European Commission

Monitoring industrial ecosystems

ENERGY - RENEWABLES

Analytical report

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Executive summary

This report on **Energy - Renewables industrial ecosystem** has been prepared in the framework of the '**European Monitor of Industrial Ecosystems'** project, initiated by the European Commission, Directorate General for Internal Market, Industry, Entrepreneurship and SMEs and the European Innovation Council and SMEs Executive Agency (EISMEA). The overall objective of the project is to analyse the green and digital transformation of industrial ecosystems and progress made over time. It contributes to the analysis of the key pillars put forward in the Blueprint for the development of transition pathways of the Industrial Forum in 2022.

This report **complements existing knowledge on the energy transition and on the performance of the energy and renewables ecosystem**. It contributes to the understanding of **renewable energy use across industrial ecosystems** and explores **how digital technologies affect energy systems**.

The report has a mixed-method approach: the analysis relied on own data collected within the EMI project such as patent statistics, survey, text mining of company websites, investment and startup data and it reviewed existing Eurostat and industry statistics including desk research and literature review.

Renewable energy use and performance

According to the International Renewable Energy Agency (IRENA)[1], the renewable energy industries created 1.2 million jobs in the year 2021 in the EU27. The three main renewable sources of energy contributing to employment generation were: **solar photovoltaic, wind energy and solid biomass responsible for 68% of the total RES employment** in the EU, with solar being the one RES source growing the most globally.

The data analysis shows a **general positive trend in phasing out non-renewable energies from the EU, and across the 14 industrial ecosystems**[2]. In general, the energy consumption of industrial ecosystems across the EU declined during the last decade (-0.15%), and the share of renewable energies in the energy consumption of industry has been increasing at an average annual rate of 2.4%, much higher than the 1.6% recommended by the European Parliament and the Council. The industrial ecosystems outperforming the EU average in the share of use of renewable energies are agri-food, textiles, electronics, digital, and healthcare. The energy intensive industries ecosystem consumes less renewables than most of the ecosystems, however, it is the second ecosystem with most diverse and balanced sources of renewable energies.

The EMI business survey of 3 900 SMEs found that the agri-food, tourism and construction industrial ecosystems had a relatively higher renewable energy adoption rate among the 14 industries. At the lower end, we find electronics and retail. Positive trends have been identified in adopting more renewables by the energy intensive industries.

In terms of **technological developments, the world share of EU patenting activity in renewable energies has been declining over the period from 2010 to 2020 to the benefit of China and South Korea,** both increasing their shares, especially since 2015. China has been increasing their patent contribution in all renewable sources, compared to France and Germany, which in the early stages, were leading patenting activity in geothermal energy technologies and to which they are currently the main global technological providers.

[1] https://www.irena.org/

[2] The EU's updated industrial strategy from May 2021 has defined 14 industrial ecosystems that are in the focus of the project. The 14 industrial ecosystems include *aerospace and defence, agri-food, construction, cultural and creative industries, digital, electronics, energy intensive industries, energy-renewables, health, mobility – transport – automotive, proximity, social economy and civil security, retail, textile and tourism.*

Renewable energy has become a key target of foreign direct investments (FDI) globally[3]. FDI into renewable energy has witnessed high investments in 2022 and most recently in 2023 as a result of several mega projects in hydrogen and offshore wind. Over the period from 2015 to 2022 intra-EU investments in renewable energy amounted to €98 bn. Inward FDI investments into the EU had a total value of €42 bn, while EU FDI into third countries had a record high of €353 bn. There has been a **sharp increase in FDI outflows from EU countries to non-EU destinations over the past decade but in particular from 2020 to 2022 amounting to a total of €92 m in 2022.**

Digital technologies

Renewable energy companies are increasingly adopting digital technologies to increase their efficiency. The digital interaction of the RES industrial ecosystem is relatively high which is demonstrated first by the fact that approximately **54% of RES companies in the analysis have a social media account and 59% of RES companies have a website of more than 10 pages** as found by the analysis conducted in this project.

The digital transition of the RES industrial ecosystem is notable, with the adoption of advanced digital technologies such as the Internet of Things (IoT), big data, and Artificial Intelligence (AI) playing significant roles.

As found by the analysis of RES company websites, **IoT holds a share of approximately 19% in terms of adoption, indicating its widespread use in the RES industrial ecosystem**. IoT enables the interconnection of various devices and systems, and it is found predominantly in applications of smart homes and smart factories.

Big data follows closely with a share of around 18%. The use of big data in the RES ecosystem revolves around collecting and analysing large volumes of data to gain insights and make informed decisions. The most common applications of big data are associated with intelligent energy management and energy consumption optimisation.

Artificial Intelligence in use has been mentioned on 13% of the RES company websites. Artificial Intelligence technologies help optimise production processes, reduce downtime, increase efficiency, and enhance safety measures across the RES.

Blockchain technology also plays a role in the RES sector, primarily in smart energy management systems and energy automation. Additionally, blockchain is associated with home energy management, facilitating decentralised energy systems and enabling better control and optimisation of energy consumption at the household level.

The energy industrial ecosystem is shaped not only by adopting digital technologies directly, but by acquiring services of digital tech startups that have been increasingly present in the field of clean energy over the period from 2010-2022. Digital tech startups and tech firms offer a range of analytical and other digital technology-based services for the energy transition.

Contrary to direct technology adoption, **digital tech startups relied most (32% of the cases) on big data and data analytics to provide services to clean energy**. Tech firms leverage big data analytics to improve energy efficiency by predicting energy demand, optimising grid operations, and enable predictive maintenance of energy assets. In many cases, companies using big data also use AI to support and improve their predicting capabilities and cloud-based platforms to process and visualise the collected data. Moreover, IoT-powered sensors are key in the data collection phase.

[3] OECD (2022). Trends, investor types and drivers of renewable energy FDI - https://www.oecd.org/publications/trends-investor-types-and-drivers-of-renewable-energy-fdi-4390289d-en.htm

1. Introduction

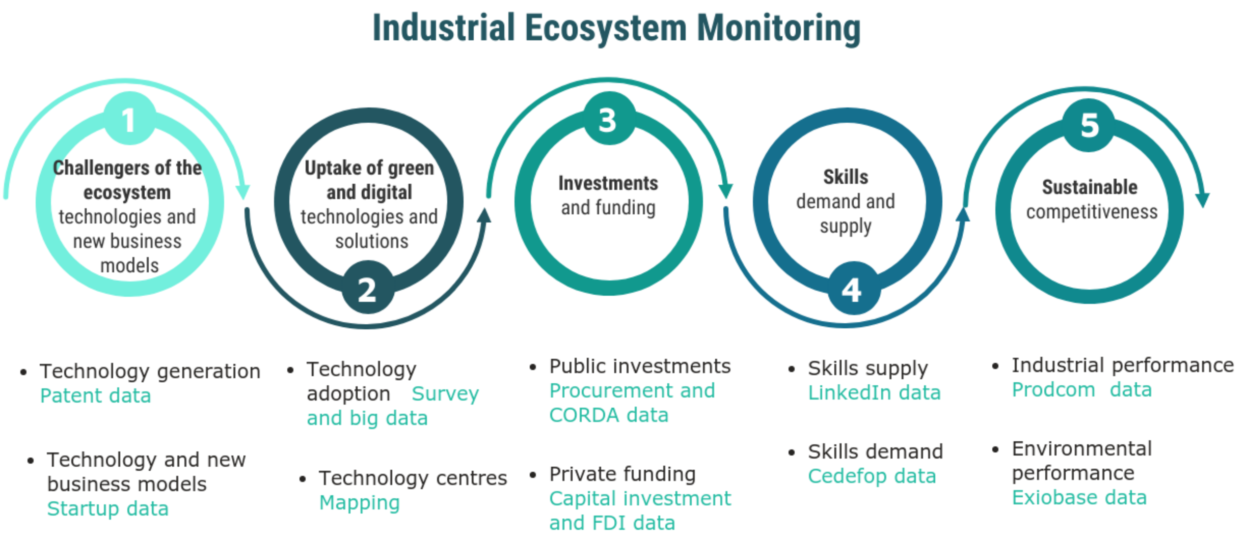
1.1. Objectives

This report has been prepared within the '**European Monitor of Industrial Ecosystems' (EMI)** project, initiated by the European Commission, Directorate General for Internal Market, Industry, Entrepreneurship and SMEs and the European Innovation Council and SMEs Executive Agency (EISMEA). The overall objective of the project is to **contribute to the analysis of the green and digital transformation of industrial ecosystems** and progress made over time.

The EU's updated industrial strategy[4] has identified 14 industrial ecosystems[5] – one of them being **'Energy – Renewable'** - that is in the focus of this report. The industrial strategy defined industrial ecosystems as encompassing all players operating in a value chain: from the smallest startups to the largest companies, from academia to research, service providers to suppliers. The notion of ecosystems captures the complex set of interlinkages and interdependencies among sectors and firms across the EU. Industrial transition is driven by technological, economic, and social changes, and in particular by green and digital technologies and the shift to the circular economy. The process is however characterised by complex, multi-level, and dynamic development. To make transition sustainable, technological change needs to be coupled with new business models, the necessary investments, skills, regulatory framework conditions and behavioural change across the ecosystem.

Measuring performance and change is vital to allow policymakers and industry stakeholders to track progress over time and get feedback whether the system is moving in the desired direction. To measure performance, a dedicated **monitoring and indicator framework** has been set up for the purposes of this project with an aim to capture them in regular intervals (see the overview of the monitoring framework in Figure 1).

Figure 1: Overview of monitoring industrial ecosystems and relevant data sources



Source: Technopolis Group, IDEA Consult and Fraunhofer ISI

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[4] European Commission (2020). A New Industrial Strategy for Europe, COM/2020/102 final and European Commission (2021). Updating the 2020 New Industrial Strategy: Building a stronger Single Market for Europe's recovery, COM(2021) 350 final

[5] The 14 industrial ecosystems include: construction, digital industries, health, agri-food, renewables, energy intensive industries, transport and automotive, electronics, textile, aerospace and defense, cultural and creative culture industries, tourism, proximity and social economy, and retail

The indicator framework includes a **set of traditional and novel data sources that allow shedding new light on ongoing transformation patterns.** The novelty of the analysis lies in the exploratory and innovative data sources used across the different chapters. Due to its effort to analyse industrial ecosystems using a more or less standardised set of indicators, the study cannot address all aspects of the green and digital transition. Therefore, additional analysis and industry-specific data sources should be used to supplement a full assessment.

The **methodological report** that sets the conceptual basis and explains the technical details of each indicator is found in a separate document uploaded on the EMI website. Moreover, some of the specific industry codes used throughout this analysis have been also included in Appendix B. The green and digital technologies considered in this study are presented in Figure 2.

