings, and new product offerings becoming available for the renovation sector<sup>104</sup>. Since the previous edition of the Competitiveness Progress Report (2021), wind energy sector employment started to grow again, thanks to capacity additions in the Netherlands, Portugal, Poland and Belgium<sup>1</sup> in 2020. Growth is expected to continue to 2021, which saw even greater capacity additions<sup>105</sup>. Overall, solar PV sector has had a positive development and jobs have more than doubled since 2015. Despite supply chain difficulties<sup>106</sup> in 2021, solar PV employment is foreseen to continue to grow.

Eurostat<sup>107</sup> data, which looks at broader clean energy sector<sup>108</sup>, supports the view that declining employment trend in the renewable energy sector seen up to 2018 has been reversed, and stood at 1.8 million in 2019 (the latest available year). Employment in renewables grew by 11% and employment in energy efficiency and management by 7% from 2018 to 2019, outpacing the overall economy that grew only by 1% in the same timeframe<sup>109</sup>.

<sup>98</sup> EurObserv'ER, 2022. The state of the renewable energies in Europe – Edition 2021 20<sup>th</sup> EurObserv'ER Report.

<sup>99</sup> Methodological revisions have affected especially biofuel data, which is updated based on project data from the Horizon 2020 project ADVANCEFUEL.

<sup>100</sup> EurObserv'ER methodology is based on investment expenditures ('follow the money approach') without taking fully into account the time span of the employment effect. This results in swings between years, which does not necessarily reflect the reality. Therefore, changes between years are only indicative as they are susceptible to investment expenditures those years.

<sup>101</sup> All other renewable energy sectors experienced some contraction in 2020 compared to 2019. Due to some updates to the methodology, employment figures for 2019 were corrected downwards.

<sup>102</sup> This refers to heat pumps used for heating mainly.

<sup>103</sup> EurObserv'ER 2022. Heat pump barometer 2021

<sup>104</sup> EHPA. 2022. European Heat Pump Market and Statistics Report 2021.

<sup>105</sup> EurObserv'ER 2022. Wind energy barometer 2022; EurObserv'ER 2021. Wind energy barometer 2021.

<sup>106</sup> EurObserv'ER 2022. Solar PV barometer 2022.

<sup>107</sup> Employment in the environmental goods and services sector [env\_ac\_egss1]

<sup>108</sup> Clean energy sector figures in the report refer to data 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. CREMA 13B - Heat/energy saving and management includes heat pumps, smart meters, energetic refurbishment activities, insulation materials, and parts of smart grids. 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.

<sup>109</sup> Eurostat [lfsi\_emp\_a].

EU Member States position differently in the clean energy value chain<sup>110</sup>. In Denmark, Croatia, Latvia, Austria, Portugal, Finland, Belgium, Czechia, Germany and Estonia over 40% of renewable energy jobs were in the manufacturing according to the latest available data. For example, export sales constitute an important source of wind jobs in manufacturing countries such as Germany, Spain and Denmark<sup>111</sup>. While, in countries like, Poland, Romania, Slovenia, Sweden, and Lithuania, majority of jobs (over 40%) were in the renewable energy generation, in other words operation, maintenance, etc. In France, 40% of jobs were in the construction, in other words installation stage, and another 40% was in generation. In Spain, jobs were more evenly spread along the value chain, and a significant share came also from scientific and technical activities.

### Global comparison

Globally renewable energy employment reached 12 million<sup>112</sup> in 2020, with the biggest share of jobs in China (39%) followed by the EU (11%)<sup>113</sup>. Solar PV industry (33%), with 4 million workers, remains the biggest renewable energy employer globally, followed by bioenergy (29%), hydropower (18%) and wind energy (10%). Overall renewables showed their resilience during the pandemic with activity surging already towards the end of 2020 and turning to global skills gaps and shortages. Especially technical skills are in growing demand across the energy industry pushing companies towards automation and digitalisation, which is already seen in falling job intensity in mature technologies such as solar PV and wind<sup>114</sup>. On the other hand, renewable energy jobs are gaining traction within the energy industry (e.g. from oil & gas sector which has many transferrable skills), while on the other hand industry convergence and accelerated digitalisation exacerbate global competition for talent across industries<sup>115</sup>. Within the already internationally mobile energy labour force, Europe was the preferred destination for relocation especially within renewables, however this requires ensuring career development and progression opportunities<sup>116</sup>.

### Recovery from the pandemic

Recovery from the pandemic has been accompanied by supply chain disruptions and employment shortages spilling over from overall economy to clean energy sectors. Manufacturing industry in the EU felt increasing labour and material shortages throughout the 2021 somewhat stabilising in the first half of 2022. Nearly 30% of businesses in manufacture of electrical equipment<sup>117</sup> experienced shortages of labour still in 2022, which is at higher level than the previous peak seen in 2018. This trend is mainly due to the overall economic recovery from the pandemic combined with the clean energy sector inertia in building the skills capacities required by the green and digital transition<sup>118</sup>. The lack of adequately skilled workforce has been highlighted by the Clean Energy Industrial Forum (CEIF), which commits to stepping up efforts and investments in the development of skills, strengthening reskilling and upskilling programmes. As an illustration, CEIF estimates for reskilling and upskilling needs are: 800,000 people in batteries value chain, 250,000 people in offshore renewable energy, 130,000 in the solar heating and cooling, and 400,000 people in heat pump value chain<sup>119</sup>.

<sup>110</sup> This is subject to Member State reporting along NACE activities in the Environmental Goods and Services sector accounts [env\_ac\_egss1].

<sup>111</sup> IRENA and ILO. 2021. Renewable Energy and Jobs – Annual Review 2021. International Renewable Energy Agency, International Labour Organization, Abu Dhabi, Geneva.

<sup>112</sup> Includes direct and indirect employment.

<sup>113</sup> According to IRENA and ILO. 2021. Renewable Energy and Jobs – Annual Review 2021. International Renewable Energy Agency, International Labour Organization, Abu Dhabi, Geneva.

<sup>114</sup> IRENA and ILO. 2021. Renewable Energy and Jobs – Annual Review 2021. International Renewable Energy Agency, International Labour Organization, Abu Dhabi, Geneva.

<sup>115</sup> The Global Energy Talent Index Report. 2022. Airswift, Energy Jobline, London.

<sup>116</sup> The Global Energy Talent Index Report. 2022. Airswift, Energy Jobline, London.

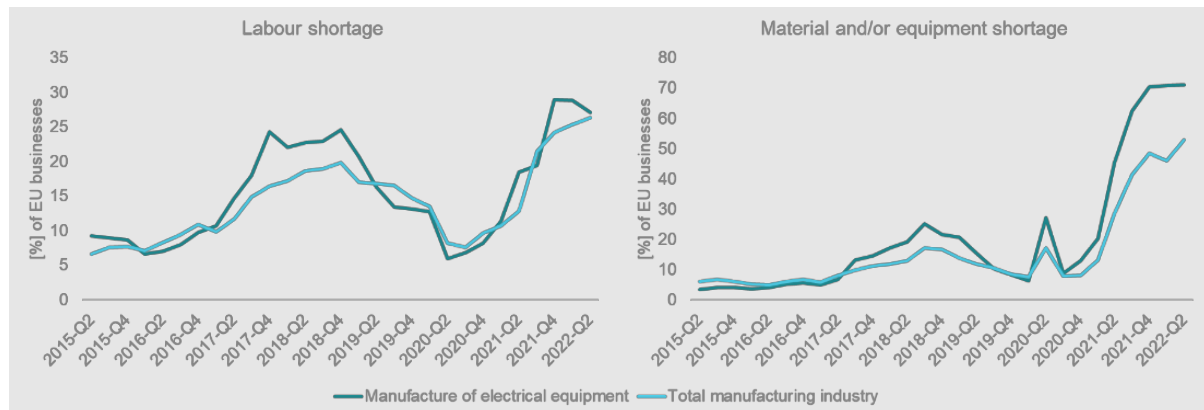
<sup>117</sup> 'NACE 27: Manufacture of electrical equipment' used as a proxy for renewable energy manufacturing industry as many renewable energy technologies fall under this category. It is also used as a proxy for renewables industrial ecosystem in the EU Industrial Strategy [COM(2020)108 final and its recent update COM(2021)350 final].

