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REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL

Progress on competitiveness of clean energy technologies
1 - Macroeconomic

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

CONTENTS

PROGRESS ON COMPETITIVENESS OF CLEAN ENERGY TECHNOLOGIES

1. INTRODUCTION

1.1. An EU climate neutral pathway for the clean energy system

Since 2019, the European Green Deal is the overarching framework for EU clean energy policy. It sets the objective for the EU to have no net emissions of greenhouse gases (GHG) in 2050 and to decouple economic growth from resource use. To operationalise the European Green Deal, the EU Climate Law[1] has enshrined into law the political priority of becoming climate neutral by 2050 and of reducing greenhouse gas emissions by 55% by 2030, compared to 1990 levels. This has been followed by the Fit-for-55 package to deliver on the European Green Deal, adopted by the Commission in July 2021, which proposes to revise existing instruments as well as propose new ones[2] in order to achieve the 2030 target in a fair, cost-effective, and competitive way. This package constitutes the most comprehensive set of proposals the Commission has ever presented on climate and energy. These initiatives will notably contribute to the development of the clean energy sector in the next decades, in particular by spurring innovation and creating new market demand in the EU, cementing EU global leadership by action and by example in the fight against the climate crisis.

The policy context is complemented by a new EU budget (the Multiannual Financial Framework) covering the period 2021-2027. The EUR 1 074 billion[3] envelope sets a clear sustainable direction for the EU, with a target of spending at least 30% of these funds on actions fighting climate change. The clean energy sector is addressed by several EU programmes, notably: the cohesion policy funds, the Horizon Europe framework programme for research and innovation (e.g. through its European Innovation Council and its Cluster on Climate, Energy and Mobility), the Connecting Europe Facility (CEF), and the LIFE programme for environment and climate action. In addition, the revision of the European Emission Trading Scheme (ETS) will increase the allocation of allowances and therefore resources for the Innovation Fund, the Modernisation Fund and the newly created Social Climate Fund. The Innovation Fund, depending on the EU ETS price, could bring an estimated EUR 47 billion, to be invested over 10 years to support the deployment in the market of breakthrough low carbon technologies. The Modernisation Fund, intended to support low income Member States in the modernisation and decarbonisation of their energy systems, would be increased by an additional 2.5% of total allowances. The Social Climate Fund would provide EUR 72.2 billion in financing over seven years, or the equivalent of 25% of expected revenues under the new emissions trading system covering buildings and road transport. It would fund Member States' programmes designed to support investment in increased energy efficiency of buildings, the decarbonisation of heating and cooling and zero- and low-emission mobility and transport, specifically directed at vulnerable households. Finally, the Recovery and Resilience Facility (RRF), created as part of NextGenerationEU and its EUR 750 billion[4], is detailed in section 2.5.

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

[2] The legislative files include proposals to review the Renewable Energy Directive (RED), the Energy Efficiency Directive (EED), the Energy Tax Directive (ETD), the EU Emissions Trading System (EU ETS), the Effort Sharing Regulation (ESR), the Alternative Fuels Infrastructure Directive (AFID), the Regulation on Land Use, Forestry and Agriculture, the CO2 emission standards for cars and vans, but also proposals to create a Carbon Border Adjustment Mechanism (CBAM), and the ReFuelEU Aviation and FuelEU Maritime initiatives. An EU Forest Strategy and a proposal to create a Social Climate Fund complete the package.

[3] 2018 prices.

[4] 2018 prices. EUR 806.9 billion in current prices.

The clear direction described above, which sets targets, regulation, and funding – notably in energy efficiency, renewable energy, and emissions reductions – enables the clean energy sector to have visibility over future market prospects and opportunities, thus increasing investors' certainty. The foundation on which the framework is built is the EU internal market, which these policies aim to continuously strengthen by removing internal and external investment and trade barriers. Most recently, the European Commission presented its new Industrial Strategy[5] – updating it following the COVID-19 crisis[6] – to provide a roadmap for the EU industry to become more competitive globally. Some highly relevant initiatives to the clean energy sector include the creation of industrial alliances to accelerate activities that would not develop otherwise. To date, relevant alliances in place are the European Batteries Alliance, the Clean Hydrogen Alliance, and the European Raw Materials Alliance. Future alliances will include Zero Emission aviation and renewable and low-carbon fuels alliances.

The dependence on key raw materials, which is relevant for certain technologies covered in this report (e.g. batteries, PV), is also a centrepiece of the new industrial policy, as the EU aims to enhance its strategic autonomy. In addition to policies ensuring the sustainability of raw material production, the EU is also firmly attached to ensuring strong life-cycle and circularity considerations within its internal market, including recyclability, reusability or waste management of its products. Relevant examples include the proposal for a Batteries Regulation and the Circular Economy Action Plan, both presented by the European Commission in 2020. The Clean Energy Industrial Forum (CEIF), set up in 2018 by the European Commission, brings together industrial actors from the renewables, batteries and construction sectors, in order to identify and take advantage of growth opportunities.

Common rules and standards for access to finance are also important for fair and competitive market access. The EU aims to ensure this for example through the revision of state-aid guidelines for research, development and innovation, for energy and environment, and for important projects of common European interest (IPCEI). They will allow Member States to address market failures in very specific situations. At the same time, initiatives such as the EU Taxonomy Regulation and its delegated acts for sustainable finance will aim to steer market uptake of a wide range of technologies, including in the clean energy sector.

Another crucial point affecting the competitiveness of the clean energy industries, are the complex and lengthy administrative and permitting procedures. Permitting delays constitute a major barrier for the transition to a decarbonised energy system, delaying deployment and investments into clean energy infrastructures and technologies by many years. A significant acceleration of deployment is needed to achieve the current 2030 renewable energy target of 32%, and an even greater acceleration will be needed to meet the newly proposed 40% target of the 'Fit for 55' package.

Urgent simplification and streamlining of permitting procedures is needed to create a common market for renewables that facilitates efficient and cost-effective deployment as well as investor certainty, also in view of the massive investments needed. To this end, the Commission plans in 2022 to present guidance on the permitting provisions of the renewable energy directive, to facilitate best practices exchanges and strongly encourages Member States to continue streamlining and simplifying procedures to this end.

Finally, trade policy has a key role to play in driving Europe's economic prosperity and competitiveness, supporting a vibrant internal market and assertive external action. Political and geo-economic tensions are leading to growing unilateralism and distortions of trade and investments. This is also impacting the energy sector, where increasingly EU companies are faced with third country governments putting in place market access barriers, local content requirements or other discriminatory or otherwise trade restrictive measures

[5] COM(2020) 102 final.
[6] COM(2021) 350 final.

aimed at promoting their domestic industry. In line with the Trade Policy Review, the European Commission is taking an active role in securing access to third country markets for our renewable energy industry through its bilateral trade agreements and its reinforced enforcement approach, while ensuring undistorted trade and investment in the raw materials and energy goods required for the transition to climate neutral economies.

1.2. Context of the Report

This is the second competitiveness progress report published in the context of the State of the Energy Union report. As competitiveness in the clean energy sector is a broad concept, the first report defined it through a range list of indicators that this report uses to assess competitiveness.

Table 1 List of indicators for the Competitiveness Progress Report

Part 1: Macro section	**Part 2: Technology specific section**		
Macro-economic analysis (aggregated, per MS and per clean technology)	1. Technology analysis Current situation and outlook	2. Value chain analysis of the energy technology sector	3. Global market analysis
Primary and final **energy intensity**; **share of RES; import dependency,** industrial electricity and gas **prices**	**Capacity installed, generation/production** *(today and in 2050)*	**Turnover**	**Trade (imports, exports)**
Turnover of the EU (clean, Fossil Fuel) sector (vs whole economy)	**Cost / Levelised Cost of Electricity (LCoE)**[7] *(today and in 2050)*	**Gross value added growth** Annual, % change	**Global market leaders vs. EU market leaders**
Gross value added of renewable energy production vs Energy Efficiency vs economy	**Public R&I funding (MS and EU)**	**Number of companies in the supply chain, incl. EU market leaders**	**Resource efficiency and dependence**[8]
Employment figures EU vs RoW; gender statistics	**Private R&I funding** (venture capital (value and number of deals) (incl sources backing VC), energy companies)	**Employment in value chain segment**	
COVID-19 disruption of value chains	**Patenting trends** (incl high value patents)	**Energy intensity / labour productivity**	
	Level of scientific Publications	**Community Production** *Annual production values*	

[7] And –if available- Levelised Cost of Storage (LCoS).
[8] Segments of the value chain that depend on critical raw materials.

2. OVERALL COMPETITIVENESS OF THE EU CLEAN ENERGY SECTOR

2.1. Energy and resource trends

Over the period 2005-2019, both primary energy intensity and final energy intensity in industry have continued to decrease at an average annual rate of around 2%[9]. In the more recent period (2015-2019) the majority of Member States achieved reductions in energy intensity, with the exception of Belgium[10], Hungary and Poland[11]. In absolute terms, over the same recent period, total primary and final energy consumption increased slightly for the majority of Member States. However, big consumers such as Germany, France and Italy managed to achieve reductions in primary energy consumption (along with Denmark and the Netherlands), leading to a small overall reduction at EU level[12]. The reduced energy intensities demonstrate the decoupling of energy demand from economic growth. However, increased effort will be needed to achieve the new energy efficiency targets proposed by the Commission for 2030.

Table 2 shows the change in these indicators over the recent 5-year period per Member State. The majority of Member States achieved reductions, albeit some at a lower rate than the EU average. Over the same period the GHG intensity has also been decreasing consistently, enabled – among others – by the increasing share of renewable energy in energy consumption.

[9] Energy Union indicators EE1-A1: Primary energy intensity EE3: Final energy intensity in industry, DE5: Share of renewable energy in percentage of gross final energy consumption, SoS1: Net import dependency – sources Eurostat: Complete energy balances [nrg_bal_c], Gross value added [nama_10_a10]; GDP: AMECO database

[10] Where there was a small increase in primary energy intensity.

[11] Where the final energy intensity in industry increased.

[12] Even though reductions achieved in recent years have been small, overall, in the period 2005-2019 EU primary energy consumption decreased by 10% and final energy consumption decreased by 5%.

Table 2: Trends per Member State on primary energy intensity, final energy intensity in industry, renewable energy share and targets, and net import dependency (fossil fuels).

Indicators	Primary energy intensity		Final energy intensity in industry		RES in gross final energy consumption		Net import dependency	
Unit	[toe/mn Euro GDP2010]	average annual change [%]	[toe/mn Euro GVA2015]	average annual change [%]	Share [%]	gap to 2020 target [pp]	Net imports [%]	absolute change [pp]
Year	2019	2015-19	2019	2015-19	2019	2019	2019	2015-19
EU	102	-2%	90	-2%	20%	🟡	61%	🔴
BE	111	🔴	137	🟡	10%	🔴	77%	🟢
BG	347	🟢	306	🟢	22%	🟢	38%	🔴
CZ	208	🟢	116	🟢	16%	🟢	41%	🔴
DK	55	🟢	40	🟢	37%	🟢	39%	🔴
DE	87	🟢	72	🟡	17%	🔴	68%	🔴
EE	190	🟢	96	🟢	32%	🟢	5%	🟢
IE	44	🟢	20	🟡	12%	🔴	68%	🟢
EL	132	🟡	141	🟢	20%	🟢	69%	🟢
ES	101	🟡	101	🟡	18%	🔴	75%	🔴
FR	100	🟢	79	🟡	17%	🔴	48%	🔴
HR	163	🟢	136	🟡	28%	🟢	56%	🔴
IT	84	🟡	74	🟢	18%	🟢	77%	🔴
CY	117	🟡	96	🟢	14%	🟢	93%	🟢
LV	165	🟡	184	🟢	41%	🟢	44%	🟢
LT	145	🟡	106	🟡	25%	🟢	75%	🟢
LU	77	🟡	105	🟢	7%	🔴	95%	🟢
HU	186	🟢	147	🔴	13%	🟡	70%	🔴
MT	71	🟡	39	na	8%	🔴	97%	🟢
NL	84	🟢	113	🟢	9%	🔴	65%	🔴
AT	86	🟡	86	🟢	34%	🟡	72%	🔴
PL	191	🟢	135	🔴	12%	🔴	47%	🔴
PT	111	🟡	145	🟡	31%	🟡	74%	🟢
RO	163	🟢	142	🟢	24%	🟢	30%	🔴
SI	144	🟢	111	🟢	22%	🔴	52%	🔴
SK	179	🟡	151	🟡	17%	🟢	70%	🔴
FI	140	🟡	228	🟡	43%	🟢	42%	🟢
SE	93	🟡	115	🟢	56%	🟢	30%	🔴

Legend

	Primary energy intensity	Final energy intensity in industry	RES gap to 2020 target	Net import absolute change
🔴	>0%	>0%	x>0.5 %	x>0
🟡	0%> and >-2%	0%> and >-2%	0.5%> and >0.1%	
🟢	<-2%	<-2%	x<0.1 %	x=<0

Position relative to EU average

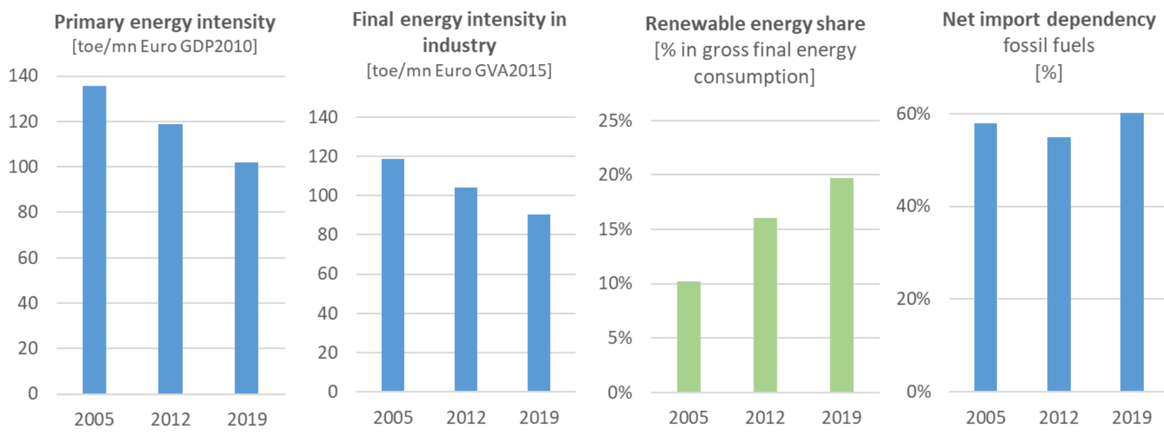
Source: Energy Union indicators, based on Eurostat data[13]

In 2019, the renewable energy share in the EU gross final energy consumption reached 19.7% (Figure below), very close to the 2020 target of 20%, with a renewable share of 34% in electricity generation.