Figure 2: Main technologies monitored in the project

Green transformation
Advanced Sustainable Materials
Biotechnology
Energy Saving technologies
Clean Production technologies
Renewable Energy technologies
Solar Power
Wind Power
Other (geothermal, hydropower, biomass)
Recycling technologies
Circular business models

Digital transformation
Advanced Manufacturing & Robotics
Advanced Manufacturing
Robotics
Artificial Intelligence
Augmented and Virtual Reality
Big Data
Cloud technologies
Blockchain
Digital Security & Networks/ Cybersecurity
Internet of Things
Micro- and Nanoelectronics & Photonics
Online platforms

Source: Technopolis Group, IDEA Consult and Fraunhofer ISI

This report contributes to the analysis of the **key pillars put forward in the 'Blueprint for the development of transition pathways'**[6] of the Industrial Forum developed in 2022.

1.2. Definition of the ecosystem

Renewable energy is in general energy derived from natural sources that are replenished at a higher rate than they are consumed. Fossil fuels such as coal, oil, and gas, are not replenishable and their combustion to produce energy causes greenhouse gas emissions, particulate matter, and other emissions to air and ground that have potentially damaging effects on humans and nature. Generating energy from renewables create much less emissions compared to fossil fuels[7].

The annual single market report 2021 states that the energy and renewables industrial ecosystem (RES) includes various economic divisions dedicated to the production, distribution, and or management of energy from wind, solar, hydropower, bioenergy, geothermal, ocean and heat pumps, usually classified within ten NACE rev2 divisions, including D35 Electricity, gas, steam and air conditioning supply, C27 Manufacture of

[6] https://ec.europa.eu/docsroom/documents/49407/attachments/1/translations/en/renditions/native
[7] UN (2023) Climate action – What is renewable energy? Accessed at https://www.un.org/en/climatechange/what-is-renewable-energy

electrical equipment, and 8 more divisions that are horizontal and contributing to all industrial ecosystems along with the RES[8].

The rationale for taking up this industrial ecosystem definition in this report, instead of following a traditional approach of analysing different industries in isolation, is the complex contribution of multiple industries to the renewable industries' activities. An ecosystem approach is more comprehensive, considering activities at different stages of the renewable industries' value chains. For instance, most energy value chains (RES and nonRES) need to go through multiple value chain stages: research; project development; sourcing; construction or installation of capacity; manufacturing/generation; distribution; end of the lifecycle. These value chain stages are more likely to be captured in an ecosystem approach than in single industries/divisions. They are more likely to be distributed across industries, and services in multiple divisions.

[8] European Commission (2021). Annual Single Market Report 2021 SWD/2021/351 final

2. Industrial ecosystem state of play

2.1 Overall situation

The core divisions of the RES ecosystem in the EU (D35 Electricity, gas, steam and air conditioning supply, C27 Manufacture of electrical equipment) grew substantially over the last decade, according to Eurostat data[9]. The number of enterprises almost doubled from 110 748 in 2011 to 209 164 in 2020. This represents a 7% compound annual growth rate for the economic division. The turnover grew by 0.6% annually over the same period. The benefits in terms of employment contribution by RES vary by country across the EU.

According to the International Renewable Energy Agency (IRENA)[10], the renewable energy industries created 1.2 million jobs in the year 2021 in the EU27. The three main renewable sources of energy contributing to employment generation were: **solid biomass, wind energy, and solar photovoltaic, with 68% of the total RES employment** in the EU, with solar being the one RES source growing the most globally. The countries with the highest share of RES employment in the EU are Germany, Poland, Denmark, Spain, France, Austria, and Italy.[11]

Employment of RES is expected to grow due to better cost-effectiveness of RES projects and as a result of the increasing fossil price instability. One of the potential benefits for the EU according to IRENA is the following: the **lifetime cost per kWh** of new solar and wind capacity is expected to become **four to six times less than the marginal costs of fossil fuels in 2022.**[12]

Energy and renewable energy policies

The Energy Union 2015[13], but also the European Green Deal[14], the RePowerEU plan[15], and the Green Deal Industrial Plan,[16] set various EU energy policy objectives which influence the EU RES. Some of the key objectives include:

- diversifying energy sources
- enabling free flow of energy through the EU with relevant infrastructure
- reduce dependence on energy imports, reduce emissions, increase jobs and growth, improve energy efficiency
- decarbonise the economy.

For these objectives to be achieved, various initiatives and strategies have been put in place, including the Fit for 55 packages;[17] continuation of the completion of the EU internal market for energy;[18] new EU energy efficiency targets;[19] boost to the EU renewable energy

[9] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Electricity,_gas,_steam_and_air_conditioning_supply_statistics_-_NACE_Rev._2&oldid=567961
[10] https://www.irena.org/
[11] IRENA and ILO (2022) Renewable Energy and jobs: Annual review 2022. https://www.irena.org/Data/View-data-by-topic/Benefits/Employment-Time-Series
[12] IRENA (2022) Renewable Power Generation Costs in 2021. ISBN 978-92-9260-452-3
[13] https://energy.ec.europa.eu/topics/energy-strategy/energy-union_en
[14] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en
[15] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A230%3AFIN&qid=1653033742483
[16] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/green-deal-industrial-plan_en
[17] European Commission (2021) 'Fit for 55': delivering the EU's 2030 Climate Target on the way to climate neutrality. COM(2021) 550 final. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0550
[18] European Commission (2023) Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Regulations (EU) 2019/943 and (EU) 2019/942 as well as Directives (EU) 2018/2001 and (EU) 2019/944 to improve the Union's electricity market design. COM(2023) 148 final. 2023/0077 (COD). https://ec.europa.eu/commission/presscorner/detail/en/ip_23_1591
[19] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2022:222:FIN

capacity passing from 40% to 45% in the year 2030;[20,21,22,23,24] improving security of energy supply,[25] among other initiatives.

Since the EU Renewable Energy Directives (RED), the EU has gone through multiple amendments, increasing the renewable targets and objectives, from RED I to RED IV. Behind these directives the key target is the deployment of renewables and the decarbonisation of the EU economy. For the first time, in March 2023, the industry as a sector is subject to the directives targets, with a commitment to reach the industry's consumption of hydrogen to be 42% renewable by the year 2030 (see Table 1).

Table 1: Simplified renewable energy policy evolution

Adoption/ proposal	Renewable Directives	Key objectives	Key driver
2001	Electricity from renewable sources	22,1% electricity produced by renewables of the total community consumption by 2010	Compliance with Kyoto Protocol
2003	Biofuels and other renewables for transport	2% biofuels since 2005 5.75% biofuels since 2010	Compliance with Kyoto Protocol
2009	RED I	20% share of EU energy consumption from renewable sources by 2020	Kyoto Protocol + Community and International commitments beyond 2012
2021	RED II	Binding targets on renewable sources in the EU's energy mix to 40% by 2030 (part of the 'Fit for 55' package)	European Green Deal commitments
2022	RED III	2030 renewable energy sources target to 45% (part of the RePowerEU plan)	Phase-out of Russian fossil fuel dependence
2022	RED IV	Council Regulation to accelerate the deployment of renewable energy	EU's plan to end dependence on Russian fossil fuels
2023	Parliament and the Council informal agreement[26]	Industry use of renewable energy to increase 1.6% annually + 42% of renewable hydrogen in total hydrogen consumption in industry by 2030	EU's Green transition
2023	RED IV Delegated Act	Defines renewable fuels of non-biological origin (RFNBOs) + Methodology to calculate GHG from RFNBOs	Hydrogen strategy + RePowerEU plan + 'Fit for 55'

Source: Technopolis Group based on European Parliament's Factsheets on renewable energy. https://www.europarl.europa.eu/factsheets/en/sheet/70/renewable-energy

[20] European Commission (2021) Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Directive (EU) 2018/2001 of the European Parliament and of the Council, Regulation (EU) 2018/1999 of the European Parliament and of the Council and Directive 98/70/EC of the European Parliament and of the Council as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652. COM(2021) 557 final. https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52021PC0557&from=EN.

[21] European Commission (COM/2022/0221) Solar Strategy. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2022:221:FIN

[22] European Commission (COM/2020/741) offshore renewable wind strategy. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2020:741:FIN

[23] European Commission (2023) Commission sets out rules for renewable hydrogen. https://ec.europa.eu/commission/presscorner/detail/en/ip_23_594

[24] European Commission (2022) Biomethane action plan. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=SWD%3A2022%3A230%3AFIN&qid=1653033922121

[25] European Commission (2022) EU's trans-European energy infrastructure policy. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32022R0869

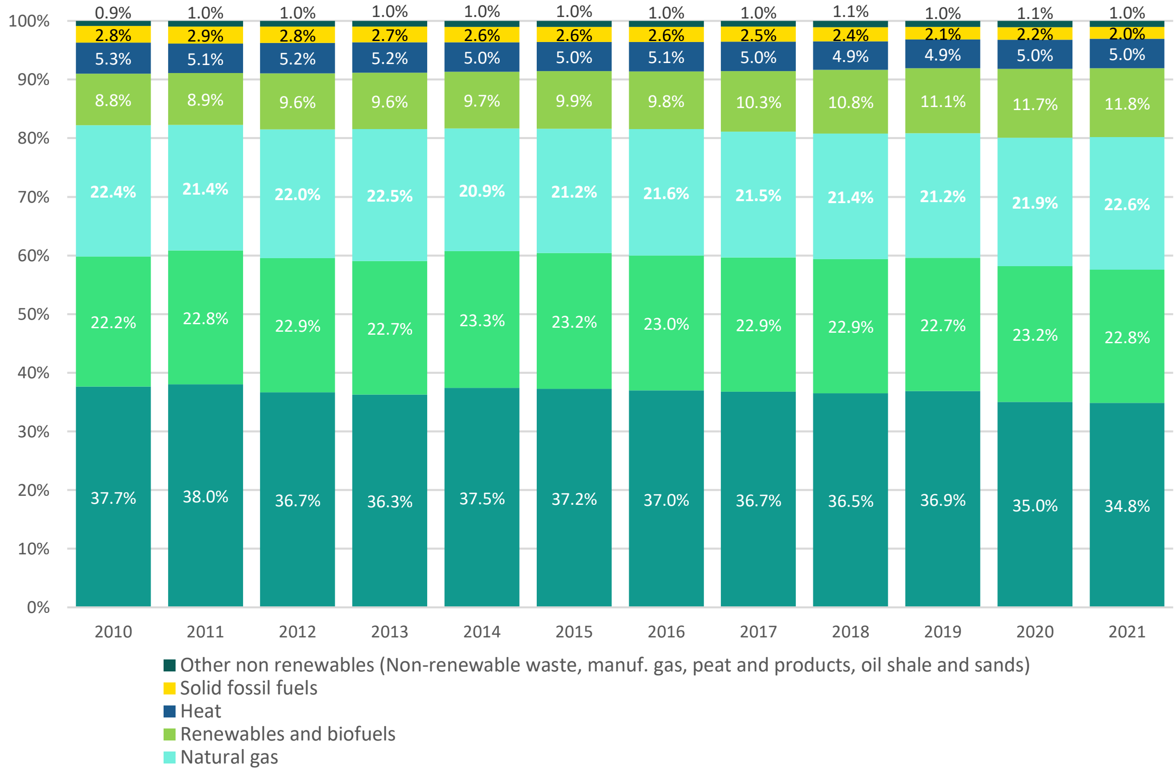
[26] European Commission (2023) European Green Deal: EU agrees stronger legislation to accelerate the rollout of renewable energy. Press release. https://ec.europa.eu/commission/presscorner/detail/en/ip_23_2061

2.2 Progress towards the reduction of strategic dependencies

The EU in 2021 produced around 44% of the total energy consumed, with 56% imported from third countries. By the same year, the **main source of energy production in the EU was renewable sources, with 41% contribution to the total energy production**. On the other hand, the energy produced in the EU, only covered 42% of the EU energy consumption, and 58% of the total energy in the EU was imported from third countries.[27]

Accounting for the total energy consumption (EU production and imported from third countries) the type and share of energy consumed included petroleum products with 35% of the total; electricity and gas with 23%; renewables (not transformed into electricity for general distribution) with 12%; derived heat with 5%; and solid fossil fuels with 3% (see Figure below).