<sup>118</sup> The inertia is due to various job misalignments, such as spatial, sectoral, occupational and temporal coupled with the fast-paced change towards green and digital while it takes time to build the skills capacity. This is based on, e.g. Czako. 2022. JRC129676 (forthcoming); Asikainen, T., Bitat, A., Bol, E., Czako, V., Marmier, A., Muench, S., Murauskaite-Bull, I., Scapolo, F. and Stoermer, E., The future of jobs is green, EUR 30867 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-42571-7, doi:10.2760/218792, JRC126047; and Cedefop (2022). An ally in the green transition. Cedefop briefing note, March 2022. <http://data.europa.eu/doi/10.2801/712651>

<sup>119</sup> Clean Energy Industrial Forum. Joint Declaration on Skills in the Clean Energy Sector, published 16 June 2022. Available at: [https://ec.europa.eu/info/news/clean-energy-industrial-forum-underlines-importance-deploying-renewables-2022-jun-16\\_en](https://ec.europa.eu/info/news/clean-energy-industrial-forum-underlines-importance-deploying-renewables-2022-jun-16_en)

Compared to labour shortages in the EU manufacturing, material and equipment shortage is even more severe reaching all-time high level in 2022. Over 70% of businesses in the manufacture of electrical equipment<sup>120</sup> faced material shortages, which is significantly higher than in the overall manufacturing industry at 53%.

**Figure 15:** Labour and material shortages experienced by EU businesses in manufacture of electrical equipment and total manufacturing industry [%]



Source: JRC based on Business Survey data from DG ECFIN

### 2.3.2 Skills and training needs

Sufficient workforce with relevant skill sets, at the right locations is an important enabler of a successful green-digital twin transition<sup>121</sup>. Availability of skilled workforce is also a precondition of the successful implementation of the EU Green Deal and the REPowerEU Plan.

Independent of sector or occupation, a set of foundational (cognitive, interpersonal, self- leadership and digital) skills is beneficial for citizens in the labour market in general. In addition, sustainability competences are necessary to perform sustainability-related jobs and to perform other jobs in a sustainable manner. Therefore, sustainability needs to be embedded in all education and training programmes, enabling effective behaviour change through attitudes and value systems. Specialists in using transformative technologies (e.g. data analysis, machine learning, robotics design) are scarce and will be needed across a broad range of industries. Green skills most relevant in the transition of the economy as a whole include hard technical, engineering and scientific skills on the one hand and managerial skills on the other.

The EU is taking action to answer skills related challenges posed by the digital-green twin transition through its overarching skills policy framework represented by the European Skills Agenda. Other related actions include the work of specialised bodies (e.g. CEDEFOP and EIT), reskilling being a key pillar of the Just Transition Mechanism, addressing skills needs in policy guidance issued on ensuring a fair transition towards climate neutrality, and recommendations on individual learning accounts, micro-credentials and learning for environmental sustainability. Funding is available to support formal and non-formal education and training related to the green transition (e.g. under Erasmus+, European Social Fund Plus, Recovery and Resilience Facility, Horizon Europe).

Skills required in clean energy industries are obtainable through formal and non-formal education pathways (vocational education and training including apprenticeships, higher education, on-the-job training, as well as specialized training programmes). Non-conventional training programmes, including certification schemes and company and industrial ecosystem certified programmes often offer a faster response to labour market needs than solutions through formal training systems. In offshore wind, specialized certificates, specialised apprenticeships and hands-on experience play an increasingly significant role across job roles and education levels. In the buildings sector, on-site training of workers with practical exercises and demonstrations, development of training and certification programmes, e-learning platforms, competence databases, knowledge

<sup>120</sup> 'NACE 27: Manufacture of electrical equipment' used as a proxy for renewable energy manufacturing industry as many renewable energy technologies fall under this category. It is also used as a proxy for renewables industrial ecosystem in the EU Industrial Strategy [COM(2020)108 final and its recent update COM(2021)350 final].

<sup>121</sup> Czako. 2022. JRC129676.

centres, skills registers, skills advisor apps, provision of free and easily accessible training materials, funding of training facilities, as well as train-the-trainer schemes have been applied to ease skills demand.

### 2.3.3 Gender balance

Equal gender participation can help society leap to a future of technological advancement in the energy sector. To ensure the transition to energy security and climate-neutrality, the gender gap must be closed and women fully involved in a technical, scientific and business transformation. Promoting gender equality in research and innovation is part of the Gender Equality Strategy for 2020-2025<sup>122</sup>, which sets out the broader commitment to equality across all EU policies.

Recent investigations by the European Patent Office (EPO) show that for applications filed in 2021, with at least one inventor based in Europe, roughly 20-21% named one or more women as inventors<sup>123</sup>. In the patent classes closely associated to the energy sector – combustion apparatus, engines, pumps and power – women are listed in less than 11% of applications, and over 15% for climate change mitigation technologies (CCMT), which is comparable to all technologies, including information and communication technologies (ICT).<sup>124</sup> Also, less than 15% of start-ups are founded or co-founded by women (and only 6% by women-only teams).<sup>125</sup> This translates into low amounts of capital invested into women-led companies, creating a vicious circle. In 2021, all-female start-ups secured only 2% of all available venture capital, compared to 3% in 2020. Mixed teams, led by both men and women, saw a small jump in funding, from 8% to 9%, but down from 11% in 2019.<sup>126</sup> Moreover, women are underrepresented in higher education in Science, Technology, Engineering, and Mathematics (STEM) sub-fields that are highly relevant for the energy sector and that remain heavily male dominated. Since in 2019 less than a third of engineering, manufacturing, and construction and less than a fifth of ICT higher education students were female.<sup>127</sup>

Women also participate less in decision-making in energy companies. The IEA analysed 2,500 energy and utility firms (38,000 employees), finding that approximately 14% of senior management are women<sup>128</sup>. This is only slightly lower than the 15.5% observed in the over 30,000 non-energy firms sampled. Somewhat surprisingly, renewable energy firms are well below the composite average at just 10.8%.

There are increasingly more initiatives stimulating women's involvement in innovation. The number of women-led start-ups receiving funding from the European Innovation Council (EIC) has grown from 8% in the first half of 2020 to 29% in second half of 2020.<sup>129</sup> A share of these funds went to startups developing technologies that will contribute to the EU's target of reducing net greenhouse gas emissions by at least 55% by 2030, which is also the key criteria in the EIC's 2022 work programme. In June 2022, the EU launched second edition of Women TechEU that provides support for up to 130 deep-tech start-ups led by women at the earliest, riskiest stage of their company's growth.<sup>130</sup> Horizon Europe also has a new eligibility criterion where research organisations applying for funding must have an actionable Gender Equality Plan, with a target for a gender balance of 50% in all Horizon Europe related decision-making bodies and evaluators.