[13] Energy Union indicators EE1-primary energy consumption, EE2-Final energy consumption, EE3: Final energy intensity in industry, SoS1: Net import dependency – sources Eurostat: [nrg_bal_c], [nrg_bal_s], Gross value added [nama_10_a10]; GDP: AMECO database.

Bioenergy accounted for 59% of the total renewable energy supplied, followed by wind (14%), hydro (12%), geothermal (8%) and solar (7%)[14]. While more than half of the Member States have already exceeded them, and a few more are very close, there are several countries further away from achieving their targets. The penetration of renewable energy needs to be significantly accelerated in order to achieve the new binding target proposed by the Commission of at least 40% renewable share in final energy consumption by 2030.

Figure 1 EU primary energy intensity and final energy intensity in industry, renewable energy share, and net import dependency (fossil fuels)



Source: Energy Union indicators, based on Eurostat data[15]

Despite a short-term reduction between 2008 and 2013, the EU energy import dependency[16] has since experienced an increase. In 2019, net import dependency reached 60.6%, the highest it has been during the last 30-year period. This is due to reduced domestic production of fossil fuels[17].

Under the package to deliver on the European Green Deal, the Commission has proposed to strengthen the EU Emissions Trading System (ETS) by tightening the cap and increasing the linear reduction factor from 2.2% per year to 4.2%. Furthermore, the EU ETS would be extended to maritime transport. The use of carbon pricing and carbon prices in economies with emissions trading systems and similar carbon pricing systems are increasing as parties put in place measures to meet Greenhouse Gas Emissions reduction targets. 2021 saw the launch of China's national emissions trading system, covering the power sector and due to expand to cover other heavy emitting sectors. Trading began in July 2021 at a price of RMB 50 (6.5 Euros) per tonne CO_2. Since 2019, Canada has a federal carbon pricing system, with a benchmark/ minimum price across all provinces, which will reach 50 CAD (around 34 Euros) per tonne in 2022 and will rise by 15 CAD (10 Euros) per year from 2023 to 2030. Other jurisdictions are also revising their ETS legislation, for example, South Korea and New Zealand where the ETS price rose to 48 NZD (28 Euros)

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14 Eurostat Complete energy balances [nrg_bal_c]

15 Energy Union indicators EE1-primary energy consumption, EE2-Final energy consumption, EE3: Final energy intensity in industry, SoS1: Net import dependency – sources Eurostat: [nrg_bal_c], [nrg_bal_s], Gross value added [nama_10_a10]; GDP: AMECO database.

16 In the context of this report, net import dependency measures the level of total net imports as a proportion of total gross inland consumption and the energy consumption of maritime bunkers (i.e. what is consumed in a country or region over a year). The indicator is based on Eurostat energy statistics.

17 Eurostat (sdg_07_10), (sdg_07_11), (nrg_bal_c).

per tonne in July 2021. The EU Emissions Trading System (ETS) prices have risen from about 25 Euros per tonne of CO_2 in 2020 to around 50 Euros per tonne of CO_2 in mid-2021.

The Commission has also reviewed the functioning Market Stability Reserve (MSR) and proposed adjustments to prevent excessive surpluses and deficits in the market. The Commission also proposes a new, separate ETS to cover emissions from fuels used in the road transport and buildings sectors, to provide incentives for decarbonisation. Social impacts on vulnerable households, micro-enterprises and transport users that arise from the new system would be addressed by a new Social Climate Fund. Direct income support would also be made available to vulnerable households, in order for them to absorb the immediate price impact of the new emissions trading system.

Comparing EU[18] to the world's biggest economies in terms of carbon pricing[19,20](based on OECD data from 2018 on pricing carbon emissions of energy use[21]), only South Korea had higher level of pricing, in which over 65% of emissions were priced above 5 EUR/tCO_2, mainly via taxes on fuel use . In the EU, on average, over 41% of emissions were priced above 5 EUR/tCO_2. Also, over 27% was priced above 120 EUR/tCO_2. As mentioned above, since 2018, the EU ETS price has increased significantly. In the US and China, 65% and 91% of emissions respectively were not priced at all or priced at less than 5 EUR/tCO_2. Taking view on industry and electricity sectors shows that emissions were priced generally at lower level. In the industry, over 90% of emissions in South Korea were priced above 5 EUR/tCO_2. In the EU this share was on average about 56%. In contrast in the US and China, 97% and 98% of emissions were not priced at all or priced below 5 EUR/tCO_2. In the electricity sector, South Korea had again the highest pricing, where 72% of emissions were priced at 5-30 EUR/tCO_2 and 25% of emissions priced at 30-60 EUR/tCO_2. In the EU, on average 77% of emissions were priced at 5-30 EUR/tCO_2. In the US and China, 93% and 100% of emissions respectively, were not priced at all or priced below EUR 5 per tCO_2.

Figure 2: Emissions priced at different levels – all sectors[22], industry and electricity (2018)

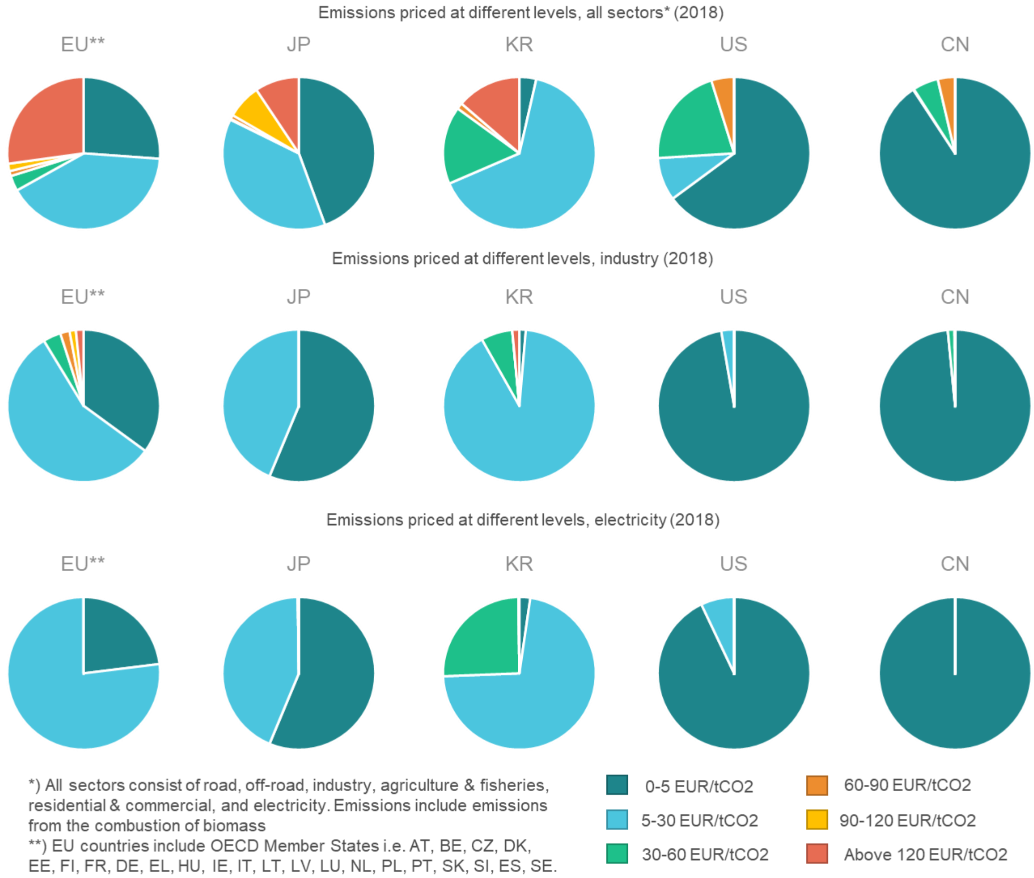
[18] This is based on OECD data which includes the following EU countries: AT, BE, CZ, DK, EE, FI, FR, DE, EL, HU, IE, IT, LT, LV, LU, NL, PL, PT, SK, SI, ES, SE.

[19] Effective carbon rates reported by OECD is the most detailed and comprehensive account of how 44 OECD and G20 countries – responsible for around 80% of global emissions – price carbon emissions from energy use. Effective carbon rates consider emission permit prices (e.g. EU ETS), carbon tax and fuel excise tax.

[20] EU was calculated as simple average of EU countries, as there was no data to do weighted average calculation.

[21] OECD (2021), Effective Carbon Rates 2021: Pricing Carbon Emissions through Taxes and Emissions Trading, OECD Publishing, Paris, https://doi.org/10.1787/0e8e24f5-en.

[22] All sectors include road, off-road, industry, agriculture and fisheries, residential and commercial, and electricity. Emissions include also emissions from the combustion of biomass.



Source: JRC elaboration based on OECD[23]

Literature is inconclusive when it comes to the effects of carbon pricing on different elements of competitiveness. Calel and Dechezlepretre (2016)[24] find that EU ETS has increased low-carbon innovation[25] among regulated firms by as much as 10%, while not crowding out patenting for other technologies. Results imply that the EU ETS accounts for nearly a 1% increase in European low-carbon patenting compared to a counterfactual scenario. In another study Ley et al. (2016)[26] investigated patent data and industry specific energy prices for 18 OECD countries over 30 years. They found that 10% increase of the average energy prices[27] over the previous five years results in a 3.4% and 4.8% increase of the number of green innovations and the ratio of green innovations to non-green innovations, respectively. In the meta-

[23] OECD. Effective Carbon Rates: Share of emissions priced - Dataset. Availablet at: https://stats.oecd.org/?datasetcode=ecr.
[24] Calel, R & Dechezlepretre, A (2016) Environmental policy and directed technological change: evidence from the European carbon market. The Review of Economics and Statistics 98:1, 173-191, DOI: https://doi.org/10.1162/REST_a_00470.
[25] Patents classified as 'Technologies and applications for mitigation or adaption against climate change' (Y02 class) are used as a proxy for low-carbon innovation.
[26] Ley, M, Stucki, T, Woerter, M (2016) The impact of energy prices on green innovation. The Energy Journal, International Association for Energy Economics 37:1.
[27] Energy prices here refer to end-use prices (per tonne of oil equivalent including taxes) for the manufacturing sector for different energy products, such as electricity, light fuel oil, natural gas and different coal products.

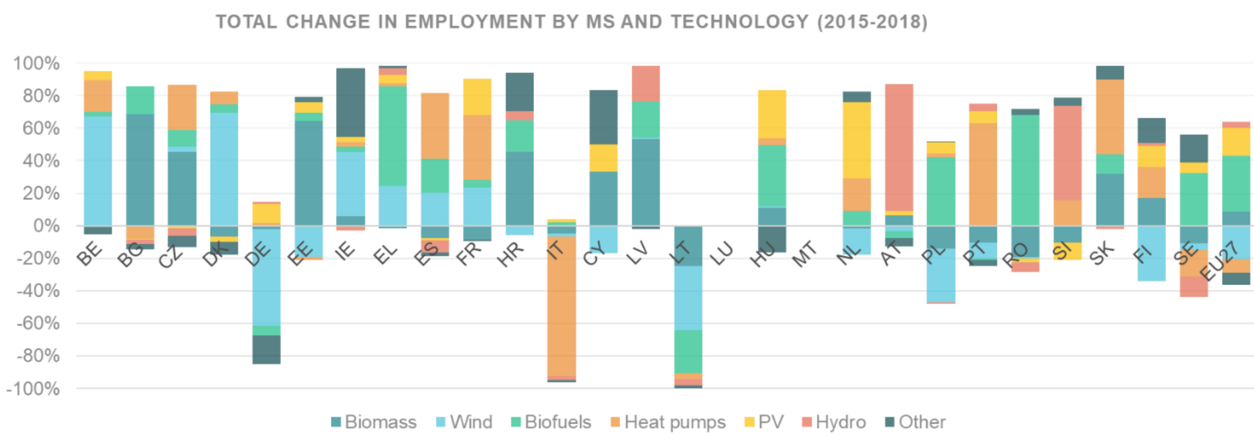
analysis of Venmans et al. (2020)[28] on the impact of carbon pricing on a range of economic indicators[29], positive effect is found on innovation and productivity, while effect on net exports, turnover, and employment remain inconclusive. Carbon prices levied on industry have been low to date, either because of exemptions to carbon taxes, or generous levels of free allowances, which in part explains these findings.

2.2. Human Capital

2.2.1. Employment in clean energy

Looking more closely at direct and indirect jobs[30][31] per renewable energy technologies over the period 2015-2018, shows that overall employment in EU has grown by an average 1% annual growth[32]. However, there are vast differences across different technologies and Member States. In terms of renewable energy technologies at EU aggregate level, the biggest decline has been in the wind sector. Decline of jobs has been biggest in Germany, Lithuania, Poland and Finland. Especially in Germany, the biggest market, decline has been due to the wind installation market slowing down, from annual installed capacity of 5.4 GW in 2016 to 1.7 GW in 2019[33] (see Offshore and Onshore wind sections). In contrast, the biggest overall increase in EU has been in the biofuels and solar PV. Biofuel jobs grew most in the Greece, Poland and Romania. Solar PV jobs grew the most in France, Hungary and the Netherlands.