Figure 3: Share of EU final consumption by energy type



Source: Technopolis Group based on Eurostat (2023) Simplified energy balances [NRG_BAL_S]

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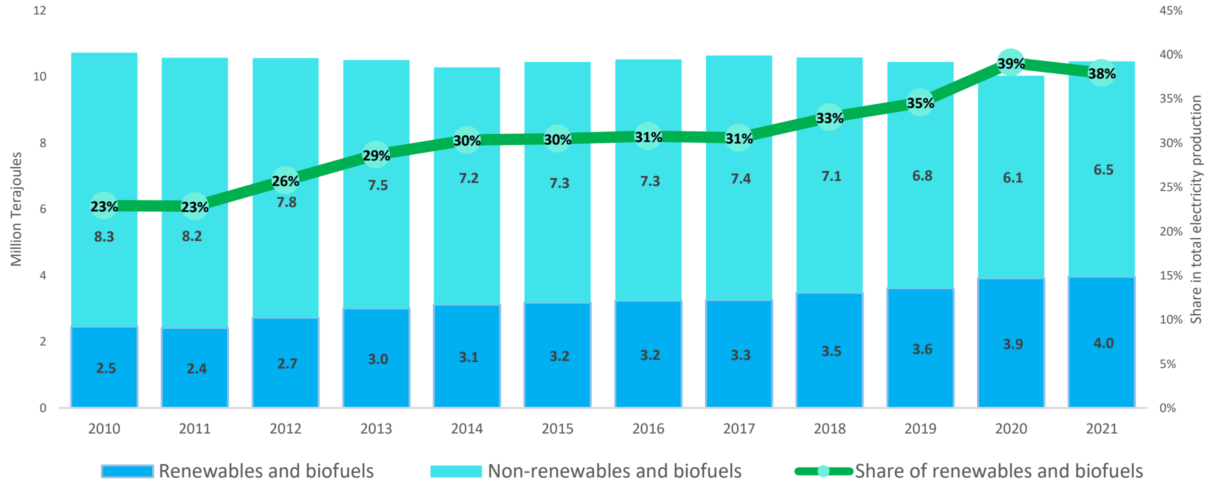
[27] Eurostat (2023) Shedding light on energy – 2023 Edition. https://ec.europa.eu/eurostat/web/interactive-publications/energy-2023#about-publication

Figure 4: EU gross electricity production and renewable electricity (Million terajoules and share in total)



Source: Technopolis Group based on Eurostat (2023) Production of electricity and derived heat by type of fuel [NRG_BAL_PEH]

Table 2 below reveals the comparative dependency on energy in the EU, which is based on the import dependency shares for the EU. The table shows that the EU decreased its dependency on oil and petroleum products from 66% to 65% during the last decade. However, its dependency on natural gas increased from 65% to 67%. It is important to highlight the EU's priority on reducing dependency on natural gas because of the recent geopolitical conflicts. The EU depends approximately 40% on imports of natural gas from Russia to meet internal demand.[28] Natural gas is a direct source of energy for the EU economy and society and a key source of electricity production by non-renewable sources.

Table 2: Energy dependency on imports from third countries and revealed comparative dependency on energy in the EU (2010-2015 and 2015-2021)

Revealed Comparative Dependency	Total Energy Import dependency on third countries		REVEALED COMPARATIVE DEPENDENCY ON ENERGY											
			Combustible fuels - renewable		Solid fossil fuels		Other solid fossil fuels		Natural gas		Oil and petroleum products		Electricity	
	2010 - 2015	2016 - 2021	2010 - 2015	2016 - 2021	2010 - 2015	2016 - 2021	2010 - 2015	2016 - 2021	2010 - 2015	2016 - 2021	2010 - 2015	2016 - 2021	2010 - 2015	2016 - 2021
Belgium	58	61	0.24	1.69	1.22	1.09	0.00	0.00	0.74	0.86	0.86	0.82	0.00	0.01
Bulgaria	45	43	0.15	0.14	0.34	0.17	0.00	0.00	1.45	1.40	1.34	1.41	0.03	0.08
Czechia	27	29	0.01	0.00	0.05	0.09	0.00	0.00	2.45	2.17	1.72	1.45	0.27	0.00
Denmark	33	36	3.42	2.84	2.08	1.79	0.00	0.00	0.15	0.08	0.84	1.00	3.07	3.65
Germany	50	58	1.34	1.18	0.62	0.60	0.00	0.00	0.91	1.06	1.05	0.90	0.21	0.38
Estonia	14	13	0.00	0.00	5.03	4.58	0.00	0.00	5.25	3.89	1.50	2.00	0.00	0.00
Ireland	82	65	2.97	1.84	0.84	0.97	0.00	0.00	0.84	0.52	0.79	0.91	1.77	1.63
Greece	69	78	0.09	0.01	0.04	0.07	0.00	0.00	1.04	0.85	0.90	0.81	1.93	1.70
Spain	70	68	2.70	1.59	0.84	0.86	0.00	0.00	0.98	0.93	0.88	0.90	0.00	0.01
France	44	43	0.36	0.09	1.63	1.60	0.00	0.00	1.28	1.35	1.33	1.31	0.05	0.08
Croatia	35	33	0.00	0.04	2.13	2.12	0.00	0.00	0.11	0.17	1.14	1.12	4.54	5.54
Italy	74	74	1.59	0.95	1.02	0.98	0.00	0.00	0.75	0.82	0.85	0.83	1.27	1.06
Cyprus	45	32	5.64	1.24	0.81	1.89	0.00	0.00	0.00	0.00	0.74	0.76	0.00	0.00
Latvia	36	29	0.12	0.04	2.07	2.32	0.00	0.00	1.79	2.26	0.81	0.88	3.11	3.55
Lithuania	82	78	0.19	0.00	0.95	0.92	13.74	14.65	0.88	0.87	0.79	0.84	3.44	2.89
Luxembourg	20	15	0.07	0.00	3.63	4.50	0.00	0.00	3.31	3.91	0.00	0.07	0.00	0.00
Hungary	50	48	0.22	0.10	0.46	0.52	0.00	0.00	1.08	1.12	1.03	0.90	1.04	1.12
Malta	48	40	0.21	12.20	0.00	0.00	0.00	0.00	0.00	1.39	0.71	0.63	0.00	0.00
Netherlands	54	62	1.02	1.06	1.46	1.25	0.00	0.00	0.33	0.47	0.91	0.80	1.22	0.95
Austria	38	38	0.01	0.01	0.47	0.57	0.00	0.00	1.51	1.40	0.98	0.97	0.06	0.27
Poland	35	40	1.17	0.23	0.21	0.28	0.00	0.00	1.20	1.04	1.77	1.50	0.49	0.61
Portugal	70	66	0.00	0.01	1.14	0.79	0.00	0.00	1.03	1.01	0.86	0.87	0.00	0.00
Romania	24	30	1.01	0.03	0.29	0.31	4.30	1.08	0.36	0.27	1.68	1.56	0.40	0.76
Slovenia	19	16	0.18	0.14	0.68	0.72	0.00	0.00	2.13	0.93	1.11	1.20	0.00	0.00
Slovakia	53	51	0.47	0.06	0.59	0.78	0.00	0.00	1.31	1.19	1.09	1.07	0.03	0.03
Finland	51	44	0.65	0.29	1.35	1.55	0.09	0.55	1.42	1.38	1.20	1.30	0.92	1.05
Sweden	34	35	0.24	0.30	1.82	1.87	0.86	0.97	0.00	0.26	1.52	1.54	0.51	0.61
EU Energy Dependency	**47**	**45**	**3**	**3**	**57**	**57**	**2**	**1**	**65**	**67**	**66**	**65**	**7**	**6**

Source: Technopolis Group, Based on Eurostat (2023) Import dependency on third countries by fuel type [NRG_IND_ID3CF]. Revealed comparative dependency on energy (RCDE) - in grey shade area-, based on the Bassala index. It shows the dependency of a country in a specific type of energy, in relation to the total energy dependency of the country, divided by the dependency of the EU in the same type of energy in relation to the total energy dependency of the EU. Example.- Croatia's RCDelectricity in the 2010-2015 period is estimated as follows. In the 2010-2015 period, Croatia's dependency on third countries for electricity was 23% and dependency on third countries for total energy was 35%, while the EU dependency on third countries for electricity in the same period was 7% and the dependency on third countries for total energy was 47%. Thus, Croatia's RCDelectricity $_{2010\text{-}2015}$ = (23% / 35%) / (7% / 47%) = 4.54.

Nevertheless, more granular yearly data shows that the EU's dependency on imports of natural gas was at its highest in 2017, with 70% of the total gas available in the EU. This

[28] Van Halm, I (2022) How can the EU end its dependence on Russian gas?. Energy Monitor. https://www.energymonitor.ai/policy/how-can-the-eu-end-its-dependence-on-russian-gas/

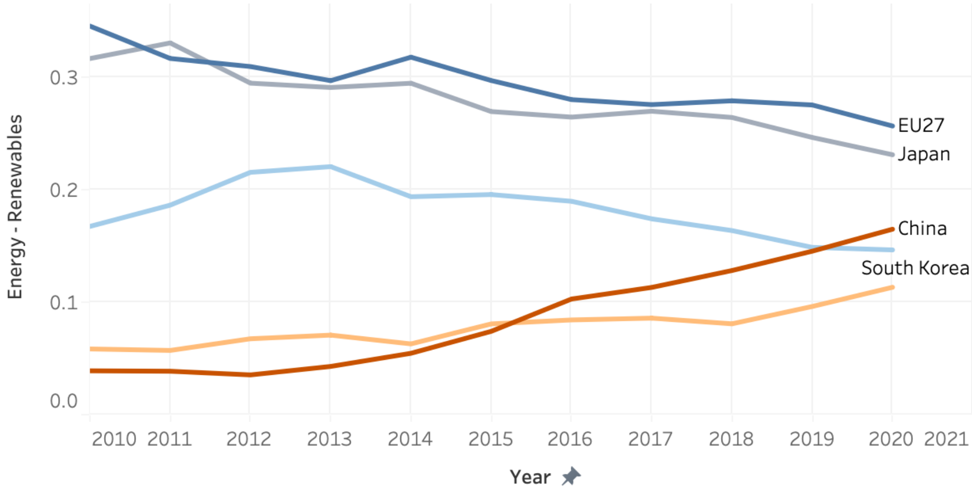
dependency declined to the lowest level during the last decade in the year 2021, with 63.9%, for a 67% average during the 2016 – 2021 period.