### 2.3.4 Impact on conventional / fossil fuel energy employment

Deployment of clean energy technologies can have an impact on conventional energy sector employment but the exact impact depends on the region, composition of the conventional energy sector and the type of renewable deployed. As already previous edition of Competitiveness Progress Report 2021<sup>131</sup> described, countries with coal mining activities are the most sensitive to the influence of renewables development<sup>132</sup>. According to EurObserv'ER indicative estimate, the biggest substitution effect took place in Germany, Romania, Spain, Poland, Italy and France. Nevertheless, all of these countries, as well as all EU countries in general, with

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<sup>122</sup> [European Commission. Gender equality strategy](#)

<sup>123</sup> [European Patent Office](#) 2022.

<sup>124</sup> [International Energy Agency. 2020](#)

<sup>125</sup> [European Innovation Council and SMEs Executive Agency \(EISMEA\). 2022](#)

<sup>126</sup> [IDC European Women in Venture Capital report 2022](#)

<sup>127</sup> JRC based on Eurostat [EDUC\_UOE\_ENRT03]

<sup>128</sup> [International Energy Agency. 2021](#)

<sup>129</sup> [Euraxess](#) 2022

<sup>130</sup> [European Innovation Council and SMEs Executive Agency \(EISMEA\). 2022](#)

<sup>131</sup> COM(2021) 952 final.

<sup>132</sup> Alves Dias, et al., Recent trends in EU coal, peat and oil shale regions, EUR 30618 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-30987-1, doi:10.2760/510714, JRC123508.

the exception of Romania, gained 2-6 times more jobs than the number of displaced fossil energy jobs<sup>133</sup>. In order to fully tap into the clean energy job creation potential in the regions most affected by the transition, various job misalignments, such as spatial, sectoral, occupational and temporal, need to be actively monitored in order to anticipate skills needs and to set up appropriate frameworks and mechanism for up-skilling and re-skilling<sup>134</sup>. Also, the most affected regions would benefit from investments in economic diversification, for instance, if material infrastructure investments went beyond environmental restoration and renewable and alternative energy with investments in support sectors such as eco-tourism or sustainable farming<sup>135</sup>.

## 2.4 Gross Value Added in clean energy

Economic data on the clean energy sector is available from the Eurostat environmental goods and services accounts and more specifically for renewables from [EurObserv'ER](#). Renewable energy turnover in the EU grew by 9% since 2019 and stood at EUR 163 billion in 2020<sup>136</sup>. Heat pumps and wind energy were exclusively responsible for the higher turnover, with 36% and 27% growth from 2019 to 2020. Turnover in the rest of the renewables remained stable or contracted in the same time period. Wind energy and heat pumps generated also the biggest shares of the total turnover, at 27% and 25% respectively. During the same period (2019-2020), gross value added in the EU renewable energy sector grew by 8% and stood at EUR 70 billion<sup>137</sup>.

Eurostat data collected from Member States on environmental goods and services<sup>138</sup> is very close to EurObserv'ER values for the renewables. Gross value added is slightly lower at EUR 66 billion in 2019, whereas output is slightly higher at EUR 187 billion in 2019. Eurostat data for 2020 is not yet available. The difference is associated to different methodologies. Energy efficiency and management activities generated another EUR 188 billion in turnover, out of which EUR 73 billion was gross value added in 2019. E-mobility sector generated EUR 15 billion in turnover, out of which EUR 6 billion was gross value added in 2019.

In comparison, fossil fuel industry continued to have a declining trend in generated turnover (EUR 530 billion in 2020<sup>139</sup>) and gross value added as reported already in the previous reports. The only exception is manufacture of coke and refined petroleum products, in which turnover has declined but value added has nearly doubled in 2011-2020<sup>140</sup>, indicating improving productivity.

Every 1 EUR of turnover in the renewable energy technologies generated approximately 0.43 EUR of gross value added<sup>141</sup>. Whereas turnover grew by 9% from 2019 to 2020, gross value added grew only by 8%, which results in a slightly worsening gross value added to turnover ratio. While this is only a slight worsening, it indicates that there is a growing leakage for example in the form of imports. Overall, clean energy industry generates about 4 times more value added from 1 EUR of turnover<sup>142</sup>, which implies that it creates more value added compared to fossil industry. Moreover, clean energy industry has nearly 70% higher gross value added to turnover ratio than the overall manufacturing industry in the EU<sup>143</sup>.

### 2.4.1 Labour productivity

Overall labour productivity<sup>144</sup> in the clean energy sector is about 20% higher than on average in the overall economy<sup>145</sup>. It is improving slightly faster at 2.5% annually since 2015, compared to 1.8% average annual increase in the overall economy. In renewable energy sector and e-mobility labour productivity increases even faster at 4% and 5% respectively since 2015. Whilst, in energy efficiency and management activities, labour productivity is growing only at 2% annually since 2015. The situation is different depending on the clean energy

<sup>133</sup> EurObserv'ER. 2022. The State of Renewable Energies in Europe. Edition 2021 – 20<sup>th</sup> EurObserv'ER Report.

<sup>134</sup> Asikainen, T., Bitat, A., Bol, E., Czako, V., Marmier, A., Muench, S., Murauskaite-Bull, I., Scapolo, F. and Stoermer, E., The future of jobs is green, EUR 30867 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-42571-7, doi:10.2760/218792, JRC126047.

<sup>135</sup> *ibid*

<sup>136</sup> EurObserv'ER. 2022. The State of Renewable Energies in Europe. Edition 2021 – 20<sup>th</sup> EurObserv'ER Report.

<sup>137</sup> EurObserv'ER. 2022. The State of Renewable Energies in Europe. Edition 2021 – 20<sup>th</sup> EurObserv'ER Report.

<sup>138</sup> Eurostat [env\_ac\_egss2].

<sup>139</sup> For comparison turnover was about EUR 1 trillion in 2012.

<sup>140</sup> Value added has increased from EUR 18 billion to EUR 33 billion in 2011-2019.

<sup>141</sup> This varies among clean energy technologies. Based on Eurostat this is slightly lower at EUR 0.35 due to methodological differences.

<sup>142</sup> Gross value added to turnover ratio of the fossil industry is less than EUR 0.10.

<sup>143</sup> Based on Eurostat [SBS\_NA\_IND\_R2] data, gross value added to turnover ratio of manufacturing (NACE C) in the EU is about EUR 0.25.

<sup>144</sup> As gross value added per employee.

<sup>145</sup> This is based on Eurostat data on gross value added [env\_ac\_egss2] and employment [env\_ac\_egss1].

technology. In heat pumps, labour productivity grew by 8% in 2019–2020, while in wind sector, which has the second highest labour productivity among the renewable energy technologies, it decreased by 2% in the same period<sup>146</sup>. Geothermal has the highest labour productivity among the renewable energy technologies and it improved by 3% in 2019–2020.

## 2.5 Social aspects and citizen engagement

From citizens' acceptance to capacity building – energy communities and institutional 'nudging'

The 2019 Special Eurobarometer 492<sup>147</sup>, on Europeans' attitudes on EU energy policy indicates a clear attitude of support towards the clean energy transition by the EU's citizens. The 2021 Special Eurobarometer 513<sup>148</sup> on Climate Change reveals that European citizens consider climate change is the single most serious problem facing the world. In terms of policy response, Europeans (90%) agree that greenhouse gas emissions should be reduced to a minimum and make the EU climate-neutral by 2050. Close to nine in ten Europeans (87%) think it is important that the EU sets ambitious targets to increase renewable energy use, and that it is important that the EU provides support for improving energy efficiency<sup>149</sup>. The above make quite clear that the acceptance of the transition is no longer a major issue in the European society. What is lacking is the capacity for citizens to participate on equal footing as they often lack the resources (e.g. capital, knowledge) to be part of the transition.