Figure 3 Total change in employment by technology and by MS over 2015-2018 period



Source: JRC based on EurObserv'ER

Figure 4 (below) shows the average annual growth rate over the period 2015-2018 across Member States and across different technologies. Jobs have grown fastest in solar PV (12%), biofuels (11%), and waste to

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28 Venmans F., Ellis J. & Nachtigall D. (2020) Carbon pricing and competitiveness: are they at odds?, Climate Policy, 20:9, 1070-1091, DOI: 10.1080/14693062.2020.1805291.

29 Net imports, foreign direct investments, turnover, value added, employment, profits, productivity, and innovation

30 It is important to note that two different data sources are used for employment figures in this report, namely Eurostat Environmental Goods and Services Sector accounts and EurObserv'ER. The figures are not directly comparable as there are methodological differences in approaches. The Annual Single Market Report 2021 estimated the employment and gross value added of Renewables Ecosystem using national accounts and NACE classification.

31 EurObserv/ER definition – direct employment includes renewable equipment manufacturing, renewable plant construction, engineering and management, operation and maintenance, biomass supply and exploitation. Indirect employment refers to secondary activities such as transport and other services.

32 EurObserv'ER tracks direct and indirect jobs in renewable energy technologies per Member State. The methodology and scopes in Eurostat EGSS accounts and EurObserv'ER are different, hence the figures should not be compared directly.

33 Based on EurObserv'ER Wind Energy Barometer.

energy sector (9%), and declined fastest in geothermal (-8%), solar thermal (-6%), in wind (-5%) and biogas (-5%). Jobs have grown overall fastest in Bulgaria (25%), Belgium (20%), Greece (20%), Ireland (16%) and Netherlands (15%). Jobs have declined fastest in Italy (-14%), in Lithuania (-13%) and in Germany (-6%). EU-average is used as a benchmark for ranking the growth rate of Member State in each technology i.e. green – growing faster than EU average, yellow – growing but at lower level than EU average, and red – declining or declining faster than EU average. Benchmarks per each technology are indicated in Figure 4.

Figure 4 Average growth rate per year in jobs (2015-2018) by technology and by Member State

Growth of employment per technology (CAGR) over period 2015-2018

	Biomass	Wind	Biofuels	Heat pumps	Solar PV	Hydropower	Others*	**Total**
BE	↓	↑	→	↑	→	→	↓	20%
BG	↑	→	↑	↓	↓	↓	↓	25%
CZ	↑	↑	→	↑	↓	↓	↓	10%
DK	↓	↑	↑	↑	↓	→	↓	5%
DE	↓	↓	↓	↑	→	↑	↓	-6%
EE	↑	↓	↑	→	↑	→	↑	9%
IE	↑	↑	↑	↑	↑	↓	↑	16%
EL	↓	↑	↑	↑	↑	↑	↑	20%
ES	↓	↑	↑	↑	↓	↓	↓	7%
FR	↓	↑	→	↑	↑	→	→	4%
HR	↑	↓	↑	→	→	↑	↑	7%
IT	↓	→	→	↓	→	↓	→	-14%
CY	↑	↓	→	→	↑	→	↑	11%
LV	↑	↑	↑	→	→	↑	↓	12%
LT	↓	↓	↓	↓	→	↓	↓	-13%
LU	→	→	→	→	→	→	→	0%
HU	↑	↑	→	↑	↑	→	↓	6%
MT	→	→	→	→	→	→	→	0%
NL	↓	↓	↑	↑	↑	→	↑	15%
AT	↑	↓	↓	→	→	↑	↓	13%
PL	↓	↓	↑	↑	↑	↓	↑	0%
PT	↓	↓	↓	↑	↑	→	↓	6%
RO	↓	→	↑	→	↓	↓	↑	9%
SI	↓	→	→	↑	↓	↑	↑	8%
SK	↑	→	→	↑	→	↓	↑	9%
FI	→	↓	→	↑	↑	→	↑	2%
SE	↓	→	↑	↓	↑	↓	↑	1%
EU27	**2%**	**-5%**	**11%**	**-2%**	**12%**	**3%**	**-3%**	**1%**
↑	>2%	>0%	>11%	>0%	>12%	>3%	>0%	
→	<2%	<0%	<11%	<0%	<12%	<3%	<0%	
↓	≤0%	≤-5%	≤0%	≤-2%	≤0%	≤0%	≤-3%	

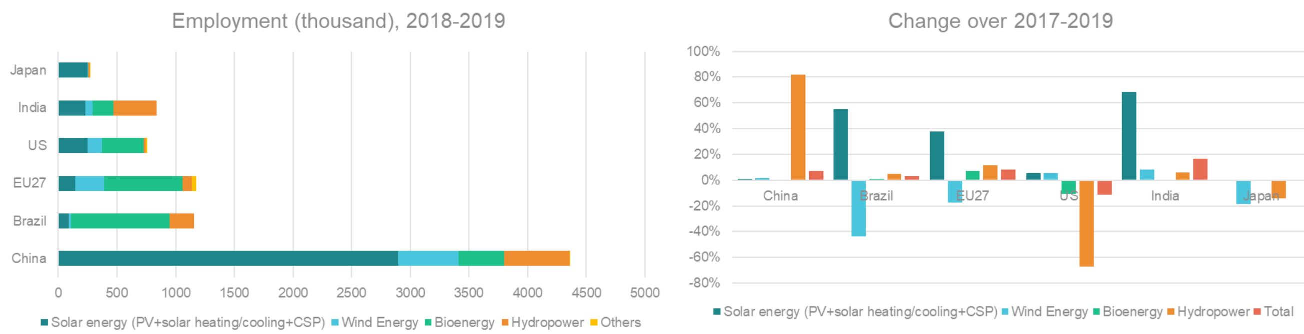
*) Others include biogas, waste, solar thermal and geothermal

Source: JRC based on EurObserv'ER

2.2.1.1.Global comparison

Overall global renewable energy employment increased by 4% from 2018 to 2019, reaching 11.5 million jobs. Solar PV remains the biggest globally with 33% share, followed by bioenergy[34] with 31% share of total jobs. The biggest increase since 2018 has occurred in India (growth of 16%), where jobs, especially in solar energy increased by 68%. In China, the biggest market, jobs in solar energy grew only by 1%, with the biggest growth occurring in hydropower with 82% growth. Also in Brazil growth of jobs was driven by increase in solar energy employment, whereas jobs in wind sector decreased. In the US and Japan overall level of jobs declined.

Figure 5 Renewable energy employment in the biggest economies



Source: JRC based on IRENA

2.2.1.2.Skills and training aspects

The clean energy system is entering a new era, where new innovations have been emerging at an accelerated pace. Such acceleration requires re-skilling and up-skilling across all skills levels to deploy and further develop clean energy technologies and solutions across different sectors. Demand for a wide range of occupational categories relevant to the greening economy is expected to increase until 2030. These include blue collar jobs like labourers in mining (covering also the mining of critical materials for clean technologies), construction, manufacturing and transport, building and related trades, as well as white collar jobs like science and engineering professionals[35].

To support the uptake of next-generation skills essential for the EU green transition, the EU launched in 2020 the Pact for Skills[36] where partnerships with industrial ecosystems such as construction and energy intensive industries are being set up through roundtables. There are over 336 signatories to the Pact, with 130 also making commitments for upskilling and reskilling[37]. Signatories can be a rage of different actors: individual companies, regional and local partnerships, industrial ecosystems and cross-sector partnerships. Key principles include the promotion of lifelong learning, monitoring and anticipation of required skills, as well as working for equal opportunity. High-level roundtables with industrial ecosystems in the construction and energy intensive

34 Bioenergy includes liquid biofuels, solid biomass and biogas.
35 https://www.cedefop.europa.eu/en/publications-and-resources/publications/3077
36 European Commission, The Pact for Skills – mobilising all partners to invest in skills, 2020.
37 https://ec.europa.eu/social/main.jsp?catId=1517&langId=en

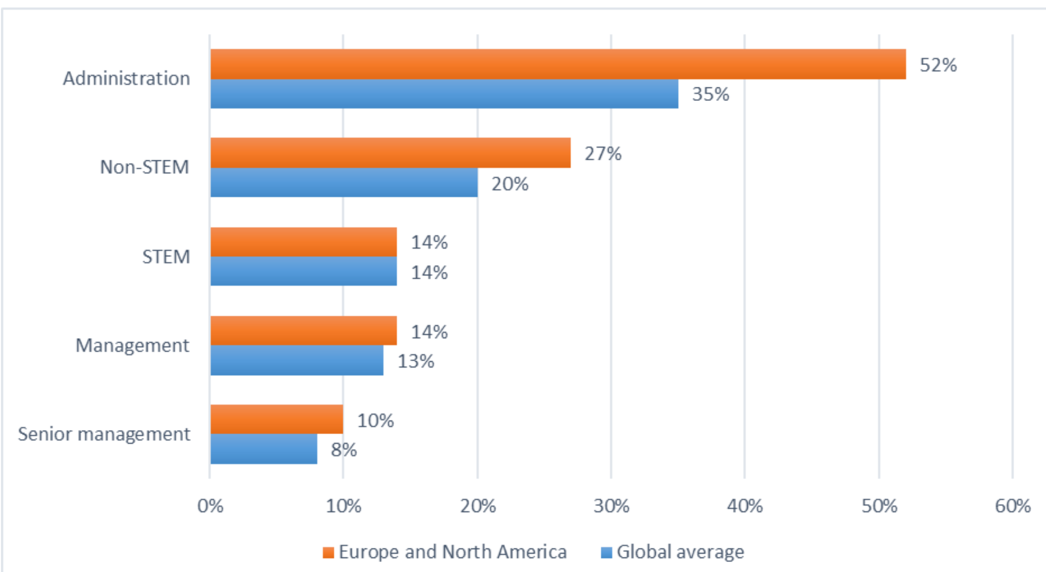
industries sectors have already taken place. These pave the way for partnerships established under the pact to benefit from platforms for networking, expertise, guidance and financial resources.

The composition of training offered in clean energy reflects the need for balance between technical, soft, and transversal skills. EU's BUILD UP Skills initiative aims to equip construction professionals, ranging from manual labourers to design professionals and senior management, with skills for sustainable and energy efficient construction[38]. Various efforts at EU level (DigiPLACE project[39], set up of Digital Innovation Hubs and others) aim at supporting the digital transformation of the construction ecosystem. Digital technologies in construction, buildings and infrastructure can improve sustainability, resource efficiency and the overall management of the assets.

2.2.1.3.Gender aspects

While women accounted for an average of 32% of the workforce in the renewables sector in 2019[40], in wind sector specifically, women represent an estimated 21% of the industry's workforce globally. In Europe and North America, the best performing region, the share is 26%[41]. This is principally due to a heavy representation of women in administration, see Figure 6. The role with the lowest share of female employment (8%) was senior management (e.g. owners or members of the board of directors of an organisation). Women being comparatively less represented in non-administrative functions might attest to the existence of a variety of gender-specific barriers. Conventional energy sectors, including extractive fossil fuel industries are even more male dominated[42].

Figure 6 Shares of women by role in the wind energy sector in Europe and North America and globally



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[38] CORDIS, New skills for the construction sector to achieve European energy targets, Results Pack, 2020.

[39] [Home (digiplaceproject.eu)](https://digiplaceproject.eu)

[40] IRENA (2019): https://www.irena.org/publications/2019/Jan/Renewable-Energy-A-Gender-Perspective

[41] IRENA (2020), Wind Energy: A Gender Perspective. IRENA, Abu Dhabi. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jan/IRENA_Wind_gender_2020.pdf

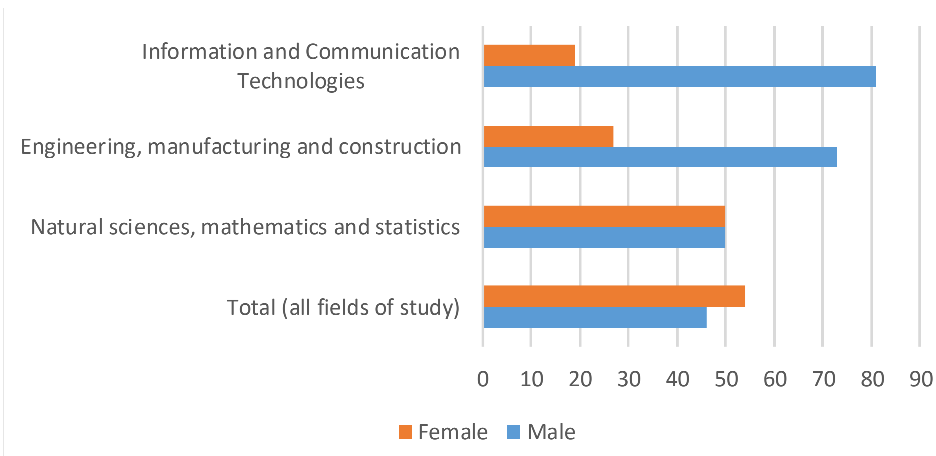
[42] https://publications.jrc.ec.europa.eu/repository/handle/JRC120302.

Source: JRC elaboration based on IRENA (2020)[43]

The energy sector also faces stark gender gaps in innovation and entrepreneurship. 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)[44]. Highest share (about 25%) of women in patent applications is in chemistry and health sectors.