2.3 Trends in patent applications

The past decade has seen significant developments in the field of renewable energy technologies across the world. Figure 5 below shows a general reduction in the share of patent applications by the RES industrial ecosystem in the total world applications. In this project, technology developments have been tracked by patenting activities related to specific sectoral activities based on patent-based classifications. The analysis is based on 'transnational patents' (Frietsch/Schmoch, 2010) (i.e. PCT/WIPO filings or direct applications at the EPO, excluding double counts) and was conducted on an extended version of the EPO's Worldwide Patent Statistical Database that Fraunhofer ISI implemented locally. The detailed methodology is presented in the EMI methodological report.

The data shows a continuous decline in the world share of EU patenting activity in renewable energies, to the benefit of China and South Korea, both increasing their shares, especially since 2015 (see Figure 5). China has been increasing their patent contribution in all renewable sources, compared to France and Germany, which in the early stages, were leading patenting activity in geothermal energy technologies and to which they are currently the main global technological providers.[29]

Figure 5: Trends in the EU27 share of patent applications in world total in the field of the renewable energy industrial ecosystem in 2010-2020 and global comparison in 2020



Source: Fraunhofer calculations, Patstat

Analysis of patenting activity related to renewable energies in the EU indicates an increasing need of knowledge from multiple stakeholders and a narrowing scope of technological applications.[30] Thus, there may be disincentives to patenting due to the narrowing of the exploitation potential of renewable energy patents and increasing efforts paid to different types of protecting innovation in the EU renewables landscape. Furthermore, increasing patenting in renewables does not always lead to positive outcomes, as increased innovation protection can limit the capacity of firms to enter the

[29] Jiang, L., Zou, F., Qiao, Y., & Huang, Y. (2022). Patent analysis for generating the technology landscape and competition situation of renewable energy. Journal of Cleaner Production, 378, 134264. https://doi.org/10.1016/j.jclepro.2022.134264

[30] Moreno, R., & Ocampo-Corrales, D. (2022). The ability of European regions to diversify in renewable energies: The role of technological relatedness. Research Policy, 51(5), 104508. https://doi.org/10.1016/j.respol.2022.104508

market and potentially increase the market prices **of renewables, leading to the reduction of incentives to adopt renewables by end users.**[31]

2.4 Foreign direct investments

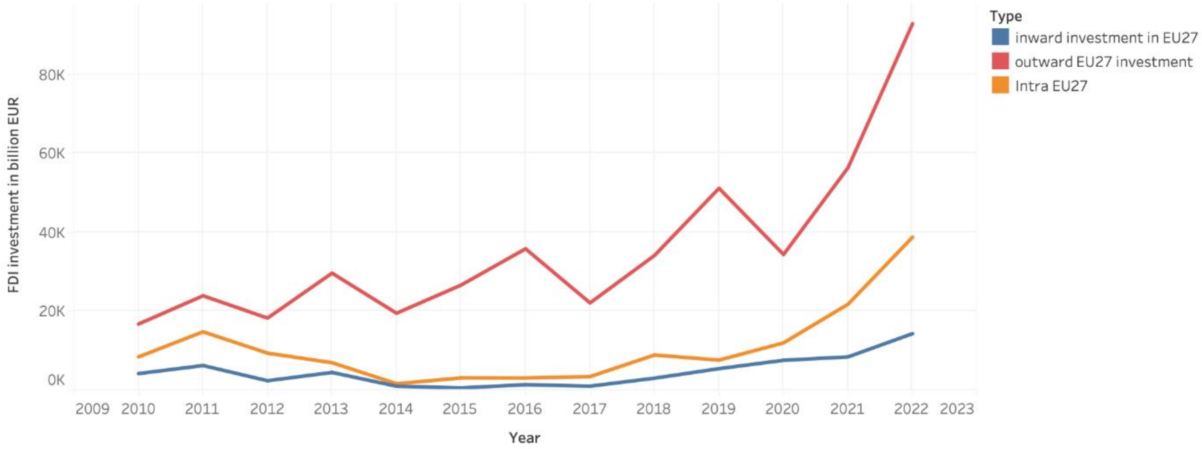
Renewable energy has become a key target of foreign direct investments (FDI) globally[32]. FDI into renewable energy has witnessed high investments in 2022 and most recently in 2023 as a result of several mega projects in hydrogen and offshore wind[33]. Renewable energy projects outpaced traditional energy investments in 2020[34]. In this project, data of fDi intelligence[35] was used to track cross-border greenfield investment intra-EU, extra-EU and globally in the RES industrial ecosystem. The data provide real-time monitoring of investment projects, capital investment and job creation.

Over the period from 2015 to 2022 intra-EU investments in renewable energy amounted to €98 bn. Inward FDI investments into the EU had a total value of €42 bn, while EU FDI into third countries had a record high of €353 bn.

There has been a sharp increase in FDI outflows from EU countries to non-EU destinations over the past decade but in particular from 2020 to 2022 amounting to a total of €92 m in 2022.

The primary recipients of FDI from the EU27 during the period of 2018-2022 were the UK and the USA, receiving €88 bn (33%) and €33 bn (13%), respectively. France, Germany, and Spain are the top investors in this sector within the EU27, accounting for 57% of the total outward investments.

Figure 6: Foreign direct investment in renewable energies



Source: Technopolis Group calculations based on fdiInsights

The picture of FDI investments from EU27 countries to third countries in the field of renewable energies shows a diverse pattern across different energy types.

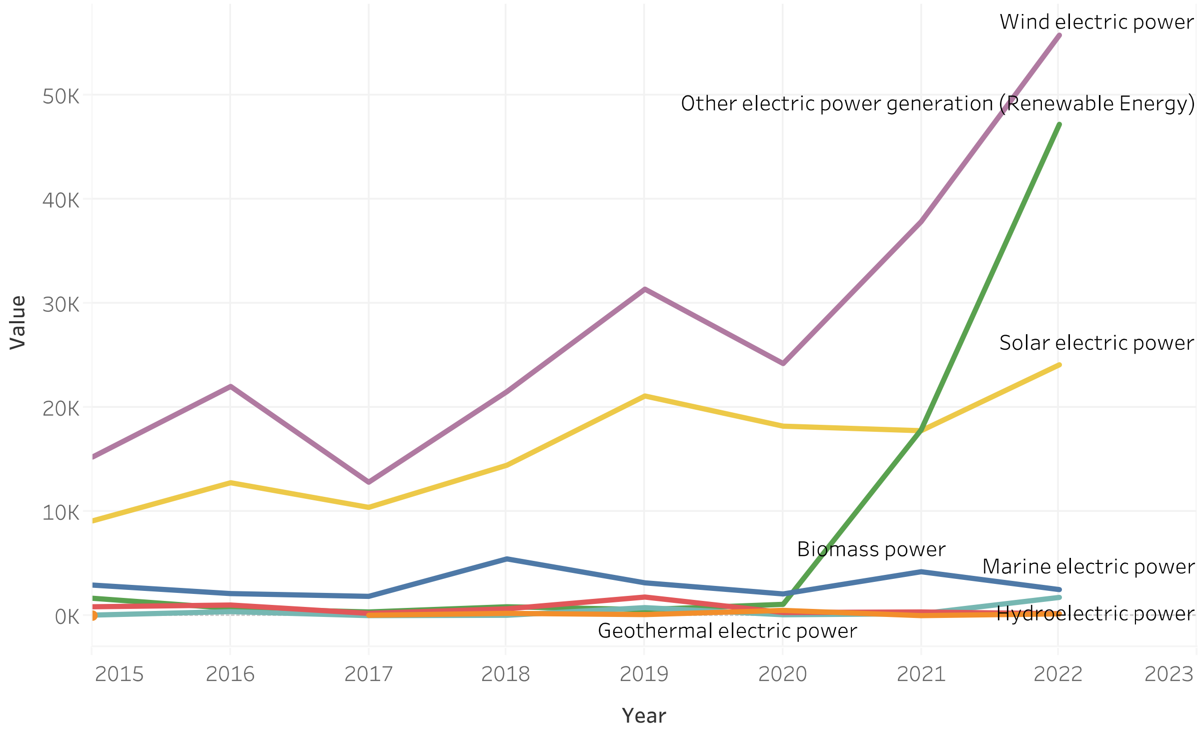
In the biomass power sector, investments peaked in 2018 at €5 445.44 m and experienced a fluctuating trend afterwards, with a decline in 2019 and 2020 but a recovery in 2021. Geothermal electric power received relatively low investments throughout the years, with a significant increase in 2020, reaching €493.65 m, and a subsequent decline in 2021.

[31] Alexiou, C. (2023). Gauging the impact of the strength of patent systems on renewable energy consumption. Renewable Energy, 210, 431-439. https://doi.org/10.1016/j.renene.2023.04.086
[32] OECD (2022). Trends, investor types and drivers of renewable energy FDI - https://www.oecd.org/publications/trends-investor-types-and-drivers-of-renewable-energy-fdi-4390289d-en.htm
[33] https://www.fdiintelligence.com/stream/Renewable-energy
[34] https://www.wilsoncenter.org/article/transatlantic-energy-economy
[35] https://www.fdiintelligence.com/

Hydroelectric power witnessed steady investments, with a notable surge in 2016 with €1 010.37 m, followed by a decrease in the following years and a slight recovery in 2021. Marine electric power fluctuated, with investments rising in 2016 and 2019 but experiencing intermittent drops in other years.

The most remarkable growth can be observed in the other electric power generation category, which includes diverse renewable energy sources. Investments surged significantly from 2017 onwards, with a great increase in 2022, reaching a total of €47 bn. This suggests a growing interest in exploring alternative renewable energy generation methods.

Figure 7: Evolution of European foreign direct investments by type of renewable energy

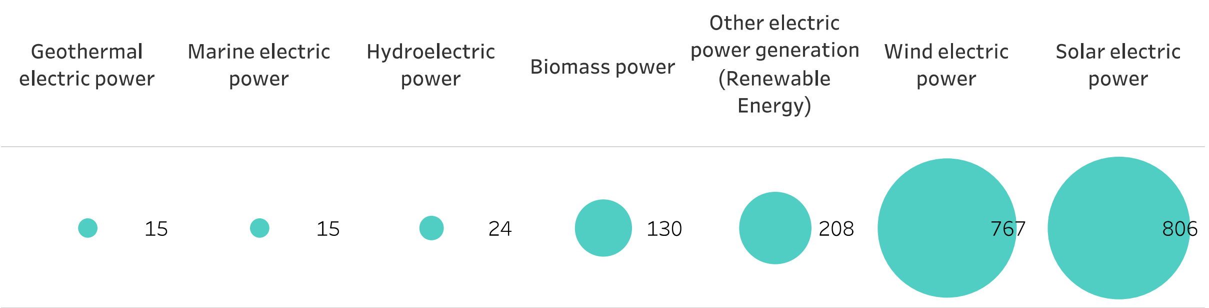


Source: Technopolis Group calculations based on fdiInsights

Solar electric power attracted substantial investments consistently, with a peak in 2019 at €21 bn. Similarly, wind electric power saw consistent growth throughout the years, reaching its peak in 2022 at €55 bn and with an annual average growth of 28% during the considered period.