As part of the EC's ambition for citizens to acquire a bigger role in EU energy policies, the institutional framework has been further developed to level the playing field for community energy initiatives and to enhance civic engagement in the energy transition. This comes as a result of the recognition that a proliferation and empowerment of energy communities can help tackle climate, social and energy security goals, while accelerating the transition, reducing energy poverty, advancing circular economy and involving local communities<sup>150</sup>.

The 2018 RED-II Directive sets out a framework for 'renewable energy communities' while the 2019 Revised Internal Electricity Market Directive introduced new roles and responsibilities for 'citizen energy communities'. Under the Green Deal and the Fit-For-55 package several policies and legislative initiatives such as the European Bauhaus aim to strengthen the connection between citizens, industry, institutions and the energy transition. On the legislative front, the proposal for amending the RED-II Directive urges for national measures to substantial increase to energy communities. Similarly the proposal for a recast of the Energy Efficiency Directive<sup>151</sup> urges Member States to promote the role of energy communities and names them as a key social partners.

The REPowerEU plan and the legislative initiatives give major boost on energy communities with multiple references promoting their role as part of a clean safe and fair transition. This comes after the new Guidelines on State Aid for climate, environmental protection and energy<sup>152</sup> that encourage MSs to exempt renewable energy community projects with installed capacity equal to or below 6 MW from mandatory competitive bidding processes, or to facilitate their participation in such processes.

The EU 'Save Energy' Communication urges for tailor-made hands-on support at local level to advise citizens on the possibilities to participate in an renewable energy community. The REPowerEU Plan [SWD(2022) 230 final] encourage energy communities generation in the biogas sector. The EU Solar Energy Strategy Communication as part of the European Solar Rooftops Initiative aims to set up by 2025 at least one renewable energy community in every municipality with a population higher than 10 000. Part of the initiative are also provisions that ensure that energy poor and vulnerable households have access to solar energy via social housing installations, energy communities, or financing support for individual projects. The communication builds a strong case on how collective solar energy projects provide a way to simultaneously reduce the consumption of fossil fuels and address energy poverty and vulnerability. MS are urged to support partnership building between local authorities, energy communities and social housing projects to facilitate the use and penetration of energy communities to reduce energy costs.

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<sup>146</sup> Based on EurObserv'ER. 2022. The State of Renewable Energies in Europe. Edition 2021 – 20<sup>th</sup> EurObserv'ER Report.

<sup>147</sup> The 2019 Special Eurobarometer 492, on Europeans' attitudes on EU energy policy.

<sup>148</sup> The 2021 Special Eurobarometer 513 on Climate Change.

<sup>149</sup> *ibid*

<sup>150</sup> Mikkonen, I., Gynther, L., Matschoss, K., Koukoulfikis, G., Murauskaite-Bull, I. and Uihlein, A., Social innovations for the energy transition, EUR 30446 EN, Publications Office of the European Union, Luxembourg, 2020, doi:10.2760/555111, JRC122289.

<sup>151</sup> COM(2021) 558 final

<sup>152</sup> Guidelines on State Aid for climate, environmental protection and energy, 2022/C 80/01



The delays in the transposition of the 2019 Internal Electricity Market Directive to effectively allow consumers to participate in energy markets (individually or via energy communities or collective self-consumption schemes) are also recognised in the REPowerEU plan. MSs are urged to move forward with the legislative work; provide assistance so to remove the barriers energy communities face (e.g. access to finance, administrative capacities, permitting and licencing processes); provide technical expertise; and establish incentives and adapt administrative requirements to the characteristics of energy communities.

## 3 Strategic analysis

### 3.1 Critical materials and industrial value chains

Availability of the necessary raw materials and smooth functioning of the relevant value chains is essential for the undisrupted deployment of the clean energy technologies, fulfilling the EU energy transition targets. The materials and value chains necessary for each technology have been analysed in the CETO reports on specific technologies (see Annex 1), under the section on “Resources efficiency and dependence”. Various materials have been identified as critical and strategic for these technologies, including steel, cement, copper, rare earths, composite materials, iron alloys, silicon metal, silver, lithium, nickel, graphite, cobalt, etc. Faced with the challenge of reducing EU dependence on Russian fossil fuels, on top of the climate crisis, the Commission adopted on 18 May 2022 the **REPowerEU** Plan. The initiative sets ambitious targets and details specific actions for boosting the deployment of renewables, mainly *wind power* and *solar photovoltaic (PV)*, *hydrogen production*, rapid deployment and wide use of *heat pumps* for heating and cooling, and *batteries* for energy storage and decarbonisation of the transport sector. Consequently, the demand for raw materials, processed materials, components and assemblies is expected to grow considerably, making extremely important to secure access to the necessary quantities of the critical materials and resilience of the relevant supply chains. The proposed European Critical Raw Materials Act will aim to create a secure, affordable, and sustainable access to the necessary materials and ensure the resilience of the relevant supply chains.

The following summarises the materials and the stage in the value chain where bottlenecks are most likely (Critical Raw Materials, CRMs, in *Italics*):

- **Wind turbines:** *Rare earths* for permanent magnets (*Neodymium* (Nd), *Praseodymium* (Pr), *Dysprosium* (Dy), *Terbium* (Tb)). Permanent magnets manufacturing is the most critical step in the value chain.
- **Solar PV panels:** *Silicon metal* (Si), *Silver* (Ag) for crystalline Silicon technologies (95% of commercial PV market), and *Indium* (In), *Germanium* (Ge), *Gallium* (Ga), *Tellurium* (Te), *Selenium* (Se) and *Cadmium* (Cd) for thin-film technologies (only 5% of commercial PV market, but important for space and defence applications). Solar PV cells (and the relevant wafers before that) is the most critical step in the value chain.
- **Batteries:** *Lithium* (Li), *Nickel* (Ni), *Cobalt* (Co), *Natural Graphite* and *Manganese* (Mn). Battery cells are currently the weakest value chain stage, but domestic production is increasing.
- **Hydrogen electrolyzers:** *Platinum Group Metals* (PGM) – specifically *Platinum* (Pt) and *Palladium* (Pd) – and *Iridium* (Ir). The raw materials step of the value chain is the most critical.

While a complete inter-comparison of the value chains of the technologies examined in Part A will follow in the next steps of the Project, some first remarks and preliminary conclusions can already be drawn. In general, as it was showcased with these technologies which are essential for the success of REPowerEU, each of the supply chains involves different critical materials and has its own weaknesses/criticalities, thus requiring customised solutions. An exception to this general trend is the similarity between the value chains of wind turbines and those of traction motors of electric vehicles. Indeed, they both require permanent magnets (though in quantities of completely different scale) which, for reasons of increased efficiency, use rare earth elements. Similarly, many of the clean technologies deployed in remote places require large quantities of copper for wiring and connection with the electricity grid. Due to the extensive use of copper in electricity grids, and despite the fact that it is not included in the EC 2020 list of critical raw materials, it is considered a strategic material for the decarbonisation. Furthermore, aluminium (for support structures), iron alloys (e.g. for piping) and other base metals appear in the value chains of more than one technologies and require further analysis.

In the next phases of CETO, a detailed analysis of the relationships between the different clean technologies value chains will be carried out, covering inter-comparison for complementarities, identification of strategic nuclei, critical individual value chains and cross-cutting elements. The analysis will benefit from the on-going update of the Commission’s 2020 foresight study<sup>153</sup> on critical raw materials, extending the scope to 15 strategic technologies in 5 sectors. This will include the most recent data on present and future materials use in clean energy technologies, several of which continue to evolve rapidly.