Gender imbalances both in the energy sector workforce as well as in energy related research and innovation activity, are closely connected to the underrepresentation of women in higher education in some STEM sub-fields. In the EU, women are overrepresented in tertiary education as a whole (54 % across all tertiary education levels and all fields). Within STEM, there is gender balance in the Natural sciences, mathematics and statistics sub-field. However, the sub-fields highly relevant for the energy sector remain strongly male dominated: in 2019 less than a third of Engineering, manufacturing and construction and less than a fifth of ICT higher education students was female.

Figure 7 Distribution of tertiary education students in STEM fields by sex, %, EU-27, 2019



Source: JRC based on Eurostat [EDUC_UOE_ENRT03]

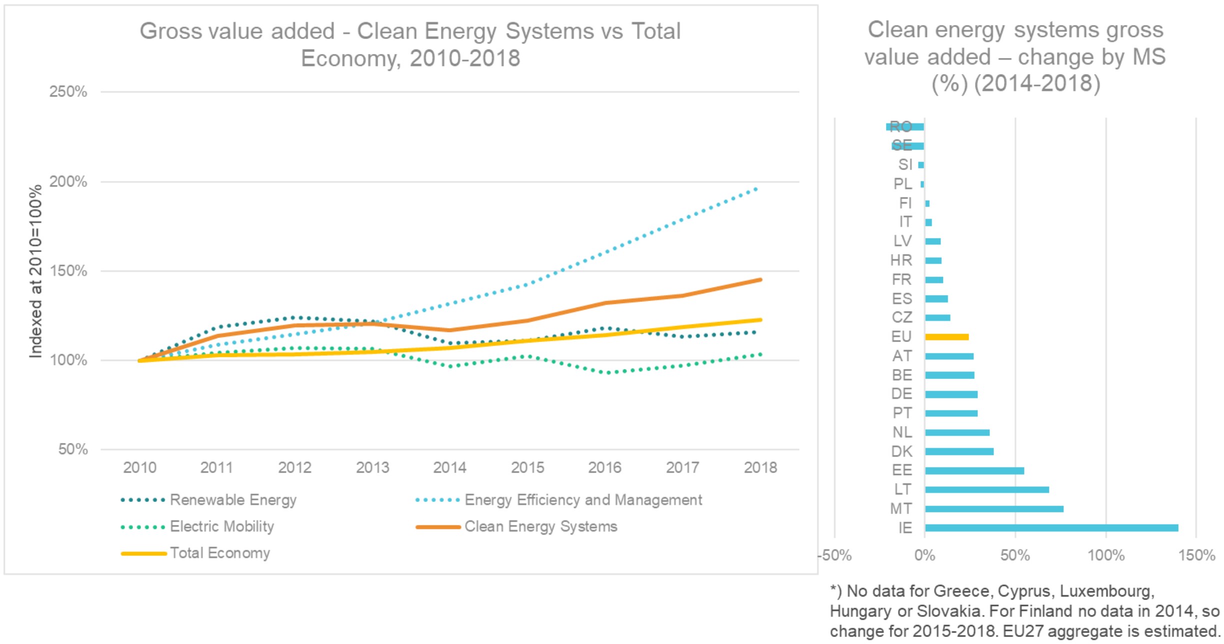
2.2.2. Gross value added in clean energy

The gross value added of clean energy systems overtook the rest of the economy with an average annual growth of 5% compared to the 3% in the whole economy since 2010. Clean energy (EUR 133 billion) represented 1% of the total value added in the EU in 2018. Within the clean energy systems, gross value added in 'Renewable energy' (EUR 60 billion) has grown with an average annual growth of 2%, while 'Energy efficiency and management systems' (EUR 67 billion) has grown on average by 9% in the same period. Gross value added in the 'Electric mobility' at EUR 7 billion has grown at less than 1% annually.

[43] IRENA (2020), Wind Energy: A Gender Perspective. IRENA, Abu Dhabi. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jan/IRENA_Wind_gender_2020.pdf

[44] IEA (2020), Gender diversity in energy: what we know and what we don't know, IEA, Paris https://www.iea.org/commentaries/gender-diversity-in-energy-what-we-know-and-what-we-dont-know.

Figure 8 Clean energy systems gross value added vs total economy - growth in EU27 2010-2018 and clean energy systems gross value added - change by Member State over 2014-2018



Source: JRC based on Eurostat 'env_ac_egss2'[45]

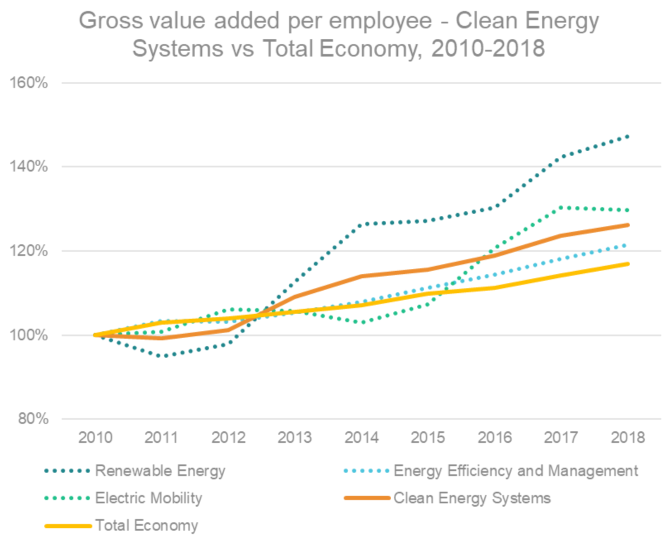
2.2.3. Labour productivity

'Renewable energy' jobs created on average EUR 104 000 of gross value added per employee in 2018 with an average annual growth[46] of 5% since 2010. This is nearly twice as much as in the rest of the economy (EUR 64 000 of gross value added per employee). Figure 9 below displays the higher growth in gross value added per employee of multiple components of the clean energy system compared to total economy as well as a break down by Member State.

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

46 Compound average growth rate.

Figure 9 Gross value added per employee – Clean energy systems vs Total economy (2010-2018), and gross value added per employee per MS in 2018 and compound average growth rate over 2015-2018 period



GVA per employee

	Renewable Energy		Energy Efficiency and Management		Electric Mobility	
	in 2018	Growth	in 2018	Growth	in 2018	Growth
BE	292	↓	83	↓	122	→
BG	65	↓	15	↓	32	-
CZ	72	→	38	↑	45	→
DK	146	↑	107	→	105	→
DE	160	↑	77	↓	91	↓
EE	42	→	33	↑	35	↑
IE	96	↓	69	↓	47	↓
EL	-		-		-	-
ES	336	↓	99	↓	71	↓
FR	88	↓	60	↓	85	→
HR	32	→	32	→	24	↓
IT	210	↓	52	→	77	→
CY	-		-		-	-
LV	36	↓	25	↑	33	→
LT	57	↓	28	↑	34	↑
LU	-		-		31	↓
HU	-		-		-	-
MT	136	↑	25	↓	26	-
NL	183	→	76	↑	95	→
AT	122	→	111	↑	93	→
PL	80	↓	32	↓	36	↓
PT	69	→	38	↓	37	→
RO	66	↑	49	↑	140	→
SI	73	→	20	↓	31	→
SK	-		-		-	-
FI	221	↑	94	→	80	→
SE	275	↓	91	↓	124	→
EU27	104	5%	64	3%	74	7%

Relative to EU average	Renewable Energy	Energy Efficiency and Management	Electric Mobility
↑	>5%	>3%	>7%
→	<5%	<3%	<7%
↓	≤0%	≤0%	≤0%

Source: JRC based on Eurostat 'env_ac_egss1' and 'env_ac_egss2'[47]

Labour productivity in 'Renewable energy' is about three times higher in Spain and Belgium than the EU average, though declining. In Spain and Belgium a large share of gross value added in renewable energy, 85% and 64% respectively, comes from generation of renewable electricity. By contrast, more than half of the value added of the renewable energy sector in Denmark, Croatia and Austria is generated by the manufacturing of clean energy technologies. Labour productivity in 'Energy efficiency and management' is highest and growing in Denmark and Austria, and in both over half of the value added is generated by the manufacturing sector. The factors behind high variation of productivity levels among Member States include income, energy prices, subsidies for renewable energy, composition of the renewable energy mix, and the scope of activities covered[48].

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

48Eurostat. Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Environmental_economy_%E2%80%93_statistics_by_Member_State#Employment.

While employment in the wind sector has decreased in the EU in the past years, the labour productivity[49] is highest, at EUR 145 000 per employee, and has grown by 4% a year on average. Second highest labour productivity is in the solar PV sector at EUR 125 000 per employee (with 2% average annual growth) and hydropower at EUR 120 000 per employee (with 6% average annual growth). Interestingly, while employment in biofuels has grown, its labour productivity is by far the lowest, at EUR 57 000 per employee and it has been decreasing by 4% a year on average. This is due to a large portion of jobs related to the feedstock procurement component of the value chain. Biomass production in agriculture and forestry sectors is more labour intensive but yields less value than i.e. biomass conversion. While there are differences among Member States and technologies (Figure 10), overall at aggregate EU level there has been no growth in turnover per employee.

Figure 10 Turnover per employee in 2018 and compound average growth rate over 2015-2018 period

Turnover per employee in 2018 and CAGR over 2015-2018 period

	Biomass		Wind		Biofuels		Heat pumps		Solar PV		Hydropower		Other*		Total	
	1000 EUR	Growth	1000 EUR	Growth	1000 EUR	Growth	1000 EUR	Growth	1000 EUR	Growth	1000 EUR	Growth	1000 EUR	Growth	1000 EUR	Growth
BE	333	↑	200	→	264	→	193	↑	188	→	175	↓	192	↓	213	1%
BG	37	↑	60	→	36	→	50	↑	50	↑	52	↑	42	↑	38	5%
CZ	67	↑	77	↑	54	↑	70	↑	74	↑	69	↑	61	↑	65	3%
DK	192	↑	181	→	171	↑	174	↑	181	↑	100	→	178	↑	182	2%
DE	122	↑	144	→	106	↑	142	↑	136	↑	139	→	126	↑	135	3%
EE	61	↑	75	↑	60	↑	67	↑	60	↓	100	→	75	↓	63	2%
IE	127	↑	113	→	50	↓	100	→	100	→	100	↑	105	↑	110	2%
EL	67	↑	69	↓	33	→	87	↑	67	↓	71	↓	61	↓	54	-5%
ES	44	↓	117	↓	60	→	95	↑	100	→	96	→	114	→	90	0%
FR	117	↑	158	→	97	↑	146	↑	141	→	148	→	136	↑	131	1%
HR	25	↑	64	↑	52	→	100	→	50	→	62	→	54	↓	36	3%
IT	72	↓	147	→	87	↓	132	↑	130	↓	130	↑	115	↓	115	0%
CY	67	↓	100	→	100	→	100	→	50	↓	100	→	83	↓	80	-7%
LV	37	↑	50	↓	33	↓	100	→	100	→	52	→	55	↓	39	1%
LT	74	↑	60	↑	33	↑	100	↑	100	→	50	↑	67	↑	49	7%
LU	100	→	100	→	100	→	100	→	100	→	140	→	100	→	114	0%
HU	34	↑	67	↑	45	→	50	→	47	→	100	→	50	↑	43	2%
MT	100	→	100	→	100	→	100	→	100	↑	100	→	100	→	100	3%
NL	115	↓	141	→	158	→	126	→	120	→	100	→	136	↓	129	0%
AT	182	↓	172	↑	152	↑	171	↑	163	↑	165	→	175	↑	170	0%
PL	41	↓	93	↑	36	→	77	↑	74	↑	80	→	60	↑	44	-2%
PT	86	↓	108	↑	67	→	63	↑	63	→	69	→	62	↑	72	0%
RO	31	↑	77	↑	28	→	67	↑	64	↑	67	↑	63	↓	35	-1%
SI	78	↑	100	→	100	→	75	↓	100	↑	75	→	83	↑	78	6%
SK	38	↓	100	→	78	↑	75	↓	50	↓	83	↑	76	↓	56	1%
FI	185	↑	186	↑	92	↓	158	↑	167	↓	162	→	153	↑	172	2%
SE	216	↓	213	→	45	↑	208	↑	191	↑	200	→	186	↑	174	-2%
EU27	**88**	**0%**	**145**	**4%**	**57**	**-4%**	**120**	**-1%**	**125**	**2%**	**120**	**6%**	**113**	**1%**	**105**	**0%**

Relative to EU average

	Biomass	Wind	Biofuels	Heat pumps	Solar PV	Hydropower	Other*
↑	>0%	>4%	>0%	>0%	>2%	>6%	>1%
→	=0%	<4%	<0%	<0%	<2%	<6%	<1%
↓	<0%	≤0%	≤-4%	≤-1%	≤0%	≤0%	≤0%

*) Biogas, waste, solar thermal, geothermal

Source: JRC based on EurObserv'ER

49 This is based on turnover per employee figures from EurObserv'ER, hence these should not be compared to labour productivity measured as gross value added per employee above.

2.3. Research and innovation trends

After the last economic crisis, public investments in R&I prioritised by the Energy Union[50],[51] went into a decline for half a decade, only showing signs of recovery after 2016. Since then, the EU MS have invested an average EUR 3.5 billion per year, but spending is still lower than that observed a decade ago. The trend from 2016 is consistent with increased investments in energy in general – and clean energy in particular - globally[52], however these do not seem to keep pace with increases in GDP or R&I spending in other sectors.

Today, at 0.027%, the EU has the lowest R&D investment intensity in the clean energy sector (measured as a share of GDP) of all major global economies, just below the US, though levels seem to be decreasing or stable for all. In 2019 the R&I budget allocated to the socioeconomic objective of energy in the EU was EUR 4.1 billion, representing 4.4% of total spending on R&I[53], having decreased slightly compared to the two previous years. This shows that, while increasing in absolute terms, investments in the technologies needed for decarbonisation are not keeping pace with the growth of the economies themselves, or prioritised as much as other sectors.