Results indicate that solar and wind energy remain highly attractive for FDI, suggesting a strong potential and positive market outlook.

Figure 8: Number of outward FDI investment projects from EU27 to other countries by renewables sub-sector, 2015 to December 2022



Source: Technopolis Group calculations based on fdiInsights

3. Renewables energy use by industrial ecosystems in the EU27

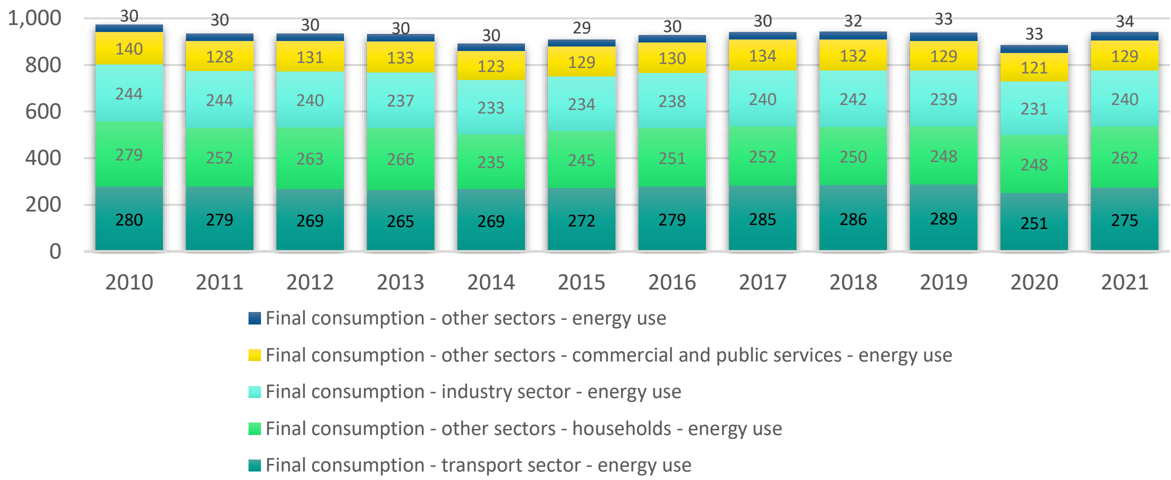
3.1. Energy and renewable use by the 14 industrial ecosystems

Energy demand

Industry's energy requirements accounted for 26% of the total EU energy consumption. The largest industrial energy consumers in the EU were chemical and petrochemical, non-metallic minerals, paper and pulp, and tobacco. Other large energy-consuming economic sectors include transport, services, agriculture, etc.[36]

The EU has steadily reduced its energy consumption during the last 11 years. Data shows an annual compound growth rate decline of 0.3% from 2010 to 2021 in the EU (see Figure 9). While it can be said that COVID had an effect in the last two years of energy consumption, it is since 2017/2018 that consumption has been declining especially in industry.

Figure 9: EU energy consumption – energy use by sector (megatonnes of oil equivalent)

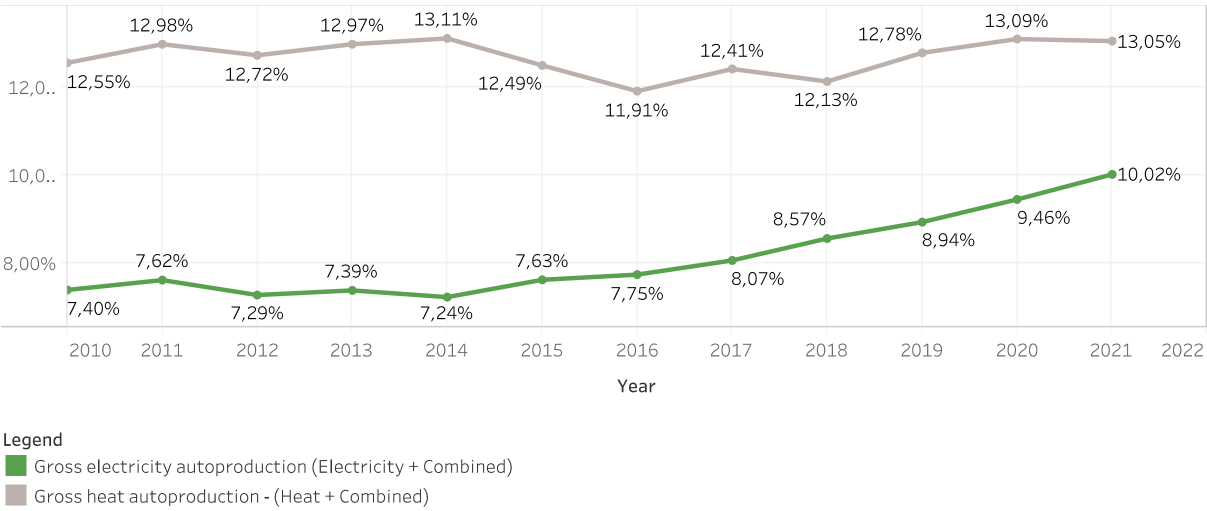


Source: Technopolis Group based on Eurostat (2023) Final energy consumption by sector [TEN00124]

Industrial companies across the EU have various mechanisms to source energy, including renewables: traditional supply by utility companies, auto-production (meaning production of electricity on site for one's own use), Power Purchase Agreements (PPA), and Purchase of Guarantees of Origin (GO). The auto-production of energy in the EU has been steadily growing, especially since the year 2017, as can be seen in Figure 10.

[36] Eurostat (2023) Final energy consumption in industry - detailed statistics. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Final_energy_consumption_in_industry_-_detailed_statistics#Energy_products_used_in_the_industry_sector

Figure 10: Energy auto-production in the EU from 2010 to 2021 by type of energy (share of terajoules produced)



Source: Technopolis Group based on Eurostat (2023) Complete energy balances [NRG_BAL_C]

The Power Purchase Agreements (PPAs) are usually accompanied by specific guarantees of origin that companies use to disclose renewable energy use. **The number of PPAs registered an increase in the EU in recent years,** and according to a 2022 report for the European Investment Bank, it is expected to increase in the long term.[37] The top PPAs industrial users are ICT, Heavy Industries, Telecom, Transport, Retail, Healthcare, Automotive, Consumer Goods, etc.

The main renewable sources in the PPAs have been wind, and more recently, there has been an important contribution of solar and mixed portfolios with solar and wind energy.

There are various sourcing models for PPAs, among which two important are the physical PPA and the virtual/financial PPA. The first one is a sourcing model with direct transmission of energy to the company by an energy generator/producer, while the second is a model where the buyer pays for the guarantee that the energy delivered by the generator/seller will be eventually transmitted to the generator's grid with renewable sources. Whilst the first model may require switching energy provider, or access points to directly receive renewable energy, the second does not require switching providers nor energy access points, as somewhere else in another point, the grid will be fed with the renewables purchased by the industrial buyer[38].

Whereas PPAs are seen as good sourcing models to ensure the additionality of renewable sources of energy in the EU, the Russia-Ukraine war generated high price increases in energy, disincentivising generators to choose for PPAs with stable prices in the long term, preferring to sell energy in different markets offering increasing prices. Generators reduced their offering of physical PPAs of renewable energies, especially from Spain, Germany, and other European countries. This has been driving the need to meet renewable energies demand with other types of 'Guarantees of Origin', such as virtual/financial PPAs, multi-buyer, multi-seller, cross-border, smaller in scale projects to reduce risks, etc.[39] Moreover,

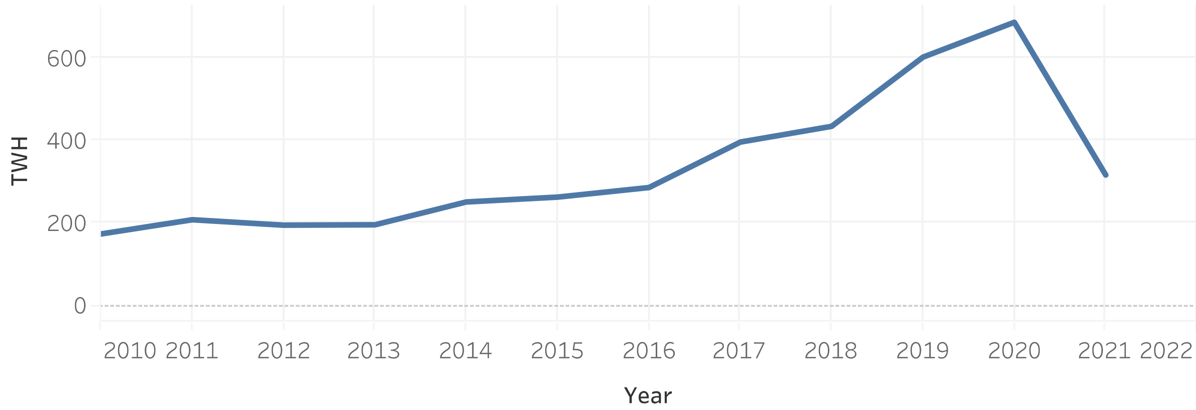
[37] European Investment Bank, European Commission, European Investment Advisory Hub (2022) Commercial Power Purchase Agreements. A market study including an assessment of potential financial instruments to support renewable energy Commercial Power Purchase Agreements. Report prepared by Bariga. https://advisory.eib.org/publications/

[38] Re-source (2021) Guarantees of Origin and corporate procurement options. https://resource-platform.eu/reports/

[39] Pexapark & Partners (2023) Renewables Industry Survey 2023.

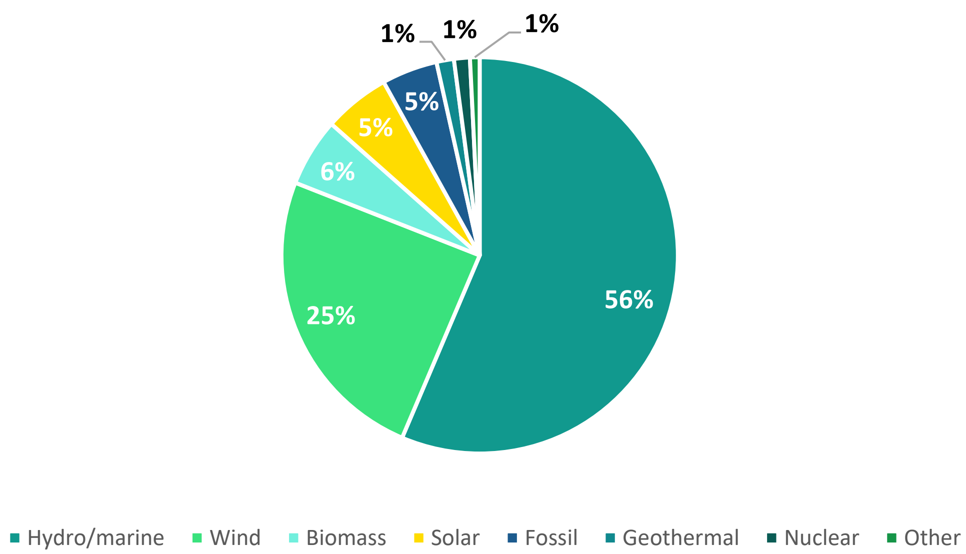
PPAs are traditionally associated to large plants with high capital expenditures and a need for support in the long term.[40]

Figure 11: Evolution of guarantees of origin consumed in the EU (Terawatt/Hour)



Source: Technopolis Group based on Association of Issuing Bodies (2021) AIB monthly statistics.