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<sup>153</sup> Bobba, S., Carrara, S., Huisman, J., Mathieux, F., Pavel, C., Critical Raw Materials for Strategic Technologies and Sectors in the EU – A Foresight Study, European commission, 2020, DOI: 10.2873/58081

## 3.2 Sustainability

### 3.2.1 Status for environmental, social, economic and governance aspects

Energy systems must be sustainable in terms of their environmental, social, and economic performance. The European Green Deal is the EU's long-term growth plan to make Europe climate neutral by 2050. Clean energy technologies are at the heart of this plan. Knowing the carbon footprint of a clean energy technology is therefore fundamental. This, and other specific policies, promote both more competitive and sustainable industries across Europe including, for example, through mandatory thresholds on carbon footprint such as proposed in article 7 of the Battery Regulation proposal (COM(2020) 798 final). Policies such as this for batteries contribute to reducing both environmental and social impacts along the whole value-chain, promoting the adoption of more sustainable and circular technologies in various applications.

Such policies are supported in the environmental context at the value chain level by e.g. Product Environmental Footprint (PEF)<sup>154</sup> and associated "Product Environmental Footprint Category Rules (PEFCR) for different technologies. For example PEFCR for batteries<sup>154</sup> and PV panels<sup>155</sup> already exist. This, and associated product policies, complement more site/technology-specific analyses and requirements.

From the social side, Social Life Cycle Assessment is being applied to specific energy technologies, such as for example batteries<sup>156</sup> and hydrogen<sup>157</sup>. In the policy arena, some horizontal mandatory requirements exist for some raw material value chains at EU-level in the context of due diligence. Again, these are complemented by other schemes with mandatory and voluntary requirements for other materials and components contained in specific technologies. For example, due diligence provisions are suggested on social and environmental risk categories in the Battery Regulation proposal (COM(2020) 798 final). Related studies<sup>158</sup> suggest that responsible sourcing schemes can positively improve the social performance of the life cycle of batteries.

Enhanced Circular Economy strategies aim to maximize the value of materials by extending the lifespan of products in which they are embedded (e.g. through reuse and second-use) and recirculating secondary materials (e.g. through recycling). Hence, current circularity performances of energy technologies and embedded components and materials need to be more systematically assessed. Doing so, improvement opportunities will be identified to improve resource efficiency and recycling, through e.g. better product design, improved collection and treatment practices. This can be done either through voluntary approaches, or through policy interventions (e.g. battery regulation proposal addressing second-use, design features, recycled content, collection targets and recycling performances). Improved circularity will, in principle, positively impact the sustainability of clean energy technologies.

Concerning EU autonomy, the EC's methodology on critical raw materials (CRMs) considers high risks of supply disruption due to materials coming from a limited number of countries that are often associated with poor governance. Equally, CRMs are associated with sectors with a high added value. Due to the link with poor governance, critical raw materials may also be associated with poor environmental and social performance; while these are not routinely assessed. Hence, CRMs provide an important basis for analysing potential supply chain risk for clean energy technologies for extraction and processing of raw materials. These are also complemented by foresight analyses to consider also other semi-finished goods in the supply chains and that focus on future demand<sup>159</sup>. Other analyses, such as for batteries, provide more in-depth modelling of value chains, related demand, and also what is actually feasible/likely in relation to supply of both primary and secondary raw materials e.g. : [RMIS – Raw Materials in the Battery Value Chain \(europa.eu\)](https://ec.europa.eu/environment/eussd/smgp/pdf/PEFCR_PV_electricity_v1.1.pdf). Such model insights could be extended to foresight analyses of economic, social, and environmental considerations.

Qualitative and quantitative analyses of sustainability performance for clean energy technologies in CETO highlight the heterogeneous and limited nature of available information and data. Methodologies used (e.g. PEFCR for Life Cycle Assessment) are also not available for all technologies. They equally highlight that different categories of considerations are relevant depending on the technology for e.g. direct impacts and perceptions. From a life cycle assessment perspective, including for carbon footprints, data can be limited for some

<sup>154</sup> [https://ec.europa.eu/environment/eussd/smgp/pdf/PEFCR\\_Batteries.pdf](https://ec.europa.eu/environment/eussd/smgp/pdf/PEFCR_Batteries.pdf)

<sup>155</sup> [https://ec.europa.eu/environment/eussd/smgp/pdf/PEFCR\\_PV\\_electricity\\_v1.1.pdf](https://ec.europa.eu/environment/eussd/smgp/pdf/PEFCR_PV_electricity_v1.1.pdf)

<sup>156</sup> see chapter 5 of JRC SASLAB Technical report (2018): <https://publications.jrc.ec.europa.eu/repository/handle/JRC112543>

<sup>157</sup> Eynard U., Martin Gamboa M., Valente A., Mancini L., Arrigoni Marocco A., Weidner Ronnefeld E., Mathieux F. (2022). S-LCA applied to hydrogen technologies in Europe: challenges for critical raw materials' responsible sourcing. Presented at International Conference of Social Life Cycle Assessment (S-LCA 2022) Sept 8<sup>th</sup> 2022, Aachen, Germany.

<sup>158</sup> <https://www.sciencedirect.com/science/article/pii/S0301420721000325>

<sup>159</sup> See e.g. <https://rmis.jrc.ec.europa.eu/?page=crms-in-strategic-sectors-and-technologies-e8c632>

technologies and may also not be based on detailed analysis requirements. Some examples of considerations for selected technologies and endpoints:

#### Batteries:

- Cost-effective batteries (including second-used EV batteries) can contribute to increasing the self-consumption and self-sufficiency of electricity end-users/prosumers, especially in rural areas. They hence contribute to energy security and quality<sup>74</sup>.
- The battery industry development can have a key role in “ensuring the access to affordable, reliable, sustainable and modern energy for all (SDG 7)”.
- Battery technology is rapidly evolving and both R&D&I activities as well as industrial initiatives are currently engaged to build a more competitive and sustainable European battery industry (EBA250, BatteriesEurope, Battery2030+, etc.).
- “Product Environmental Footprint Category Rules (PEFCR) for High Specific Energy Rechargeable Batteries for Mobile Applications”<sup>61</sup> were published in 2018. Revisions are ongoing to key parameters such as climate change benchmarks to support Article 7 of the Battery regulation proposal, which foresees the declaration of the carbon footprint of batteries that are put in the EU market, to promote the adoption of more environmentally-friendly products.
- Supporting studies to the PEFCR have not identified specific hotspots therefore the impact of batteries on ecosystem and biodiversity “is not at the moment of concern”.
- No significant impacts on land use have been identified by the supporting PEFCR.
- Directive 2006/66/EC of the European Parliament and of the Council of 6 September 2006 on batteries and accumulators and waste batteries and accumulators and repealing Directive 91/157/EEC, already prohibits to put into the EU market batteries and accumulator containing hazardous materials, with specific reference to mercury and cadmium above specific thresholds.
- Several materials belonging to the Critical Raw Materials List for the EU<sup>66</sup> are used in manufacturing batteries; the demand of such batteries is expected to rapidly increase in the next decade following the trend of the batteries demand in various sectors (e.g. mobility, energy storage, portable devices)<sup>67</sup>.
- The adoption of more resource-efficient batteries and the increased flows of secondary materials obtained from batteries recycling has potential to maximize the value of materials and to keep them within the EU, hence decreasing the EU dependency from imports. The new Battery Regulation proposal foresees progressive minimum recycling efficiencies for lead-acid, Li-based and other waste batteries. In addition, specific materials recovery levels needs to be achieved for cobalt, cobalt, copper, lead, lithium and nickel.
- Recent analysis shows that, starting from 2030, the flow of materials available for recycling is expected to be quite important in terms of secondary supply<sup>70</sup>.
- The Battery Regulation proposal states that rechargeable industrial batteries and EV batteries with a capacity above 2 kWh are accompanied by a documentation reporting the due diligence policies adopted along the batteries value chain. Information on specific materials related risk embedded in batteries are available in (Mancini et al., 2020)
- Analyses identifying social hotspots along the battery value chain are provided by (Bobba et al., 2018) and (Eynard et al., 2018). Moreover, an analysis of social risk in battery raw materials supply is provided in (Mancini et al., 2020) while (Mancini et al., 2021) investigates the social impacts of responsible sourcing initiatives in artisanal cobalt mining sites in the Democratic Republic of the Congo.