EU research funds have been contributing an increasing share of public funding and have been essential in maintaining research and innovation investment levels over recent years, contributing on average an additional EUR 1.5 billion per year. Combined with an estimated average EUR 20 billion of private spending[54], the average annual total investment in the Energy Union R&I priorities over recent years (2014-2018) is in the order of EUR 25 billion[55].

In 2019, total public investment from all EU MS was still 5% lower than 2010, but had increased by 2% compared to 2015. Table 3 shows that there is a mixed picture at Member State level. About a quarter have consistently increased spending overall throughout the 10-year period, with an equivalent number showing a decrease. For the remaining, the trend coincides with the total for all EU MS, or information on R&I spending is not available. While there is a clear need to improve monitoring of R&I investment, there is also increased momentum and engagement from the Member States in view of the reporting foreseen in the Energy Union Governance Regulation. This goes beyond public R&I investment, to also stepping up efforts at national level to monitor R&I investments from the private sector.

50 COM(2015)80; renewables, smart system, efficient systems, sustainable transport, CCUS and nuclear safety.
51 JRC SETIS https://setis.ec.europa.eu/publications/setis-reseach-and-innovation-data_en.
52 https://www.iea.org/reports/world-energy-investment-2020/rd-and-technology-innovation.
53 Eurostat, Total GBAORD by NABS 2007 socio-economic objectives [gba_nabsfin07]. The energy socioeconomic objective includes R&I in the field of conventional energy. The Energy Union R&I priorities would also fall under other socioeconomic objectives.
54 Private investment estimates have been revised upwards, due to changes in classification and the underlying data.
55 The increased total compared to last year's reporting is due to the revision of the private investment estimates (see above).

Table 3 Overview of public R&I investment and patenting per Member State .

Indicators	Public investment (MS national funding)				Inventions (patent families)	
Unit	[mn Euro]	as share of GDP [%]	change [%] compared to 2010	change [%] compared to 2015	patents per mn inhabitants	share of 'green' patents [%]
Year	2019	2019	2019	2019	2018	
EU	3742	0.03%	-5%	2%	19	11%
BE	213	0.04%	🟢	🟢	13	10%
BG	n.a.				0.4	14%
CZ	160	0.07%	🟢	🟢	3	7%
DK	70	0.02%	🔴	🔴	79	25%
DE	831	0.02%	🟢	🟢	57	13%
EE**	5	0.02%	🔴	🔴	3	13%
IE	21	0.01%	🔴	🔴	11	6%
EL	n.a.				0	8%
ES	108	0.01%	🔴	🔴	3	11%
FR	1152	0.05%	🟢	🟡	21	12%
HR	n.a.				0.1	12%
IT*	381	0.02%	🔴	🔴	5	7%
CY	1	0.00%		🟢	6	6%
LV	n.a.				2	8%
LT**	15	0.03%	🟢	🟢	1.6	5%
LU	n.a.				38	7%
HU	10	0.01%	🔴	🔴	1	10%
MT	0.3	0.00%	🟢	🟢	3	3%
NL	240	0.03%	🔴	🟢	19	8%
AT	134	0.03%	🟢	🟢	25	12%
PL	90	0.02%	🔴	🔴	4	8%
PT	63	0.03%	🟢	🟢	1	6%
RO*	7	0.00%	🔴	🔴	2	12%
SI	n.a.				7	8%
SK	5	0.01%	🔴	🟢	3	17%
FI	117	0.05%	🔴	🔴	30	9%
SE	125	0.03%	🔴	🟢	28	8%

Legend

🔴 <-2%

🟡 2%> and >-2%

🟢 >2%

Position relative to EU average

*2018 value; data not yet available for 2019

** the 2011 / 2014 value is used for the 10- or 5-year change

Source: JRC[56] based on IEA[57], own work.

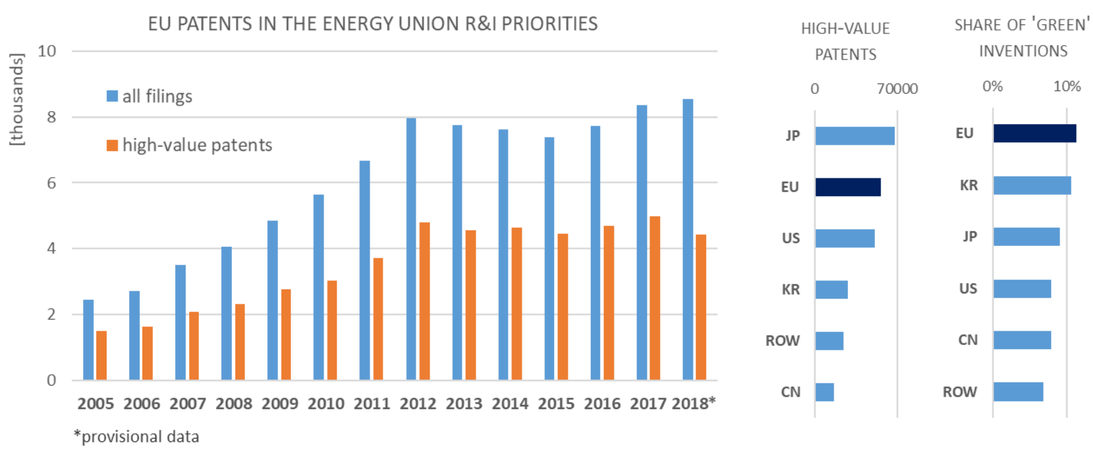
Private investment in the Energy Union R&I priorities in the EU is estimated at 0.18% of GDP, above the US but lower than other major competing economies. This represents 12% of the business expenditure on R&D, which is above the 6% estimated for the US, but about half of the share observed for major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

[56] JRC SETIS https://setis.ec.europa.eu/publications/setis-reseach-and-innovation-data_en.
[57] Adapted from the 2021 edition of the IEA energy technology RD&D budgets database.

Following a peak in 2012, overall patenting activity in clean energy technologies[58] decreased[59]. This trend seems to be reversing from 2016, with annual filing levels in the EU (Figure 11), and globally, returning to those observed in 2012. The EU has a greater share of 'green' inventions in Climate Change Mitigation Technologies, compared to other major economies (and the world average) indicating greater focus and specialisation of inventive activity in clean energy technologies. This specialisation is not equally shared at Member State level. Larger economies, with traditionally strong innovation ecosystems may have high outputs in terms of patents per capita as part of a large portfolio of innovation; others may not be as strong in terms of output, but show higher specialisation for these technologies within their patenting activity.

Overall, in terms of high-value inventions[60], the EU is second only to Japan, mainly due to Japan's advantage in transport technologies; however, the EU leads when it comes to renewables and energy efficiency. The EU also continues to host a quarter of the top 100 companies in high-value patents in clean energy over the last 5-years. Nonetheless, there is increasing (global) unease about the impact of state- or subsidy- backed technology domination, closed markets and different intellectual protection rules and policies on innovation and competitiveness in the sector, especially as manifested by China. Despite those concerns, over a quarter of the clean energy inventions protected internationally over the last 5 years by EU applicants have also targeted the Chinese market.

Figure 11: EU patenting trends in the Energy Union R&I priorities, and positioning in high-value patents and share of 'green' technologies in patenting activity versus major economies[61]



Source: JRC[62] based on EPO Patstat

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

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

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

[61] Cumulative number of high-value patents in Energy Union R&I priorities over 2005-2018; average share of 'green' patents in Climate Change Mitigation Technologies for 2017-2018; data for 2018 is provisional.

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

In terms of collaborations in green innovation, beyond the alliances built within Europe due to geographical proximity, EU firms tend to collaborate most with US counterparts[63]. EU Member States generate 33% of co-inventions in green technologies through Intra-EU connections, 29% with the USA and only 6% with China. France and Germany are the two Member States with the highest number of international partners and co-inventions. The US has the highest number of co-inventions in clean energy technologies, nearly 40% of which are with the EU. East-Asia countries, namely China, Japan, South Korea and Taiwan have strong mutual collaborations.

According to the recent UNESCO Science Report[64], the volume of scientific publications from the EU[65] on nine SDG7[66] renewable energy topics has increased from nearly 60k in the period 2012-2015 to over 70.5k in the period 2016-2019 (18% increase). However, the report also notes that high-income economies are no longer dominating topics related to clean energy and innovation, and some of the strongest growth is instead taking place in lower middle-income countries. For example, the respective publications from East & Southeast Asia increased by 45% and those from South Asia more than doubled.

2.4. The clean technologies funding landscape

2.4.1. Introduction

The Climate Tech domain encompasses a broad set of sectors which tackle the challenge of decarbonising the global economy[67]. It also includes novel technologies e.g. long-duration energy storage, green hydrogen production, storage, and use of hydrogen in heavy industry, carbon management) that, together with more mature generation technologies (e.g. solar and wind) under deployment, will be crucial to achieve carbon neutrality by 2050, if properly developed and scaled-up.

Climate Tech is an emerging and challenging domain for Venture Capital (VC) investors. These novel technologies usually involve high investments in R&I, long lead times to reach maturity and typically require a significant amount of capital in pilot plants[68]. This calls for substantial public support along the start-up lifecycle to de-risk and stimulate further private investments for their development and implementation at scale.

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

[64] UNESCO (2021) UNESCO Science Report: the Race Against Time for Smarter Development. S. Schneegans, T. Straza and J. Lewis (eds). UNESCO Publishing: Paris.

[65] The study refers to EU28 (including the UK).

[66] "Ensure access to affordable, reliable, sustainable and modern energy for all."

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

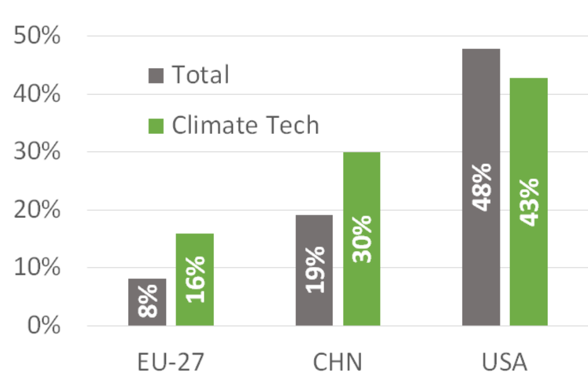
[68] Giving rise to the notion of Deep Green start-ups: cutting edge technologies focused on addressing environmental challenges (e.g. green battery manufacturing, electric aircraft). Deep Green are at the intersection between Climate Tech and Deep Tech, defining the latter as companies building on scientific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

2.4.2. VC investment trends in Climate Tech companies (Global and EU)

Worldwide VC investments[69] in climate tech start-ups and scale-ups reached EUR 14 billion in 2020[70], increasing more than 1250% since 2010 (EUR 1 035 million). Within this, VC investments in EU-based climate tech companies have been 11 times higher over the past 5 years than they were between 2009 and 2014, reaching more than EUR 2.2 billion in 2020[71].

EU firms received 16% of global VC funding in the climate tech domain compared to only 8% of overall VC funding (all domains)[72]. Figure 12 highlights the attractiveness of EU climate tech start-ups but also the investment gap in EU start-ups as VC investments range far behind levels in the US and China.

Figure 12: VC funding in Climate Tech vs Total (2020)[73]



Source: JRC elaboration based on PitchBook data.

At the same time, for the first year in 2020, early stage investments in EU climate tech start-ups were higher than those in the US and China.

EU-based climate tech start-ups still trail their counterparts in ability to scale. Over the past 5 years, they only benefited from 7% of all later stage investments in climate tech start-ups, far behind the US (44%) and China (41%)[74]. Furthermore, out of the total number of climate tech Unicorns[75], those based in the EU account for only 6%, compared to US (56%) and China (26%)[76].

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69 Investments include Early stages (Accelerator/Incubator, Angel, Seed and early stage VC) and later stages (later stage VC and Private Equity Growth).

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

71 JRC elaboration based on Pitchbook data 2021.

72 JRC elaboration based on Pitchbook data 2021.

73 Where Climate Tech is expressed as % of global Climate Tech investments and total is expressed as % of all global VC investments.

74 JRC elaboration based on PitchBook data.

75 The standard definition of unicorn is a privately held start-up valued at more than USD 1 billion.

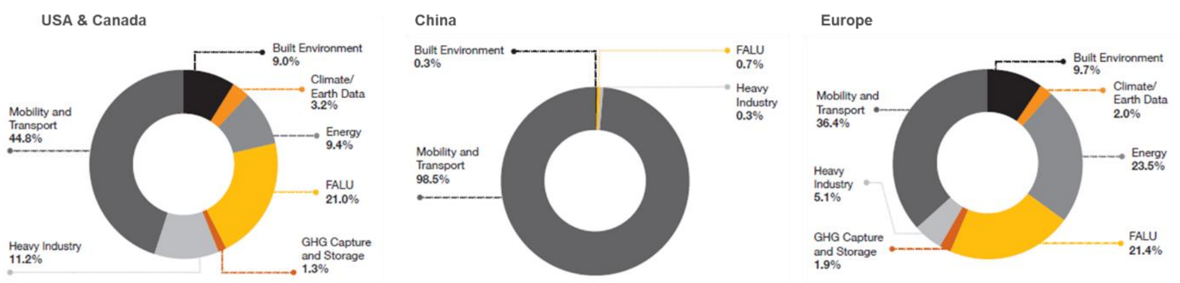
76 JRC elaboration based on PitchBook data.

2.4.2.1.Climate Tech investments in the Energy Sector

Worldwide, the Energy domain[77] accounted for 8.2% of total VC Climate Tech investment between 2013 and 2019, far below the Mobility and Transport domain (63%) and Food, Agriculture and Land use (13.6%)[78]. Global investment in Energy start-ups has grown at a moderate pace, recording a Compound Annual Growth Rate (CAGR) of 41%, which is substantially lower than the overall growth rate of climate tech investment). This reflects the relative maturity of two of the major sources of renewable energy – wind and solar – which are now being deployed globally at scale, and are increasingly financed through traditional project, debt and other finance rather than venture capital.