Figure 12: Share of guarantees of origin consumed in 2021 (Association of Issuing Bodies – AIB)



Source: Technopolis Group based on Association of Issuing Bodies (2021) AIB monthly statistics.

Energy-derived resource dependency

Clean technologies for energy production require specific raw materials. Their availability can be critical for the continuation of the green transition of the EU economy and its industrial activities. For instance, the production of wind energy depends on boron, permanent magnets, Dysprosium, Niobium, Neodymium, Praseodymium, Terbium; solar photovoltaic depends on boron, silver, germanium, gallium, indium, cadmium, and silicon metal; batteries depend on natural graphite, cobalt, lithium, graphite, manganese, nickel, titanium, vanadium, niobium. There are multiple other materials necessary for fuel cells, hydrogen production technologies, digital technologies, photonics, and other technologies

[40] Council of European Energy Regulators – CEER (2021) CEER 2nd Paper on Unsupported RES - Renewables Work Stream (RES WS) of Electricity Working Group. Ref: C21-RES-75-05. 20 October 2021. https://www.ceer.eu/list-of-publications

critical for the energy sector.[41] The demand for minerals for renewable energy is estimated to quadruple by 2040. Likewise, dependency on raw materials comes in hand with dependency on technological expertise for their processing and manufacturing.[42]

The green transition based on renewable energies will be more minerals and metals intensive than the conventional fossil fuel energy systems, with implications in terms of supply risks, even with some of the recent minerals and metals deposits discovered in Sweden and Finland, due to citizens' reluctance to mining activities.[43]

Contribution of RES to the green transition of the 14 IEs

In average all industrial ecosystems within the EU sourced 17% of their energy needs from renewable energies. Likewise, the compound annual growth rate of the share of renewable consumption by industry in the EU was 2.4% on average from 2014[44] to 2019. It is worth recalling Table 1, which indicates the agreement of the Parliament and The Council to impose a 1.6% increase in the share of renewables consumption by industry, which on average, it is achieved according to the data presented below.

It is important to highlight that agri-food has the highest share of renewable consumption among the IEs. The top 3 IEs in increasing their share of renewables consumption were construction (3.3%), and proximity and social economy (3.2%).

On the other hand, **there are IEs that have not been able to meet this requirement yet, namely: agri-food (0.8%), mobility, transport and automotive (1.5%), and tourism (1.5%).**

The RES at the disposal of each IE vary according to the location of its industries (availability RES and infrastructure), specific energy demand specifications (e.g. tolerance to power variability), and so on. Accounting for the total energy consumed from 2014 to 2019 by the 14 IEs, **the renewable energy type most consumed by IEs was electricity produced from renewable sources**. Biomass renewable inputs were the main sources of renewables for the Agri-food IE, and it is also very important for the Energy Intensive Industries (EII). The Energy and Renewable IE (RES) has highly diversified sources of renewables. Its energy generation relies mostly on electricity from renewables, wind energy, hydropower, wood, and its waste and other biomass, solar, and energy residuals are highly relevant (see Figure 13).

IEs capacity to adopt renewable energy tends to correlate with a country's capacity to generate energy from RES. Germany, Sweden, Italy, Austria, and Spain, are the 5 countries consuming and generating electricity from RES in the EU. Germany and Spain stand out in terms of generation capacity. Germany's main renewable sources of electricity are onshore wind, followed by solar power. Spain relies mainly on onshore wind, hydropower, and solar.[45]

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[41] SCRREEN2 Project (2022) Sectors with highest CRM demand growth potential. https://scrreen.eu/results/

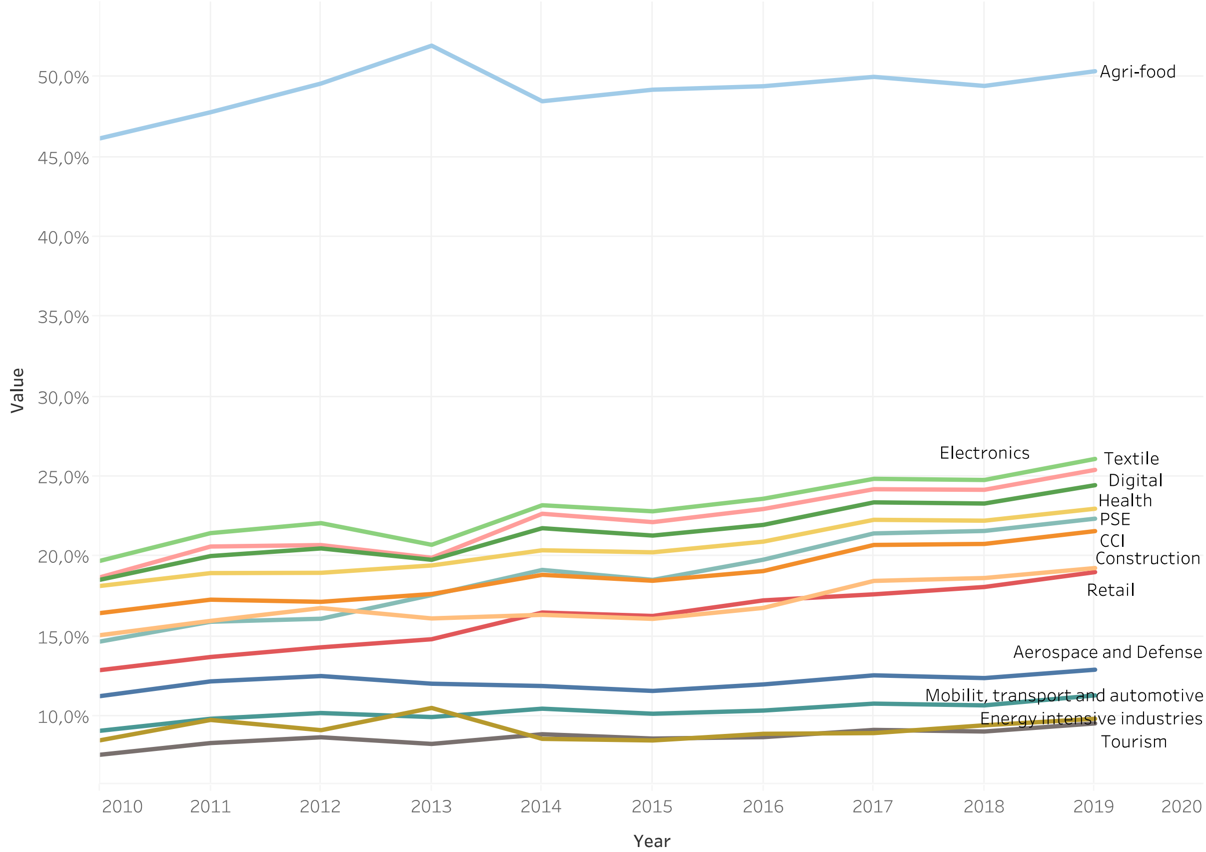
[42] European Commission (2022) Report from the Commission to the European Parliament and The Council. Progress on competitiveness of clean energy technologies. COM(2022) 643 final. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52022DC0643

[43] European Commission, Joint Research Centre, Carrara, S., Bobba, S., Blagoeva, D.et al., (2023) Supply chain analysis and material demand forecast in strategic technologies and sectors in the EU – A foresight study, Publications Office of the European Union. https://data.europa.eu/doi/10.2760/386650

[44] 2014 is the first year with all EU member states disclosing full data o renewable energy by industry, since Eurostat started reporting it.

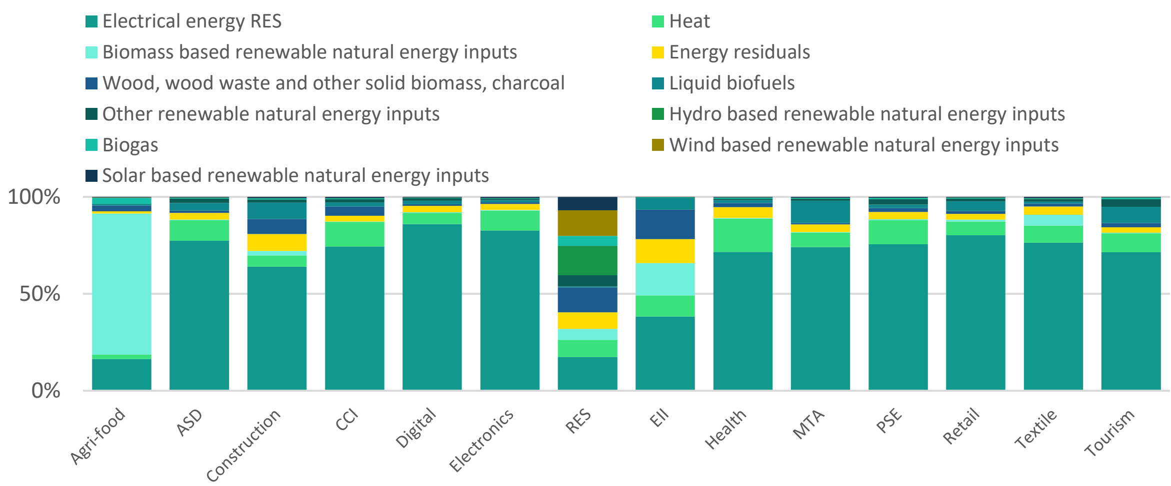
[45] Entsoe (2023) Statistical factsheet 2021. Provisional values as of March 2023. https://www.entsoe.eu/data/power-stats/

Figure 13: Evolution of the share of renewable in the total energy consumption by industrial ecosystem in the EU (2010 – 2019)



Source: Technopolis Group, based on Eurostat (2023) Energy supply and use by NACE Rev. 2 activity [ENV_AC_PEFASU]

Figure 14: Renewable energy consumption by IE (Terajoules, 2014 - 2019)



Source: Technopolis Group based on Eurostat (2023) Energy supply and use by NACE Rev. 2 activity [ENV_AC_PEFASU]

3.2. Survey results on IEs adoption of renewables

With the objective of monitoring the state of digital and green technology uptake, a business survey has been implemented in the framework of this study. The survey collected data about the progress towards the green and digital transition of European SMEs across industrial ecosystems and the related investments, challenges, and opportunities. The survey was based on using Computer Assisted Telephone Interviewing (CATI). The final sample included 3 900 companies in all industrial ecosystems**. This survey complements other existing barometers such as** the Flash Eurobarometer 498 on SMEs, green markets and resource efficiency published in March 2022[46].