#### Photovoltaics:

- At international level the IEA PVPS Task 12 group issued methodology guidelines on PV-specific parameters used as inputs in LCA (Frischknecht et al., 2016). ‘Product Environmental Footprint category rules’ for PV power systems<sup>10</sup> were developed by the EC in the framework of the Product Environmental Footprint initiative pilot phase.
- In terms of climate change, thin-film modules have the lowest emissions, followed by poly-crystalline silicon and then mono-crystalline silicon. There is considerable scope to reduce these values, and projections for 2050 indicate that life cycle emissions for PV can drop to 10 gCO<sub>2</sub>-eq/kWh and below (Pehl et al., 2017).

- The Energy Payback Time of PV systems is dependent on the geographical location: PV systems in Northern Europe need around 1.2 years to balance the input energy, while PV systems in the South equal their energy input after 1 year and less, depending on the technology installed and the grid efficiency (Fraunhofer ISE, 2022b).
- The EC published a report on the potential impacts of PV applications on the ecosystem and the biodiversity (Lammerant et al., 2020).
- Some of the raw materials used to manufacture solar cells are critical, such as borates, silicon metal, germanium, indium, and gallium. Moreover, the criticality of photovoltaic technology goes beyond the raw materials availability. China dominates nearly all aspects of solar PV manufacturing and use.
- In the EU, treatment of end-of-life PV modules must comply the WEEE Directive since 2012. Several organisations have developed recycling processes. Several sustainability aspects are being addressed in the framework Ecodesign (EC, 2022b).
- Ardente, F. et. al., 2019 assessed the resource efficiency and related environmental benefits and burdens of a pilot PV waste recycling processes. Overall, recycling processes with high-efficiency can recycle up to 83% of the waste panel. An ongoing EU-funded project called PHOTORAMA is currently working to improve recycling of Photovoltaic (PV) panels and recovery of Raw Materials (RM).

Wind:

- There are no technology specific guidelines. Life cycle inventory data of differing qualities are available in e.g. studies of the main wind turbine manufacturers (Vestas, SGRE). Manufacturers provide no detailed life cycle data on the latest offshore wind turbines.
- The Energy Pay-Back Time of wind energy systems is dependent on the capacity (MW) of the turbine as well as its geographical location (capacity factor); often being between circa 6 to 12 months.
- Wind energy technologies can rely on critical raw materials such as dysprosium, neodymium, praseodymium, terbium and borate. The EU import reliance of such materials is high.
- Most materials of wind turbines can be recycled, however composite waste poses challenge. Beyond the current approaches to keep composite waste from wind turbine blades out of landfill, innovations and measures for circular economy strategies are observed in other wind turbine components (e.g. components such as the tower, mooring, nacelle housing and grid integration technologies).
- The lack of economically viable permanent magnets recycling processes, combined with non-separate collection waste flow reduce the potential availability of secondary raw materials from wind turbines.
- The adoption of more resource efficient wind turbine technologies as well as the use of alternative materials to substitute CRMs, for example, may have the potential to reduce the value chain import dependency and help keep materials within the EU.

### **3.2.2 Concept and needs for an integrated sustainability assessment**

Clean energy technologies must be assessed in a robust, consistent and quality assured manner in the context of sustainability. This includes in relation to both direct impact considerations, but equally assessments must analyse entire value chains/life cycles associated with different technologies. Carbon footprints, amongst others, are essential parameters in the context of carbon neutrality and must be assessed using a full life cycle approach. Foresight analyses provide insights into autonomy, supply bottlenecks as well as demand, and equally a basis for analyses of economic, environmental, as well as social considerations. Benchmarks for different considerations are vital, including to monitor/communicate progress. Such benchmarks are now being used for potential mandatory entry-market on carbon footprint, e.g. in article 7 of the Battery regulation proposal.

For some key parameters, such as carbon and environmental footprints that account for the entire life cycle, the EU's Product Environmental Footprint requirements can be directly applied. Product Environmental Footprint Category Rules also exist already for some clean energy technologies, providing furthermore detailed analysis specifications to facilitate coherence and quality assurance. The [European Platform on Life cycle Assessment](#) offers references methods and data (through the International Life Cycle Data Network).

For other sustainability parameters, data, monitoring, and assessment methodologies may be lacking. Social Life Cycle Assessment could be helpful to assess social considerations but requires further development for clean energy technology analyses; both for current and forward looking perspectives.

Circularity is increasingly a key focus. Quantification of current and future-potential circularity opportunities is vital for most clean energy technologies. The economic, environmental and social implications of different current/future circularity potential and options can be assessed in existing life cycle assessment frameworks using detailed modelling of value chains. In this respect, the EC's Raw Materials Information System (RMIS) offers some relevant references data on recycling rates of raw materials<sup>160</sup> and materials stocks and flows datasets on specific technologies, for example batteries<sup>161</sup>.

For the analyses of value chains in relation to current and future orientated autonomy (security-of-supply risk, criticality, resilience), no EC guidance exists. Nevertheless analyses are conducted using detailed and simplified modelling approaches, see e.g. JRC's [Raw Materials Information System](#). Again, such analyses can be conducted as part of broader and detailed life cycle assessments.

Clearly, significant efforts are now necessary to come to agreed modelling and analyses methodologies (E.g. PEFCR, S-LCA guidelines), datasets and meaningful indicators (such as circularity criteria) to be applied to specific energy technologies, so that sustainability performances can be appropriately discussed across technologies and monitored..

### 3.2.3 Roadmap for further sustainability assessments

CETO has conducted initial qualitative analyses for selected sustainability criteria of clean energy technologies (Tasks A1 and A2). These qualitative analyses should be further expanded and maintained through more detailed studies but focusing on a limited subset of parameters. It may be good to make clear distinctions between economic, social, and environmental considerations. Equally, a split can be made between direct impacts and those associated with value chains.

At the same time, development is recommended of quantitative modelling for analysis of value chains and of future potential for selected clean energy technologies for selected policy endpoints (autonomy, circularity, climate, environmental, social and economic). This could be done initially for the most dominant clean technologies, building on e.g. examples of more advanced value chain analyses/modelling such as for batteries.

## 3.3 SWOT analysis

The section aims to provide overall SWOT analyses for global competitiveness, technology independence and sustainability and builds on the analysis made for each technology and reported in the individual reports listed in Annex 1. **Table 3** shows the analysis for global competitiveness, interpreted here according to the following criteria:

- Capability of EU organisations and companies to manufacture, supply, deploy and operate clean energy
- EU capability to create and maintain an environment that sustains more value creation for its enterprises and more prosperity for its people.

**Table 4** shows the SWOT addressing technology Independence, where this is considered to be synonymous with the term technology sovereignty as defined by the 2021 study<sup>162</sup> of the European Parliamentary Research Service's Scientific Foresight Unit: *"...the ability for Europe to develop, provide, protect, and retain critical technologies required for the welfare of European citizens and prosperity of businesses, and the ability to act and decide independently in a globalised environment."*<sup>163</sup> Finally **Table 5** considers the socio-environmental sustainability of the clean energy technology sector in the EU context.