Europe (EU and UK) is investing a higher share of VC in Energy domain (23.5%) compared to the US (9.4%) and China (less than 1%). Most investment is taking place in developing the core technologies for renewable energy generation (predominantly PV cells) and the energy storage (batteries) to support their proliferation[78].

Figure 13 Area-specific VC funding as % share of the overall Climate Tech VC investments in the US, China and Europe



Source: PwC analysis on Dealroom data

2.4.2.2.The Digitalisation of Energy and VC funding dynamics

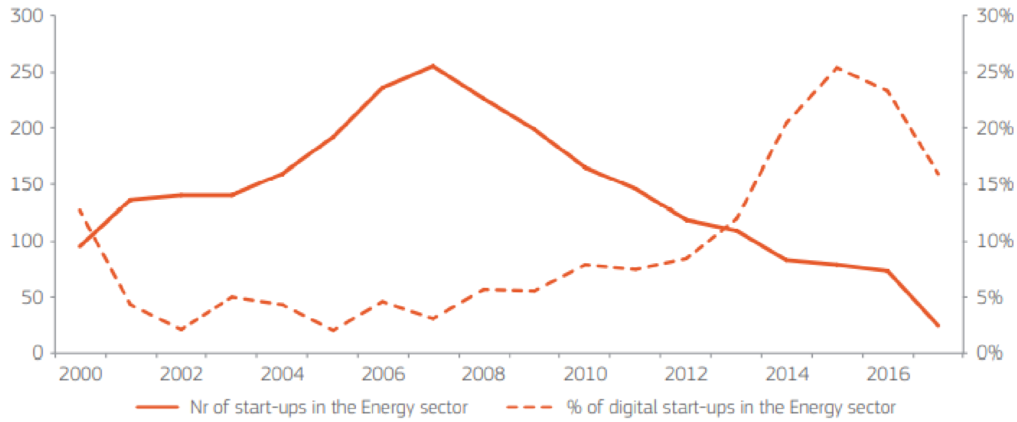
As the digitalisation of energy is a crucial enabler of the energy transition, understanding the trend of VC investments in digital start-ups entering the energy sector is key to support the development of a more integrated, interconnected, secure, transparent and competitive energy system, where not only energy but also data need to flow freely in the system.

Figure 14 shows that, despite considerable decrease in number of VC-backed energy start-ups worldwide at the beginning of the last economic crisis, the share of digital start-ups in the Energy sector has increased and reached its maximum in 2015.

[77] Identified by the PwC report as one of the key sectors contributing to the majority of global GHG emissions – together with Mobility & Transport, Food, Agriculture and Land Use, Heavy Industry, Built environment (vertical areas), GHG Capture and Storage, and Climate and Earth Data generation (horizontal areas).

[78] PwC, The State of Climate Tech 2020. The next frontier for venture capital, 2020.

Figure 14: Total number of Energy start-ups and the percentage of digital start-ups[79] in the Energy sector that received VC funding between 2000 and 2017



Source: JRC analysis based on Venture Source, Dow Jones data

2.4.3. The Clean Tech funding landscape in EU

Both the overall Climate Tech VC funding dynamics in the EU and the attraction of VC investors for EU-based Climate Tech are strongly related to the number of overarching policy goals in the climate and energy sector established at EU and Member States level (see section 1.1), together with tools supporting Climate Tech (e.g. fund of funds, grants, equity and debt co-investment, R&D tax credit), and the overall EU support for a R&I green innovation ecosystems.

The EU public funding institutions have shown they can lead green innovation excellence. The Horizon Europe pillar III on "Innovative Europe" aims at supporting the development of disruptive and market-creating innovations through three distinctive and complementary instruments:

The European Innovation Council (EIC)[80], with a budget of EUR 10.1 billion, is a one stop shop for scaling up the next European's unicorns, providing financial support, investment opportunities and coaching to breakthrough and disruptive innovation projects[81]. So far, the EIC pilot has achieved 90% of innovations addressing Sustainable Development Goals (SDG), in particular in the field of Green Deal, Digital and Health.

The European Institute of Innovation & Technology (EIT), with a budget of EUR 2.965 billion, aims at strengthening Europe's innovation ability by powering solutions to pressing global challenges and by nurturing entrepreneurial talent. Supporting the development of EIT Knowledge and Innovation Communities (KICs), EIT has the scope to increase the collaboration between business, education and research organisations, public authorities and civil society.

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79 Digital start-ups in the Energy sector: this set includes start-ups in the Energy sector whose description of activity includes any digital-related keyword.

80 European Innovation Council (europa.eu)

81 Through the EIC Pathfinder, Transition activities, Accelerator, and Business acceleration services. So far, the EIC pilot has achieved 90% of innovations addressing Sustainable Development Goals (SDG), in particular in the field of Green Deal, Digital and Health.

The European Innovation Ecosystems initiative, with a budget of EUR 527 million, focuses on building an interconnected, inclusive, innovation ecosystem, complementing the actions carried out by the EIC and the EIT, as well as activities managed under other pillars of Horizon Europe and initiatives developed by Member States and Associated Countries.

Furthermore, the InvestEU programme and cohesion policy aims at supporting access to and availability of finance primarily for SMEs, including innovative ones and those operating in the cultural and creative sectors, as well as for small mid-cap and other companies. In addition, the European Investment Fund (EIF) invests in European VC funds, providing venture debt directly to start-ups and connects investors with start-ups, and the European Investment Bank (EIB), beyond loans, provides venture debts, invests in private equity funds, provides guarantees to improve the costs of financing for strategic projects or sectors.

While some of their offerings overlap, these institutions are designed to complement each other across the start-up's life-cycle[82]. As an example, the EIB played a role in attracting private investments in Northvolt - the Swedish green battery company founded in 2016 - which is building the first European commercial-scale battery plant in Sweden and raised EUR 1.4 billion in financing in June 2020 . EIT InnoEnergy supported the company to put together a consortium of investors and access EIB funding: the EUR 350 million loan from EIB is accompanied by EUR 886 million from private investors[83]. After the first plant in Sweden, Northvolt plans a joint venture with Volkswagen to build a battery plant in Germany.

Moreover, additional funding programmes exist to convey revenues from climate-related policies in support of the energy transition. The Innovation Fund supports the deployment in the market of breakthrough low carbon technologies. The Modernisation Fund intends to help low income Member States in the modernisation and decarbonisation of their energy systems. The Social Climate Fund would fund Member States' programmes designed to support investment in increased energy efficiency of buildings, the decarbonisation of heating and cooling and zero- and low-emission mobility and transport.

Despite these innovation ecosystem support instruments, EU-based climate tech start-ups still trail their counterparts in ability to scale, thus hindering the EU from reaping the climate and competitiveness benefits of EU innovation as well as preventing movement of promising ventures to the US or Asia to reach scale. For example, while Northvolt is a success, it dwarves the rest of EU investments, thus illustrating the need of public funding for the development of commercial scale pilot plants.

Overall, the significant difference in regional VC funding, including climate tech, across geography is partially due the different VC funding culture. As an example, the US institutional investors have traditionally been more willing to engage in VC, and the US has a stronger history of start-ups and scale-up success, thus creating a more favourable start-ups ecosystem.

In addition, key structural barriers are holding back the EU-based climate tech scale-ups compared to US and China, such as:

- Innovation performance barriers: difficulty in translating a strong EU research performance into innovation; lack of breakthrough/disruptive innovations creating new markets.
- Innovation funding barriers: i) transition from lab to enterprise, ii) scaling up for high risk innovative start-ups. The more difficult access to finance reported by EU scale-ups is consistent

[82] World Economic Forum in collaboration with KPMG, Bridging the gap in European scale-ups funding: the green imperative in an unprecedented time, 2020.
[83] VW, BMW, Goldman Sachs, AMF, Folksam Group and IMAS Foundation.

with a higher reliance on internal funds among these firms, as well as a relatively under-developed venture capital market in EU compared to US[84].

- Innovation ecosystem barriers: despite many national and local ecosystems exist, the EU's market and regulatory fragmentation hinders growth and leads to different maturity of VC ecosystems; there is a pressing need to include all regions and all talent. Within this, the lack of labour force with the right skills can represent an obstacle to growth among scale-ups.

2.4.4. New generation of financial mechanisms to support Climate Tech scale up in EU and EU supporting initiatives

Filling the gap in scale-up between EU and other major economies requires mobilising private investors to participate more actively in the European VC market and in the funding of climate tech and Deep Climate Tech start-ups[85]. This is still a poor fit for the business model of "traditional" VC funds.

As an example, blended finance[86] structures could address the mismatch of the VC model and deep-tech investment and scaling up EU's industrial transformation, by mobilising private investments or incentivising patient capital from the private sector. While blended finance is rare in the EU, successful examples exist (Estonian EIC-funded start-up Skeleton[87] and the German "Future Fund"[88])[89]. The future success of SPACs faces uncertainty.

The recent lackluster aftermarket performance for SPACs could intensify the downward pressure on new SPAC IPO issuance and general enthusiasm for the product. A related decline of investor sentiment around SPACs is to be expected if returning capital due to failure to find a target becomes a regular occurrence. Regulation and litigation risks are also looming, which may discourage new SPAC activity. [90]

In view of the Green Deal's objectives and recognising the role of technological innovation as key enabler for climate neutrality, the EU has put a number of relevant support mechanisms in place. For example, the 2020 European Industrial Strategy package sets key actions to improve access to finance for Small and Medium Sized Enterprises (SMEs), including a mechanism to boost the scale of VC funds, increase private investment and facilitate the cross-border expansion and scale-up of SMEs. Furthermore, the joint fund

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84 EIB, Investment report 2019/2020: accelerating Europe's transformation

85 Deep Tech start-ups build on scientific knowledge and are characterised by long R&D cycles and untested business models. Deep Climate tech start-ups are companies using cutting edge technology to address environmental challenges. As they rely on large capex investments in pilot plants for new technologies to be able to scale their revenues, they require even a higher levels of investments – compared to Climate Tech.

86 Blended finance is a structuring approach which uses public funding to de-risk private investments and, by doing so, acclimatize private investors with a new technology, sector, region or asset class. It leverages a combination of grant with equity, debt investments or insurance-like products from either the public or private sectors and mobilizes consortium of investors to meet the funding needs of deep tech start-ups.

87 One of the largest European manufacturers ultracapacitor-based energy storage. The products are used to power and save energy in various applications in the automotive, transportation, grid, and renewable energy industries. the Clean Tech solutions have caught the attention of new industrial investors and top European entrepreneurs, and the company raised EUR 41.3 million in equity round, bringing its total capital raised to over EUR 93 million. The investment is in the top five funding rounds of the cleantech sector in the EU in 2020 and will further accelerate Skeleton's growth.(https://community-smei.easme-web.eu/articles/green-innovations-eic-funded-company-skeleton-technologies-raised-eu413-million-equity).

88 The German federal government is providing EUR 10 billion for an equity fund for technologies of the future (Zukunftsfonds or "future fund"). The fund will primarily benefit start-ups in the growth phase with high capital requirements. Together with further private and public partners, the fund projects to mobilise at least EUR 30 billion in venture capital for start-ups in Germany, and combined with existing financial instruments, over EUR 50 billion in venture capital are expected to be mobilised for start-ups in the next few years, together with private investors. (Federal Ministry of Finance, 2021).

89 World Economic Forum, Bridging the gap in European scale-up funding: the Green Imperative in an unprecedented time, 2020.

90 PitchBook SPAC market update Q3 2021, Uncertainty Clouds Future for SPACs

between EIB, EC and Breakthrough Energy Ventures Europe (BEV-E) allows for the blending of institutional (risk-averse) with a VC (less risk-averse) investment approaches[91]. Next Generation EU financing and the EU Sustainable Finance Regulation may further accelerate clean energy VC support.

Further scaling up can be achieved by streamlining existing mechanisms, making use of synergies across instruments at EU and MS level, further exploring new funding solutions (creation of funds directing private savings towards VC-funded firms, blended instruments) and introducing further funding incentives (e.g. government financing/co-financing for start-ups). The European Scale-up Action for Risk capital (ESCALAR), a pilot programme launched by the European Commission and managed by the EIF, is a good example for a new investment approach.[92] It is also crucial that policy initiatives, EU programmes and related instruments maintain and increase the attractiveness of EU Climate Tech firms for VCs. Furthermore, public and corporate procurement opportunities could foster long-term growth in strategic sectors or even kick-start emerging markets, while involvement of investment management firms could improve perspectives for VC firms. Finally, involving universities could attract highly skilled workers and encourage entrepreneurship.

2.5. Covid-19 impact and recovery

2.5.1. Impact

2.5.1.1. Impact on clean energy generation, investments and R&I

The renewable energy sector generally proved to be resilient during the pandemic[93]. As displayed in Figure 15, while electricity generation from coal, gas and nuclear decreased, renewables overtook fossil fuels for the first time as the EU's main power source for the year 2020 (renewables 38% of EU electricity, versus 37% fossil fuels and 25% nuclear)[94]. Wind (14%) and solar (5%) generated one fifth of EU's electricity in 2020, the remaining 19% came mainly from hydropower and bioenergy which have stagnated the past few years[95]. In all IEA global post-pandemic scenarios, renewables grow rapidly – mainly solar due to its high-cost reductions (followed by onshore and offshore wind).