Table 3: Survey sampling strategy

Industrial ecosystem	#	Industrial ecosystem	#
Aerospace & Defense	240	Retail	400
Agri-food	430	Textiles	255
Construction	470	Tourism	430
Creative and culture	365	Proximity and social economy	150
Electronics	115	Health	180
Energy-intensive	560	Mobility, Transport & Automotive	355

Source: Technopolis Group and Kapa Research, 2023

SMEs participating in the EMI business survey were asked whether they had adopted and invested in renewable energy technologies over the past five years to satisfy their energy demand. The field work was conducted between January-April 2023. The Flash Eurobarometer asked about the actions the company had undertaken to be more resource efficient such as using predominantly renewable energy (e.g. including own production through solar 3 panels, etc.). This field work took place in November-December 2021. The results of both surveys are displayed in Figure 15.

Figure 15: Adoption of renewable energy by IE

Industrial ecosystem	EMI survey - field work January-April 2023 - Adopted the use of renewable energy technologies	Flash Eurobarometer survey - field work November - December 2021 - Using predominantly renewable energy
Agri-food	29,5%	27,0%
EII	27,9%	9,0%
Health	27,2%	9,0%
Tourism	23,9%	22,0%
Construction	19,8%	21,0%
Textiles	18,0%	12,0%
PSE	17,8%	25,0%
Mobility	15,9%	19,0%
CCI	15,0%	25,0%
Aerospace	14,3%	18,0%
Retail	9,9%	15,0%
Electronics	9,7%	10,0%

Source: Technopolis Group and Kapa Research, 2023

[46] European Commission (2022). Flash Eurobarometer 498 SMEs, green markets and resource efficiency

Both surveys found that the **agri-food, tourism and construction industrial ecosystems had a relatively higher adoption rate among the 14 industries**. At the lower end, we find electronics and retail. Interestingly, the EMI survey found a much higher adoption rate and investment into renewable energies in the field of energy intensive industries. This result can reflect recent shifts towards more energy efficient business operations.

In other cases, differences are due to definitions and the sample. The reason for the difference in the case of healthcare is related to the coverage of the ecosystem: the EMI survey has a bias towards manufacturing industries and healthcare industries as it includes less survey respondents from hospitals and healthcare service providers. Regarding proximity and social economy, the EMI survey focused on the social economy side of the ecosystem including cooperatives, non-profits and associations.

It is also important to consider the differences in the survey results compared to the statistical data from Eurostat (keeping in mind that the latest year available in Eurostat is 2019). While the EMI survey focused mainly on the core NACE rev. 2 of each industrial ecosystem, Eurostat data displayed in the previous section, includes all the NACE codes as per IEs definitions (core and horizontal NACE codes).

SMEs were also asked about the share of energy they source from renewable sources. The table below shows the responses of those that have adopted renewable energy. The results indicate that when adopted, SMEs tend to use renewable energy between 20-50% of their total energy consumption, at most. It is worth noting that this data refers to SMEs, which implies that even small adoption of RES can make a large contribution to their total energy consumption. Furthermore, SMEs represented in this sample, correspond to the key industry classifications of the industrial ecosystem.

Figure 16: Declared share of renewable energy consumption by SMEs

Industrial ecosystem	Between 20-50%	Less than 5%	Between 5-20%	Between 50-75%	More than 75%
Health	75,8%	6,7%	14,1%	2,0%	1,3%
Tourism	66,5%	17,0%	11,0%	4,5%	1,0%
CCI	64,4%	11,9%	11,9%	3,0%	8,9%
EII	61,0%	15,9%	19,3%	2,3%	1,6%
Agri-food	57,3%	9,3%	18,3%	5,9%	9,3%
Mobility	54,9%	16,7%	23,5%	3,1%	1,9%
Construction	48,1%	20,8%	22,2%	4,2%	4,6%
Aerospace	44,1%	11,8%	23,5%	11,8%	8,8%
Electronics	41,2%	20,6%	32,4%	0,0%	5,9%
Retail	38,9%	21,4%	22,1%	13,7%	3,8%
Textiles	37,5%	37,5%	25,0%	0,0%	0,0%
Proximity	23,6%	41,8%	29,1%	5,5%	0,0%

Source: Technopolis Group and Kapa Research, 2023

4. Digital technologies transforming the RES

4.1. Use of digital technologies by RES as revealed by text mining of company websites

The objective of the big data analysis in the RES ecosystem has been to measure the adoption of digital technologies. It aims to utilise large volumes of data for regular and up-to-date monitoring of the progress made by industries in their strategic choices to meet the 2030 targets and the adoption of basic to advanced digital technologies.

The analysis employs the OPIX platform, which utilises a selection of models specifically tailored to the RES industrial ecosystem and the technological scope of the analysis. The main data source for the analysis is the websites of companies within the RES ecosystem, namely the sectors of electricity, gas, steam, and air conditioning supply (EGSA), and manufacture of electrical equipment (MEE). **The analysis covers a sample of 6 001 companies, comprising a total of 1 897 516 website pages.** This sample is further divided into 83% SMEs and 17% large companies from the RES industrial ecosystem. Only companies with English content have been included in this particular analysis.

The scoping of the digital transition is based on the study's specific focus on advanced technologies and basic digital technologies as presented in the introduction. The analysis gives particular attention to advanced technologies such as Artificial Intelligence, big data, blockchain, cloud computing, and the Internet of Things (IoT).

Methodology

The methodological approach of the analysis is supported by models that utilise scientific and industry data corpuses specific to the RES industrial ecosystem. These models are designed to provide detailed insights into the scope of the digital transition pillar.

The models generate a list of High Priority Clusters (HPCs) that frame the digital transition pillar using key terms. This approach enables a high level of granularity in the analysis, allowing for a more precise understanding and interpretation of the activities undertaken by companies in the RES sector.

By utilising HPCs and their corresponding key terms, the analysis can set minimum thresholds for the presence and frequency of these terms within HPCs. These thresholds serve as qualifying criteria for companies. Overall, the use of models based on scientific and industry data corpuses, combined with the identification of HPCs and key terms, provides a robust and systematic approach to analyse the digital transition pillar within the RES industrial ecosystem.

Results

The digital interaction of the RES industrial ecosystem is relatively high which is demonstrated by the fact that approximately **54% of RES companies in the analysis have a social media account and 59% of RES companies have a website of more than 10 pages.**

The digital transition of the RES industrial ecosystem is notable, with advanced technologies such as the Internet of Things (IoT), Big Data, and Artificial Intelligence (AI) playing significant roles.

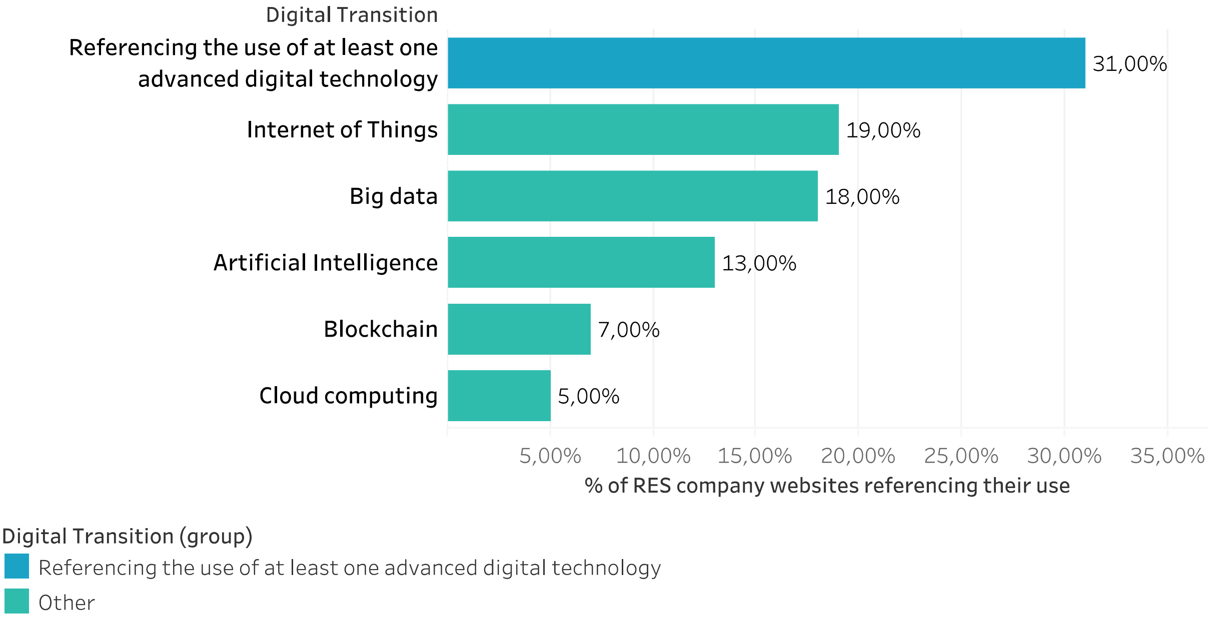
In terms of adoption, **IoT holds a share of approximately 19%, indicating its widespread use in the RES industrial ecosystem**. IoT enables the interconnection of various devices and systems, and it is found predominantly in applications of smart homes and smart factories.

Big data follows closely with a share of around 18%. The use of big data in the RES ecosystem revolves around collecting and analysing large volumes of data to gain insights and make informed decisions. The most common applications of big data are associated with intelligent energy management and energy consumption optimisation. By leveraging data analytics, companies can identify patterns, trends, and anomalies in energy usage, leading to more efficient operations.

Artificial Intelligence in use has been mentioned on 13% of RES company websites. Artificial Intelligence technologies help optimise production processes, reduce downtime, increase efficiency, and enhance safety measures across the RES.

Blockchain technology also plays a role in the RES sector, primarily in smart energy management systems and energy automation. Additionally, blockchain is associated with home energy management, facilitating decentralised energy systems and enabling better control and optimisation of energy consumption at the household level.

Table 4 Digital transition of the RES industrial ecosystem: share of RES companies referencing the use of digital technologies on their websites



Source: Technopolis Group, based on Opix's big data services

A comparison between SMEs and large companies shows that SME in manufacturing of electrical equipment relate more to the use of Internet of Things and big data, whilst large companies relate more to the use of Artificial Intelligence, blockchain and cloud computing. Large companies of the electricity, gas, steam, and air conditioning supply sector indicated an interest for blockchain and the Internet of Things, whilst SMEs indicated more focus on big data, AI and cloud computing.

The examples cited below provide some further insights regarding the use of digital technologies across the RES (see Table below).