<sup>160</sup> <https://rmis.jrc.ec.europa.eu/?page=scoreboard2021#/ind/15>

<sup>161</sup> <https://rmis.jrc.ec.europa.eu/apps/bvc/#/v/apps>

<sup>162</sup> Key enabling technologies for Europe's technological sovereignty, STOA European Parliament, 2021, PE 697.184, I, doi: 10.2861/24482, QA-01-21-349-EN-N

<sup>163</sup> The STOA definition encompasses three key elements:

- Technological – the development of European research and development (R&D) competencies by maintaining a strong knowledge base, industry, and networks in the critical technologies;
- Economic – the achievement and preservation of a position of leadership in key enabling technologies (KETs), the ability to turn R&D into market products, and access to a diversity of resources along the value chain with the aim of reducing dependence on third countries;

**Table 3.** CETO SWOT analysis of global competitiveness for the EU clean energy technology sector.

<p><b>Strengths</b></p> <ul style="list-style-type: none"> <li>— Reputation as provider of reliable technology solutions: e.g. offshore wind, CSP, hydropower.</li> <li>— R&amp;I: strong public funding, high-standing of the EU research community, impactful coordination (SET Plan): leader on high value patents</li> <li>— Production equipment: e.g. for PV, batteries, bioenergy</li> <li>— World-leading project development, capability to execute complex, high-performance, large scale engineering projects: e.g. power blocks, chemical systems</li> <li>— Digital systems and solutions already implemented in several sectors</li> <li>— Key player in international standards (industrial, environmental, ESG)</li> </ul>	<p><b>Opportunities</b></p> <ul style="list-style-type: none"> <li>— Growing global market for clean energy technologies needed to achieve climate change mitigation goals</li> <li>— Higher fossil fuel prices and security of supply concerns driving green investments</li> <li>— Demand for sustainable solutions</li> <li>— Updated EU industrial strategy</li> <li>— EU carbon markets can help deploy large-scale green industries and support investments for R&amp;I</li> <li>— Additional investment from RRP and Innovation Fund,</li> <li>— Steadily growing VC and competitive VC ecosystems (PV, heat pumps, grids)</li> <li>— Workforce with relevant skills</li> <li>— Integrated cross-sectorial solutions (e.g. energy + infrastructure, energy + agriculture)</li> </ul>
<p><b>Weaknesses</b></p> <ul style="list-style-type: none"> <li>— High energy and production costs</li> <li>— External dependencies for some materials and components</li> <li>— Skilled workers shortages and gender-imbalance for STEM fields</li> <li>— Lower private R&amp;I funding compared to main competitors.</li> <li>— Innovation “valley of death”, funding for first-of-a-kind plants</li> <li>— Investment, financing of new tech projects (risk-premium)</li> <li>— Administrative barriers (e.g. long permit-granting process) for investments</li> </ul>	<p><b>Threats</b></p> <ul style="list-style-type: none"> <li>— Falling behind in R&amp;I</li> <li>— Infringement of IPR</li> <li>— Divergent MS policies and/or investment uncertainties</li> <li>— Subsidised international competition</li> <li>— Lower cost technology solutions from international competitors</li> <li>— Unfavourable geopolitical developments</li> <li>— Squeeze-out of some developing technologies</li> </ul>

Source: JRC analysis

- Regulatory – the development of adequate policies and standards that reflect European values, to influence global regulation, standards and practices

**Table 4.** CETO SWOT analysis of technology independence for the EU clean energy technology sector.

<p><b>Strengths</b></p> <ul style="list-style-type: none"> <li>— Technical capability to produce all clean energy technologies</li> <li>— Innovative capability</li> <li>— Expertise in installation and operations</li> <li>— Technology expertise and R&amp;D</li> <li>— IPCEI process to address key areas (e.g. batteries, hydrogen)</li> <li>— Pilot plants: e.g. CCSU, biofuels, ocean</li> </ul>	<p><b>Opportunities</b></p> <ul style="list-style-type: none"> <li>— EU market growth can drive re-development of manufacturing base</li> <li>— Develop substitutes for critical materials and enhancing recycling</li> <li>— Products for circular economy and ESG-compliant</li> <li>— Diversification of importers to enhance resilience (triggered by Russian war)Export potential for high-end sustainable energy technology</li> </ul>
<p><b>Weaknesses</b></p> <ul style="list-style-type: none"> <li>— Scale-up of manufacturing (to reduce costs)</li> <li>— Funding of FOAK plants</li> <li>— Import of many electronics components</li> <li>— Digital intelligence (for grids, smart cities etc)</li> <li>— Loss of IPR</li> <li>— Many EU mining activities closed (raw materials)</li> <li>— Critical raw materials : high dependency on third countries</li> </ul>	<p><b>Threats</b></p> <ul style="list-style-type: none"> <li>— Loss of skills and expertise</li> <li>— Timescales to development new large-scale manufacturing facilities (solar glass)</li> <li>— Potential disruptions in the supply chain due to economic/geopolitical circumstances</li> </ul>

Source: JRC analysis



**Table 5.** CETO SWOT analysis of socio-environmental sustainability for the clean energy technology sector

<p><b>Strengths</b></p> <ul style="list-style-type: none"> <li>— EU policy framework (taxonomy, circular economy, social justice)</li> <li>— Solutions available for reduced environmental impact (on land, water, air, and for biodiversity)</li> <li>— Developed EU re-cycling technology and capacities (e.g. PV)</li> <li>— Synergies between different SDGs</li> </ul>	<p><b>Opportunities</b></p> <ul style="list-style-type: none"> <li>— Know on sustainability with EU companies as solution providers</li> <li>— Low and high-skill employment growth</li> <li>— Better products, lower life costs (less O&amp;M)</li> <li>— Avoid programmed obsolesce</li> <li>— Globalise ESG standards</li> </ul>
<p><b>Weaknesses</b></p> <ul style="list-style-type: none"> <li>— EU dependence on CRMs</li> <li>— Recycling industry pending material input</li> <li>— Many cases of down-cycling rather than re-cycling</li> <li>— ESG control of imported materials and goods</li> </ul>	<p><b>Threats</b></p> <ul style="list-style-type: none"> <li>— Higher costs of recycled materials</li> <li>— Short term cost gains vs. long term sustainability</li> </ul>

Source: JRC analysis

## 4 Conclusions

This report provides a strategic analysis of the EU clean energy technology sector, to complement the CETO individual technology and system integration reports. The main findings are summarised as follows:

Clean energy technologies are contributing to trend of decreasing energy consumption and energy intensity. With increasing renewables in the energy mix, GHG intensities have also decreased. The EU has one of the lowest value of GHG emissions per unit of GDP among the major global economies. Increasing the share of renewable energy produced in the EU can also mitigate current high costs and their negative impact on the competitiveness of the EU industry in general. While the EU overall economy contracted by 4% in the EU in 2020, gross value added of renewable energy sector increased by 8%, and turnover grew by 9% in 2019-2020. Looking more broadly at the clean energy sector, this has a nearly 70% higher ratio of gross value added to turnover ratio than in the overall manufacturing industry in the EU. In 2021, the EU production value of most clean energy technologies and solutions increased, reversing the 2020 decline. Nevertheless, the simultaneous increase of prices may give an overly positive picture of production growth. In addition, some technologies experienced an increase of imports to meet the growing demand in the EU.