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

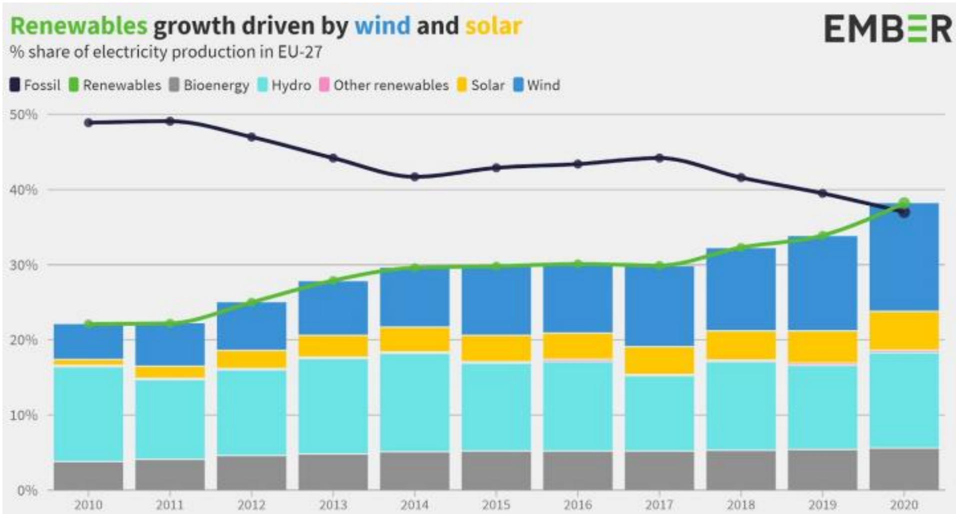
92 https://ec.europa.eu/growth/content/escalar-%E2%82%AC12-billion-help-high-potential-companies-grow-and-expand-europe_en

93 IEA, World Energy Outlook, 2020.

94 Agora Energiewende and Ember (2021), The European Power Sector in 2020: Up-to-Date Analysis on the Electricity Transition, https://ember-climate.org/wp-content/uploads/2021/01/Report-European-Power-Sector-in-2020.pdf.

95 Ibid.

Figure 15 Growth of renewables share in electricity production compared to fossil fuels



Source: Agora Energiewende and Ember, 2021

2020 was also a year of unprecedented global spending on the deployment (excluding investments in companies, R&D and manufacturing) of low-carbon technologies, reaching USD 501.3 billion, a growth of 9% compared to 2019[96]. Falling capital costs enabled a record number of solar and wind to be installed globally, while investment in heat pump installation increased 12%, energy storage (esp. batteries) remained level with respect to 2019, despite falling prices, and CCS investments tripled. Hydrogen investments dropped 20% but 2020 was still the second highest annual investment ever[97].

Europe and China are currently vying for top position among markets active in energy transition investment[98]. Europe accounted for the biggest part of the global investment in 2020, with USD 166.2 billion (up 67%), China at USD 134.8 billion (down 12%) and the US as USD 85.3 billion (down 11%). Europe’s performance was driven by a i) record year for electric vehicle sales, and ii) the best year in renewable energy investment since 2012.[99].

Early trends indicate general resilience in global R&I spending for renewable energy as well. Growth in global public spending on energy R&D slowed from 7-10% in 2017 and 2018 down to 2% in 2020, but the renewable component grew more quickly, achieving 83% of total energy R&D spending. Similarly, while overall corporate R&D energy spending dropped in 2020, the renewable component continued to grow[100]. Worldwide, in spite of an overall downward investment dynamic and despite the fact that significant VC funding was redirected to pandemic-related industries such as pharmaceuticals and healthcare, Climate Tech domain is proving to be resilient to the COVID-19 outbreak and remained attractive to the VC funding. Examples include Amazon’s USD 2 billion “Climate pledge” venture fund, Microsoft’s USD 1 billion Climate Innovation Fund.

96 BloombergNEF, Energy Transition Investment Hit $500 Billion in 2020 – For First Time, 2021.
97 Ibid.
98 BloombergNEF, Energy Transition Investment Trends – Tracking global investment in the low-carbon energy transition, 2021.
99 BloombergNEF, Energy Transition Investment Hit $500 Billion in 2020 – For First Time, 2021.
100 IEA, World Energy Investment, 2021.

2.5.1.2. Impact on supply chains and installed capacity

EU energy technology supply chains have generally been resilient to the impacts of the pandemic. Covid-induced restrictions temporarily disrupted supply chains and delayed construction of renewable energy installations in key markets (especially onshore wind and solar PV). Yet, since mid-May 2020, renewables-based construction projects, equipment supplies, policy implementation (permitting, licensing, auctions) and financing have returned to near normal levels in many countries because project developers and manufacturers have modified their operations to adapt to ongoing social-distancing rules[101].

In addition to bottlenecks due to disruptions in production, logistics and transportation sectors, operating costs of some energy technology supply chains increased due to price increases in products and services such as transportation. Yet these impacts were common to all economic sectors[102]. While important EU suppliers in China and other Asian countries generally were able to limit impacts, supply chains faced greater impacts from intra-EU measures such as border closures and lockdowns. Intra-EU difficulties were therefore often more important than manufacturing and logistics challenges in non-EU countries. Supplier concentration exacerbated these impacts, while global supply chains provided advantages such as supply diversification and access to global markets[103].

2.5.2. Recovery

The analysis of the 22[104] RRPs approved by the Commission by 5 October 2021[105] shows that EUR 177 billion have been allocated to climate-related investments, representing 40% of the total of EUR 445 billion of RRF funds allocated to these Member States. Nearly all Member States are using RRF funds for investments in building renovation and clean transport (around 62 billion is dedicated to sustainable mobility), and many are using it to invest in renewable energy. In this context, Member States[106] have significantly built on the 'flagship initiatives' put forward by the Commission in relation to the green transition, in particular the 'Power up', 'Renovate' and 'Recharge and refuel' flagship initiatives. About 43% of climate-related investments (EUR 76 billion) is dedicated to energy efficiency (27.9%) and renewable energy and network (14.8%).

Research and innovation also represented an important share within the climate-related investments , as Members States allocated nearly EUR 12.3 billion to investment in R&I in climate change mitigation and adaptation and the circular economy in their Recovery and Resilience Plans. The timely implementation of the RRPs can help Member States achieve the more ambitious targets for 2030 in line with the European Green Deal Package[107].

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101 IEA, Renewables 2020 – Analysis and forecast to 2025, 2020.

102 Study on Resilience of the critical supply chains for energy security and the clean energy transition during and after the COVID-19 crisis (2021).

103 Ibid.

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

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

106 Annual Sustainable Growth Strategy 2021, COM(2020) 575 final, 17 September 2020, section IV.

107 The Commission has already disbursed EUR 52.4 billion in pre-financing from the RRF to Austria, Belgium, Croatia, Cyprus, Czechia, Denmark, France, Greece, Italy, Latvia, Lithuania, Luxembourg, Portugal, Slovenia, Slovakia and Spain, equivalent to 13 % of the grant and (where applicable) loan component of those Member State's financial allocation, except for Germany where it corresponds to 9%.

2.6. Innovative and cooperative business models

The energy transition changes the way the energy system operates. Distributed renewables, proactive consumers, the opportunity to track and trace energy sources, monitor energy consumption and energy efficiency in real time and provide flexibility services to the system create new innovations, actors, and type of business. The section below explores three key business models that help creating markets for new technologies, services and innovations, in a decentralised energy system: energy communities, one stop shops for building renovation, and energy service companies (ESCOs). Many of these new business models are enabled by smart grid technologies analysed in the next section.

2.6.1. Energy communities

Under the Clean Energy Package, extensive provisions were introduced in the Electricity Directive ('citizen energy communities') and the Renewable Energy Directive[108] ('renewable energy communities') to promote energy communities and prosumers, thereby allowing consumers to take an active role in the energy market and strengthening energy production from renewable sources. In particular, energy communities in EU legal framework have been conceptualised in Article 2 (11) Electricity Market Directive ('citizen energy communities') and in Article 2 (16) Renewable Energy Directive ('renewable energy communities'), and linked to an enabling framework to facilitate their participation on the relevant energy markets (Article 16 Electricity Market Directive; and Article 22 Renewable Energy Directive). Both legal concepts share a common core: they need to be organised through a legal entity, are effectively controlled by non-professional actors, have an open and voluntary participation structure and have as a purpose to provide social, economic and environmental benefits rather than financial profits. However, there are also some fundamental difference in terms of energy source, ownership and participation:

- 'renewable energy communities' (REC) are about all sources of renewable energy. 'Citizen energy communities' (CEC) are about all sources of electricity, but not other forms of energy. Note that both concepts overlap when an energy community is active in 100% renewable electricity, in which 'renewable energy communities' become a subset of 'citizen energy communities';
- members or shareholders that effectively control the 'renewable energy community' need to be located in proximity of the renewable energy projects that are owned and developed by that community. As such, renewable energy communities are 'local' energy communities. This is not the case for 'citizen energy communities', allowing for more flexibility and thus both local communities and communities-of-purpose;
- all types of actors can participate in 'citizen energy communities', whilst for 'renewable energy communities' this is limited to citizens, SMEs and local authorities.

Note that energy communities are in essence not about technology, smart grids, etc. Developments in this field can be useful for energy communities, but this is not a technological concept.

In border regions, there can be a significant added value of a cross-border approach, allowing to benefit from local complementarities across borders in areas such as renewable energy production or storage solutions, taking into account the 'energy efficiency first' principle. However, energy markets do not yet function across borders as seamlessly as they do within a country. For example, cross-border electricity

[108] In RED II, introduction of enabling frameworks by Member States to facilitate their development, to ensure inter alia that unjustified barriers to renewable energy communities (RECs) are removed and relevant distribution system operators cooperate with the RECs, but also that RECs are regulated according to the activities they engage in. Member States also have to take the characteristics of RECs into consideration when they design their support schemes.

transactions are frequently limited because legal frameworks do not allow for low-voltage exchanges of electricity across the border. Energy communities can play a significant role in charting the way ahead. Both the Electricity Market Directive and the Renewable Energy Directive set the conditions for Member States to include options for cross-border implementation of energy communities in their national transpositions[109].

In terms of enabling framework, both ‘citizen energy communities’ and ‘renewable energy communities’ benefit from set of rights and responsibilities to facilitate their market integration, most notably related to enabling activities (generate, store, sell, share, aggregate or other energy services), and ensuring non-discriminatory treatment in terms of charges and procedures (e.g. supply licensing; grid access procedures). For ‘renewable energy communities’ there are some additional set of privileges. In this regard, it is important to understand that the criteria of the legal concept of ‘renewable energy communities’ are more narrow than for ‘citizen energy communities’, so harder to fulfil. The latter forms the basis to justify the privileges included in the enabling framework of Article 22 Renewable Energy Directive, including but not limited to the requirement for Member States to consider the characteristics of ‘renewable energy communities’ when designing support schemes.

Whilst only recently conceptualised in EU legislation, Energy communities are not a new phenomenon. Nowadays, there are thousands of these initiatives scattered across Europe, each with different scales and use of technology, ownership structures and actors involved.

Currently, at least two million European citizens collectively engage in more than 8400 energy communities, having realized a minimum of 13000 projects since 2000[110]. They support the energy transition and contribute to the competitiveness of renewable energy technologies in various ways. Energy communities raise technology awareness and acceptance, promote energy efficiency, produce and distribute renewable-based electricity, provide services around e-mobility, and run energy consulting services. They experiment innovatively with business models and self-sufficiency concepts for the benefit of local communities.

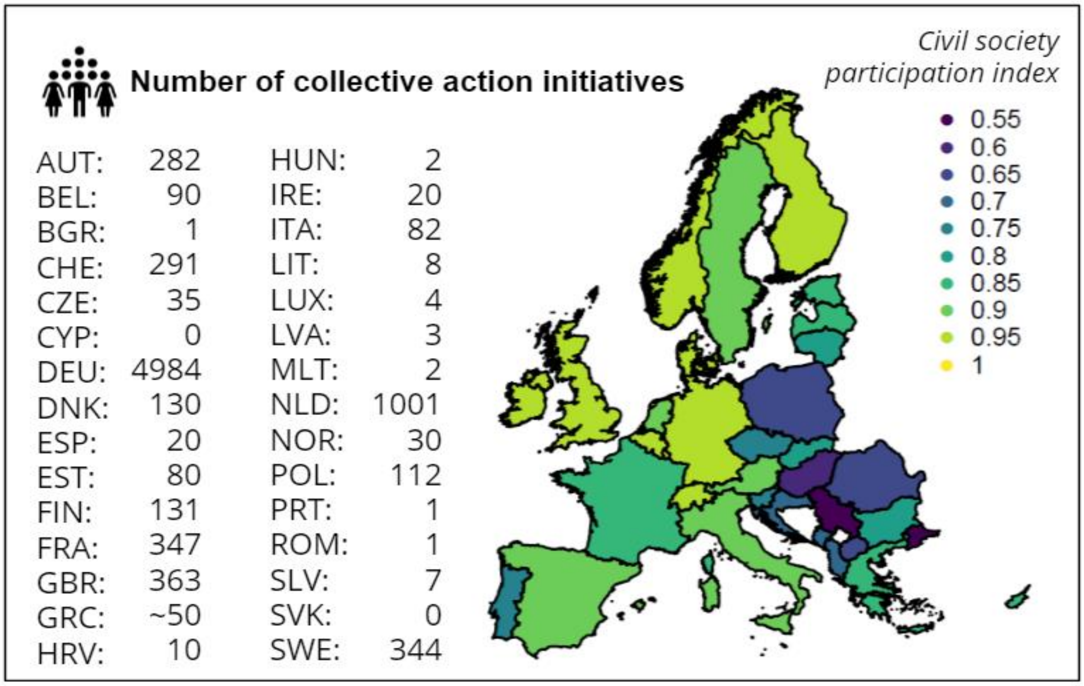
Figure 16 details the number of initiatives and projects per country. Differences across countries can be explained by varying strength of governmental support and incentives schemes, historic path dependencies of the energy system, and social and technological preferences. Current total renewable capacities installed by energy communities in Europe can be estimated at least as high as 6.3 GW, contributing up to 7% to the nationally installed capacities. The lion’s share is taken by solar PV (~50%), followed by onshore wind (~10%). A conservative estimate of the total invested finances amounts to at least 2.6 billion EUR[111]. The continuation and extension of energy communities in Europe depend on favorable legislation and financial incentives as well as on the competitiveness of technologies that are accessible to citizens (i.e., granular technologies, such as roof-top solar, small- to medium-size wind and solar parks, heat pumps, micro hydro, biomass furnaces, and biogas installations).

[109] “EU Border Regions: Living labs of European integration”, COM(2021) 393 final, 14.7.2021.

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

[111] ibid

Figure 16 Collective action initiatives in Europe



Source *Schwanitz, V. J., Wierling, A., Zeiss, J. P., von Beck, C., Koren, I. K., Marcroft, T., … Dufner, S. (2021, August 22). The contribution of collective prosumers to the energy transition in Europe - Preliminary estimates at European and country-level from the COMETS inventory*.

Many of the above-identified energy communities are member of REScoop.eu[112] the European federation for energy cooperatives.
Whilst the legal organizational form of cooperative is by far the most prominent for energy communities across the EU, there are various types of legal entities (partnerships, limited liability companies, associations etc.), as well as organizational and social arrangements that have developed in the different Member States of the EU. Indeed, various member states will have different experiences with energy communities. For example, in the Netherlands community actors are usually individuals or small businesses, whilst in Germany and Greece municipalities have played a crucial role.

Until today, less than half of Member States have notified the full transposition of the Electricity Market Directive rendering it difficult to establish a causal relation between the surge in energy communities and the EU legal frameworks for 'citizen energy communities'. So far, no Member State has notified full transposition of the Renewable Energy Directive (REDII). Whilst the EU frameworks provide a good basis to trigger the development of energy communities across the EU,[113] much will depend on how Member States will implement the enabling framework for these types of energy communities, notably how Member States translate the right to non-discriminatory, proportionate, fair and transparent procedures. For 'renewable energy communities' the implementation of Article 22 (7) RED II will be of particular importance as energy communities today struggle to build their business case without financial support. Partly due to the phase-out of feed-in-tariffs and transition to premium price auctions, the development of

[112] *www.REScoop.eu.*
[113] Energy Communities under the Clean Energy Package - REScoop.

energy communities in Germany have stagnated as they experience difficulties competing for subsidies with large undertakings.[114] In response, energy communities are exploring new activities and services such as electro-mobility sharing, optimizing collective self-consumption, interacting with dynamic pricing and providing flexibility services to the public network. Especially the latter is a promising activity to create an additional source of revenue for energy communities, provided existing barriers are removed (complexity of ITC services, lack of local flexibility markets at DSO level, difficulties with aggregating different devices due to lack of data interoperability, lack of standardization etc.). Some of these barriers are already addressed through the Electricity Market Directive.[115]

The NECP framework already has a requirement for Member States to report on renewable energy communities, however only a few Member States included (voluntarily) quantitative targets or concrete measures for the development of energy communities in their NECPs (most demonstrate awareness but no planning). Member States with early legal frameworks in place for energy communities, including the Netherlands, Denmark and Germany today have the highest number of energy communities (see graph above).[116] Outdated regulatory frameworks and administrative procedures adjusted to large vertically integrated undertakings have also been identified as one of the major barriers for the development of energy communities.[117]

In order to boost the development of energy communities in the sense of the EU Directive, the Commission is in the process of setting up an Energy Community Repository. The Energy Community Repository will contribute to the dissemination of best practices and provide technical assistance for the development of concrete energy community initiatives across the EU. The aim of this project is to assist local actors and citizens willing to set up REC and CEC in rural and urban areas, through technical and administrative advice and encourage their development. The data collected through this project would constitute a very important source of information for European institutions and national, regional and local authorities. It will contribute to the identification and dissemination of best practices and know-how for communities that wish to set up a sustainable energy project, in particular in Member States that do not have so far strong tradition of energy community initiatives. The projects that will receive targeted technical assistance under this repository will serve as examples of positive local actions that should inspire widespread efforts for citizen-driven initiatives through the development of energy communities. . Energy community initiatives could also be supported by cohesion policy funding, including through the Community Led Local Development (CLLD) instrument. In addition, the Commission is in the process of setting up an Advisory Hub for rural energy communities, i.e. 'citizen energy communities' and 'renewable energy communities' in rural areas in order to remedy the disproportionate impact of the energy transition on communities in rural areas by supporting the development of sustainable energy action that can be conducive to the local economy and increase security of energy supply. Special emphasis will be put on the involvement to local authorities, linked to the Covenant of Mayors.

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[114] Entwicklung und Umsetzung eines Monitoringsystems zur Analyse der Akteursstruktur bei Freiflächen-Photovoltaik und der Windenergie an Land (umweltbundesamt.de).

[115] Article 32 on local flexibility markets; Article 23 juncto 24 on data management and interoperability.

[116] One of the drivers for the heterogeneous picture of energy communities across Member States have been the varying national legislative frameworks in place for energy communities. See Frontiers, 'Assessment of policies for gas distribution networks, gas DSOs and the participation of consumer', pp. 8-9; Ronne, A., and F.G. Nielsen, 'Consumer (Co-)Ownership in Denmark', Energy Transition - Financing Consumer Co-Ownership in Renewables, Palgrave Macmillan, Cham, 2019.

[117] Benjamin Huybrechts and Sybille Mertens, 'The relevance of the cooperative model in the field of renewable energy [2014] Annals of Public and Cooperative Economics, pp. 199-201; Binod Prasad Koirala, 'integrated community energy systems' (DPhilthesis, Delf University of Technology 2017, p.1; Stakeholder interview with Cormac Walsh from Energy Cooperatives Ireland, 12th of June 2021; Frontier et al's report (2019), 'Potentials of sector coupling for decarbonisation – Assessing regulatory barriers in linking the gas and electricity sectors in the EU - Final report', p. 49.

2.6.2. Renovation of buildings - One stop shop

The market-based model of one-stop shops (OSSs) is among the most prominent recent approaches aimed at supporting building renovation decisions. OSSs work as a market place, offering integrated renovation solutions, encouraging action, guiding building owners through the entire renovation journey, providing technical and administrative assistance and helping secure the right financial solutions. While all energy efficiency projects could be good candidates, OSSs are particularly well equipped in addressing the renovation market fragmentation barriers on both demand and supply sides, overcoming some of the sociotechnical barriers surrounding the decision to renovate in a holistic way. For these reasons, OSSs are especially well suited to support small-scale renovation projects (e.g. individual buildings or apartments).

OSSs are only recently appearing in Europe. From a recent analysis of the current OSSs present in Europe conducted by the JRC[118], 62 OSSs have been identified across the EU in 2020, located in 22 countries, 57 were found to be operating or planned to be launched soon across the EU and Norway, and 6 have been closed. Around two third of the Member States have at least one OSS on the national renovation market. Regionally, Western Europe has the most abundant OSS markets, centred in France, the Netherlands, the UK, Belgium, Spain and Denmark.

Overall, OSSs have been found to be a promising approach to bring together homeowners and actors from the construction supply side and increase demand in energy renovations because they i) are locally embedded; ii) establish a trust-based relationship with the clients; iii) simplify the renovation decision process, informing, motivating, and providing support from the start to the end; iv) boost the interest of not yet committed energy users through awareness raising; facilitate access to financing and occasionally offer better rates; v) follow-up on finished projects; vi) and reach out to vulnerable populations, contributing to tackle energy poverty.

2.6.3. ESCOs

Energy Service Companies (ESCOs) are another business model that plays an important role in energy efficiency and functioning of energy services markets by providing turnkey services, addressing several market barriers on the ground and unlocking the energy savings potential[119]. Their distinct feature is associated with their incentive/remuneration structure; ESCOs assume performance risks by linking their compensation to the performance of their implemented projects, thus incentivising themselves to deliver savings-oriented solutions.

The EU's legislative framework contributes to fostering the energy services market. The Energy Efficiency Directive (EED)[120] provides the key requirements for promoting energy services and energy performance contracting in the Member States. The revised EED[121] strengthens the role of energy services and notably use of Energy Performance Contracts (EnPC) in contributing to the renovation wave with specific focus given to the public sector to lead by example.

[118] Boza-Kiss, B., Bertoldi, P., Della Valle, N. and Economidou, M., One-stop shops for residential building energy renovation in the EU, EUR 30762 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-40100-1, doi:10.2760/245015, JRC125380.
[119] Boza-Kiss, et al. 2017, 2019; Moles-Grueso, et al. 2021.
[120] Directive (EU) 2018/2002 of the European Parliament and of the Council of 11 December 2018.
[121] Proposal for Directive (EU) 2021/0218 of the European Parliament and of the Council of 14 July 2021.

The average ESCO market of the European Union has been on a steady rise for the last decades, and the growth and maturity has continued or even increased slightly between 2015 and 2018. However, important barriers still remain: lack of technical knowledge and experience in procurement, lack of financing and low level of awareness of energy performance contracting which have contributed to the low level of trust to energy services providers. The drivers and barriers determining ESCO markets are distinctly local and specific to the legal, policy, fiscal, financial and cultural context in each Member State. With the recent revision of the EED, it is expected that persisting barriers can be better overcome to ensure necessary conditions and incentives for the uptake of the EnPC and energy services markets.

Figure 17 The speed and direction of development between 2015 and 2018 in national ESCO markets

Source: The assessment is purely based on own research data (JRC survey 2018)

It is therefore important that Member States continue promoting the uptake of energy services and energy performance contracting through clear and transparent rules including certification of energy services providers, and also capacity building. Dissemination of experience of implemented projects and best practices are necessary to increase trust and ensure better understanding of energy performance contracting and ESCO's role in contributing to the renovation wave and bringing multiple benefits including new and innovative business models.

Table 4. Size of the ESCO and EnPC markets of the EU in JRC reports.[122]

[122] Boza-Kiss Benigna, Zangheri Paolo, Bertoldi Paolo, Economidou Marina, Practices and opportunities for Energy Performance Contracting in the public sector in EU Member States, EUR 28602 EN, Publications Office of the European Union, Luxembourg, 2017, ISBN 978-92-79-68832-4, doi:10.2760/49317, JRC106625.

	Number of active ESCOs (2018)[123]	Number of EnPC providers (2016)[124]	Number of EnPC providers to the public sector (2020)[125]	Number of EnPC contracts signed (2016)[126]	Number of EnPC contracts signed in the public sector (2020)[127]	Value of the EnPC contracts signed in the public sector (m€) (2020)[128]
EU	**1383**	**261**	**246**	**559**	**617**	**975**
AT	36	17.5	5	26.5	11	6.5
BE	9	>7	9	5	11	20
BG	12	12.5	5.8	2	10	3
HR	12.5	5	10.5	3	50	25
CY	22	19	0	0	0	0
CZ	15	9	7.2	45	25	21
DK	4	7	2.7	11	9	70
EE	4	0	2	"few"	1	1
FI	15	6	3	4	5	3.5
FR	45	10	10	40	50	70; 50[129]
DE	560 (Service suppliers)	8.5; 138[130]; 50[131]	8	30	58	90; 7,700[132]
GR	6	3[133]	12	5	8	100
HU	10	5[134]	4	1.5	20	2.8
IE	25	n/a	10.8	n/a	4	16.6
IT	3400	4.5-20(?)	20	50	230	250
LV	4.5	3	0	0	6	12.6
LT	n/a	4.5	2	3.5	6	3.2
LU	n/a	1(?)	n/a	1	n/a	n/a
MT	n/a	0	n/a	0	n/a	n/a
NL	57 (EnPC only)	15; 57[135]	40	27	n/a	n/a
PL	25	12.5; 20[136]	7.5	15	13	39

123 When not stated the contrary, data is about 2018. Main source:
Boza-Kiss, B., Toleikyté, A., Bertoldi, P. 2019. Energy Service Market in the EU - Status review and recommendations 2019. Scientific and Technical Report. European ESCO Market Reports series. EUR 29979 EN, European Commission, Luxembourg, 2019, ISBN 978-92-76-13093-2, doi:10.2760/768, JRC118815.

124 When not stated the contrary, data is about 2016. Main source: Boza-Kiss et al. (2017).

125 Source: Moles-Grueso, S., Bertoldi, P., Boza-Kiss, B. Energy Performance Contracting in the Public Sector of the EU – 2020, EUR 30614 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-30877-5, doi:10.2760/171970, JRC123985.

126 Source: Boza-Kiss et al. (2017).

127 Source: Moles-Grueso, et al. (2021).

128 When not stated the contrary, data is about 2020. Main source: Moles-Grueso, et al. (2021).

129 Value for 2018, in Boza-Kiss et al. (2019).

130 Value for 2018, in Boza-Kiss et al. (2019,

131 Value for 2020, in Moles-Grueso et al. (2021).

132 Value for 2018, in Boza-Kiss et al. (2019).

133 Value for 2018, in Boza-Kiss et al. (2019).

134 Value for 2018, in Boza-Kiss et al. (2019).

135 Value for 2018, in Boza-Kiss et al. (2019).

136 Value for 2018, in Boza-Kiss et al. (2019).

PT	13.4	12.5	15	n/a	13	50
RO	10	<10	4	0	0	0
SK	40	10[137]	8.5	45	25	25
SI	10	4[138]	6	15	44	96, 25[139]
ES	70	25	>50	250	59	60
SE	20	4.5	3	6	1	10

Country values are calculated using average values of estimates reported in a specific year (i.e. 2016, 2018 or 2020). For Total EU values, the most recent values reported were selected.

137 Value for 2018, in Boza-Kiss et al. (2019).
138 Value for 2018, in Boza-Kiss et al. (2019).
139 Value for 2018, in Boza-Kiss et al. (2019).