EU employment in the renewables remained at about 1.3 million over the period 2015 to 2020, but the distribution of jobs among technologies changed, with heat pumps overtaking solid biofuels and wind energy to become the largest employer in 2020. If energy efficiency and e-mobility are included, clean energy sector employment climbs to 1.8 million (1% of the EU total employment). A significant gender gap continues, but analysis is hampered by a lack of consistent gender-disaggregated data. From the available data on patents and venture capital investment, it emerges that women inventors were only just over 15% for climate change mitigation technologies. The share of start-ups founded or co-founded by women was less than 15% in the EU in 2021. An increasingly number of initiatives aim to stimulate women's involvement in innovation, and hopefully the impact of this will soon become apparent.

The EU continues to be a global leader for 'green' inventions and high-value patents in climate change mitigation technologies. EU climate-tech start-ups and scale-ups have attracted an increasing amount of venture capital (VC) investments over the last 6 years, accounting for 15% of global climate tech VC investments in 2021, more than a twofold increase (x 2.2) as compared to 2020. Nonetheless EU-based scale-ups still lag behind compared to other major economies and further involvement of the private sector will be key to reverse this trend. Structural barriers and societal challenges still hold back EU-based climate tech scale-ups compared to other major economies.

Data on public R&I investments in the Member States shows increases both in terms of absolute spending and as a share of GDP in 2020, but still remain below EU 2010 levels in absolute terms. Considering both MS and EU framework programme funding, in 2020, the EU was second in public R&I investment among major economies, both in absolute spending: EUR 6.6 billion (where, the US leads with EUR 8 billion,) and as share of GDP: 0.046%, behind Japan 0.058% and just ahead of US and KR.

Analysis of supply chains across a broad range of technologies identified various materials as critical and strategic, including steel, cement, copper, rare earths, composite materials, iron alloys, silicon metal, silver, lithium, nickel, graphite, cobalt, etc. With the REPowerEU plan expected to further boost demand, the proposed European Critical Raw Materials Act will aim to create a secure, affordable, and sustainable access to the necessary materials and ensure the resilience of the relevant supply chains.

The CETO sustainability analyses of individual technologies highlighted the heterogeneous and limited nature of available information and data. Methodologies used (e.g. PECFR for Life Cycle Assessment) are also not available for all technologies. They equally highlight that different categories of considerations are relevant depending on the technology for e.g. direct impacts and perceptions. It is recommended that the CETO qualitative analyses should be further expanded and maintained through more detailed studies but focusing on a limited subset of parameters. At the same time, development is recommended of quantitative modelling for selected policy endpoints (autonomy, circularity, climate, environmental, social and economic), building for instance on the work done for batteries.

The studies and analyses performed for CETO in 2022 have underlined the clean energy technology sector's need to improve the quality and timeliness of public data, in particular regarding investments and socio-economic aspects. This can bring benefits to policy makers, prospective investors and sector participants.

## List of abbreviations and definitions

CEAP	Circular economy action plan
CETP	Clean Energy Transition Partnership
CPC	common patent classification
ESG	Environmental and social governance
ETS	Emission Trading System
FiT	feed-in tariff
FOAK	First-of-a-Kind
GW	Giga Watt
IA	Innovation Action
IEA	International Energy Agency
IRENA	International Renewables Energy Agency
IP	Implementation Plan
IPCEI	Important projects of common European interest
IPR	Intellectual property rights
LCoE	levelised cost of electricity
MENA	Middle East and North Africa
MS	[EU] Member State
O&M	Operations and maintenance
PEFCR	Product environmental footprint category rule
PPA	power purchase agreement
PV	photovoltaic
RED	renewable energy directive (RED-II is the 2018 revision)
RES	Renewable Energy Source
RIA	Research and Innovation Action
SET-Plan	EU Strategic Energy Technology Plan
STEM	Science, technology, engineering, mathematics
SWOT	Strengths, weaknesses, opportunities, threats (analysis)
TRL	Technology Readiness Level
VC	Venture Capital

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## Annexes

### Annex 1 CETO report series 2022

Technology Topic	Citation
Advanced biofuels	Hurtig, O., Scarlat, N., Motola, V., Buffi, M., Georgakaki, A., Letout, S., Mountraki, A. and Joanny Ordonez, G., Clean Energy Technology Observatory: Advanced biofuels in the European Union - 2022 Status Report on Technology Development, Trends, Value Chains and Markets, European Commission, 2022, JRC130727.
Batteries	Bielewski, M., Pfrang, A., Bobba, S., Kronberga, A., Georgakaki, A., Letout, S., Kuokkanen, A., Mountraki, A., Ince, E., Shtjefni, D., Joanny Ordonez, G., Eulaerts, O. and Grabowska, M., Clean Energy Technology Observatory: Batteries for Energy Storage In the European Union - 2022 Status Report on Technology Development, Trends, Value Chains and Markets,, EUR 31220 EN, European Commission, 2022, doi:10.2760/808352, JRC130724.
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Carbon Capture Utilisation and Storage	Kapetaki, Z., Eulaerts, O., Georgakaki, A., Gonzalez Sanchez, M.D.R., Grabowska, M., Ince, E., Joanny Ordonez, G., Kuokkanen, A., Letout, S., Mountraki, A. and Shtjefni, D., Clean Energy Technology Observatory: Carbon Capture, Utilisation and Storage in the European Union - 2022 Status Report on Technology Development, Trends, Value Chains and Markets, EUR 31229 EN, European Commission, doi:10.2760/268143 (online), JRC130663.
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## Annex 2 CETO sustainability assessment check-list

The following check-list was developed to allow the information available for each technology to be summarised in a comprehensive way. The compiled list are available in the individual reports listed in Annex 1.

<b>Parameter/Indicator</b>	<b>Input</b>
<b>Environmental</b>	
LCA standards, PEFCR or best practice, LCI databases	Y/N, reference(s)
GHG emissions	Representative kg CO <sub>2</sub> eq/kWh
Energy balance	EROEI, EPBT if available
Ecosystem and biodiversity impact	Comment if data or references or reports from sector working groups available
Water use	Representative m <sup>3</sup> /MWh for current technologies
Air quality	Comment if issue(s) exist
Land use	Representative W/m <sup>2</sup> for main current technologies, where relevant
Soil health	Comment if relevant and data available
Hazardous materials	Note if used in supply chain e.g. REACH materials
<b>Economic</b>	
LCC standards or best practices	Available Y/N, reference(s)
Cost of energy	Yes, LCoE, LCoS, LCoH, CAPEX, OPEX (or refer to other sections in this report)
Critical raw materials	Note if used in supply chain
Resource efficiency and recycling	Tbd (e.g recycling rates)
Industry viability and expansion potential	Yes, see markets section
Trade impacts	Yes, see markets section
Market demand	Yes, see markets section
Technology lock-in/innovation lock-out	Comment if dominant technology or technology provider
Tech-specific permitting requirements	Comment
Sustainability certification schemes	Y/N, reference(s)
<b>Social</b>	
S-LCA standard or best practice	Y/N, reference(s)
Health	Note known issues and refs
Public acceptance	Note known issues and refs
Education opportunities and needs	
Employment and conditions	For employment data see section 3.5
Contribution to GDP	see VC analysis section
Rural development impact	Comment if relevant to specific tech
Industrial transition impact	Comment if relevant to specific tech
Affordable energy access (SDG7)	Comment if relevant to specific tech
Safety and (cyber)security	Comment if relevant to specific tech
Energy security	Comment if relevant to specific tech
Food security	Comment if relevant to specific tech
Responsible material sourcing	Note EU REGULATION (EU) 2017/821 requirements if relevant



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