Table 5 Digital Transition – Company Examples (non-exhaustive)

Examples of Artificial Intelligence applications	
"Siemens Energy is using artificial intelligence to enhance power plant performance and reduce operational costs. They have developed GT Auto Tuner, which utilizes reinforcement learning algorithms to optimize combustion control and minimize seasonal tuning. Additionally, they offer Intelligent Controller packages for gas turbines that incorporate a trained neural network-based control policy"	"Capital Energy has been investing heavily in Artificial Intelligence (AI) technology to improve its operations and decision-making processes. The company's AI systems analyse vast amounts of data from various sources such as sensors, cameras, and other devices installed across its facilities. This information helps Capital Energy optimise its production processes, reduce downtime, increase efficiency, and enhance safety measures. Additionally, the company also leverages machine learning algorithms to predict

Examples of Artificial Intelligence applications	
	future trends and make informed decisions based on historical patterns and real-time data analysis. Overall, Capital Energy's use of AI technology has enabled it to stay ahead of competition while ensuring maximum productivity and profitability"
"Solarig is a leading provider of Artificial Intelligence solutions for renewable energy companies globally. The company's AI algorithms enable its clients to optimize their operations and reduce costs through predictive analytics and automation. Solarig's proprietary software platform ICARUS leverages machine learning techniques to detect anomalies in PV module performance and identify potential failures before they happen. Additionally, the company offers advanced drone inspection services powered by computer vision algorithms that can quickly scan large areas of solar farms and pinpoint specific issues that need immediate attention. Overall, Solarig's AI-based O&M solutions help its clients maximise ROI while minimising downtime and risk"	"Wind-Consult is a German consulting firm specialising in renewable energy systems that focuses on developing sustainable solutions using artificial intelligence (AI). They use AI algorithms such as deep learning and neural networks to analyse large amounts of data from wind turbines and other sources to improve their efficiency and reduce costs"
"NLCoustics specialises in developing innovative solutions based on artificial intelligence (AI) technology for various industries including power generation, transmission & distribution, oil & gas, renewable energies, transportation, and manufacturing. One of their flagship products, the NL Camera, is designed specifically for partial discharge detection in electrical assets through ultrasound analysis. This tool allows customers to identify potential faults early on, prevent downtime, reduce costs associated with repairs and maintenance, and improve overall safety standards. Additionally, the NL Camera comes equipped with intelligent features like automated filtering, phase resolved partial discharge patterns recognition, and severity assessments via machine learning algorithms which enable accurate evaluation and follow-up of detected partial discharges. Overall, NLCoustics' commitment to providing cutting edge technology backed by expertise and support makes them a trustworthy partner for businesses looking to optimize their operations and stay ahead of the competition"	"B-ECO Srl is an Italian company specialised in the design and installation of innovative systems for the optimization of energy resources in buildings. With over 20 years of experience, B-ECO provides complete solutions for the construction industry, ranging from photovoltaics to geothermal energy, from heat pumps to ventilation systems, from solar panels to LED lamps, from home automation to smart grids. Thanks to its expertise in the field of artificial intelligence, B-ECO has developed advanced algorithms capable of analysing large amounts of data generated by sensors installed throughout the building, allowing for optimal control of energy flows and maximizing energy savings"

Source: Technopolis Group, based on Opix's big data services.

4.2. Digital tech companies transforming the renewable energy ecosystem

Technology startups represent key building blocks in the transition towards a more digital, green and resilient economic model. Entrepreneurial activity helps accelerate the diffusion of technologies in industrial ecosystems and startups that provide green and digital mobile solutions are relevant indicators of how the industrial ecosystem is transforming itself to reach environmental sustainability objectives. This section analyses technological and innovative startups based on companies active in the renewable energy ecosystem sourced from the Crunchbase and Net Zero Insights database. Net Zero Insights focuses on capturing sustainability-driven startups and covers widely the innovations developed in the context of the green transition. This analysis allows us to identify the energy fields where entrepreneurs are the most active. More specifically, the analysis identifies also the type of digital tech companies that are providing digital solutions for the RES ecosystem.

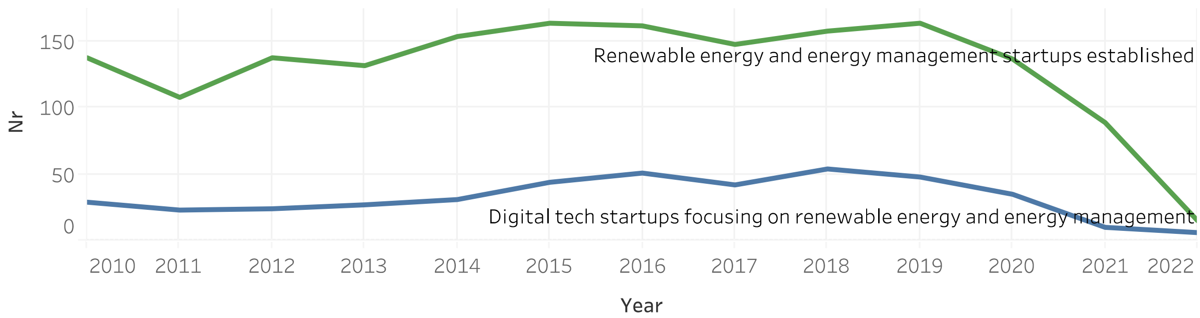
Inherent characteristics of the traditional energy sector, such as the super centralised energy systems and high capital costs, have historically left startups playing a minor role in the energy sector.[47] However, the climate urgencies that have pushed the transition towards a cleaner energy system, the aim of avoiding energy dependencies on third countries like Russia, and the regulatory framework, are favouring the transition to a more decentralised energy model that has opened the door to startups to play a major role in the energy sector.

Although with different approaches, the evolution of energy startups has already been studied by the International Energy Agency (IEA).[48] The results indicate that the number of energy-related startups globally has been stable over the last decade but with a marked drop since 2020.[49] However, it should be noted that the IEA report and other consulted studies have a sectoral approach and look at the entire energy sector, including companies innovating in the fossil fuels field, electric vehicles infrastructure and other non-renewable energy-related startups.

In this project, startups have been captured that support the clean energy transition and can be classified based on their energy focus. In particular, the analysis focused on solutions such as **renewable energy generation, energy storage technologies and energy management technologies**. To this end, tech firms that develop digital technologies and environmental sustainability solutions have been linked to the energy industrial ecosystem following their industrial classification and keyword search within the business descriptions. In the second step, we investigated how these companies used advanced digital technologies to support their solutions.[50]

Figure 17 presents the evolution of startups engaged in the energy transition as well as the number of those startups using advanced digital technologies. The overview indicates a positive trend in the number of established startups since 2010. There is also an increase in the share of **startups that rely on digital technologies to deliver solutions focused on the energy transition.** The downtrend observed since 2019 can be attributed to the time it takes for a startup to become visible in the consulted databases.

Figure 17: Renewable energy and energy management startups and digital tech companies with a clean energy focused established over time



Source: Technopolis Group based on Crunchbase and NetZero Insights, 2023

Zooming into the focus of the startups in scope allows us to make further observations. As illustrated in the Figure below, the **relative share of energy management technologies, biofuels and photovoltaic within the full portfolio of clean energy tech companies have declined in favour of technologies such as wind energy, hydrogen and geothermal energy**.

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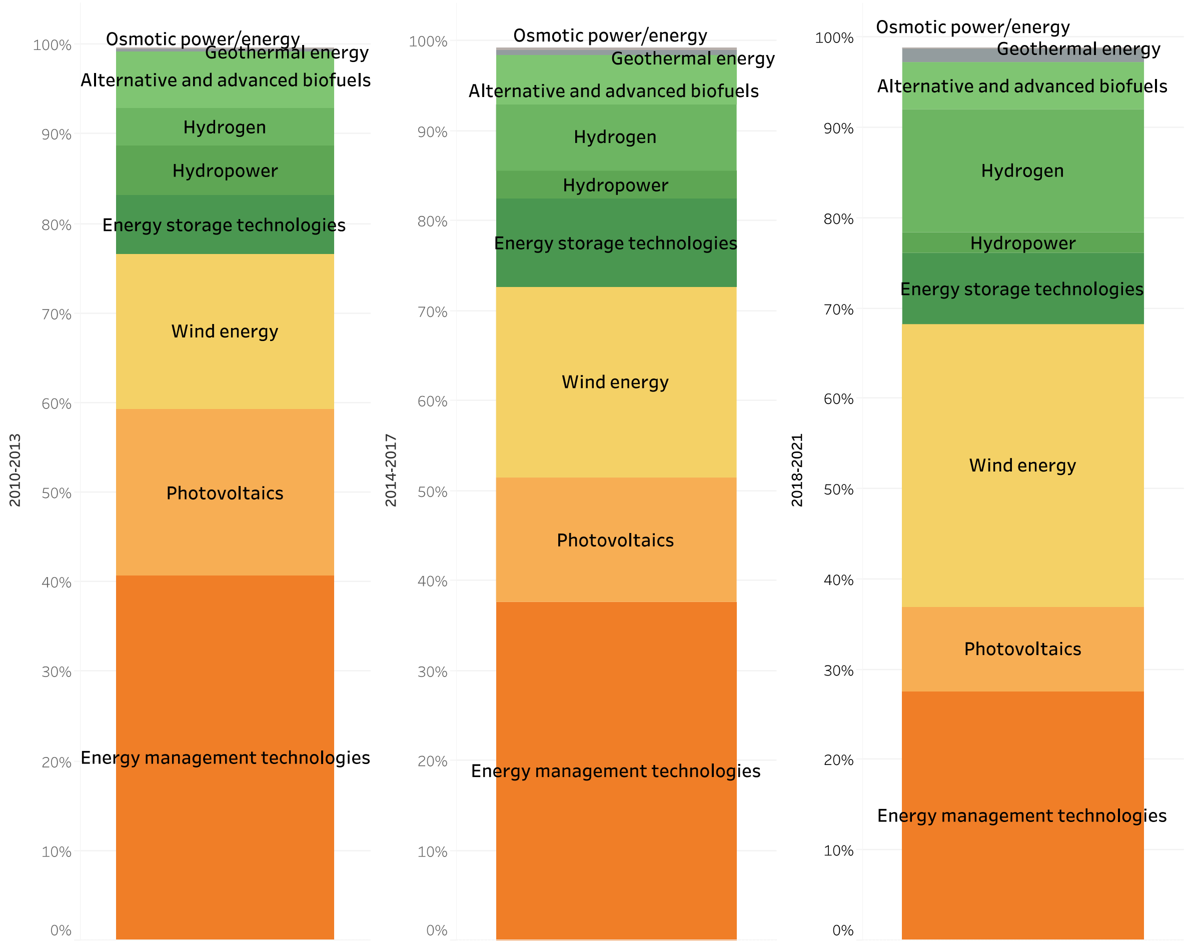
[47] Gaddy, B. E., V. Sivaram, T. B. Jones, and L. Wayman. 2017. "Venture Capital and Cleantech: The Wrong Model for Energy Innovation." Energy Policy 102: 385–95.
[48] International Energy Agency
[49] https://technation.io/emerging-energy-tech-report-2022/#foreword
[50] In the scoping phase of this exercise, the study team developed a taxonomy of energy fields and digital technologies against which we have executed our analysis.

As it is illustrated in the Figure below, 36% of the startups established since 2010 offer solutions that **improve energy management**. Within this category are mainly companies offering energy efficiency technologies for civil and industrial users, smart grid solutions tackling analytics, infrastructure monitoring, service platforms, and optimisation of energy distribution. 45% of these companies use advanced digital technologies as part of their solutions. For example, the company Enerbrain[51] has developed IoT-powered hardware and a cloud-based monitoring solution that fine-tunes energy usage in real-time, allowing 30% operational savings[52].

Although the yearly number of established startups has remained stable, the share of startups developing energy management solutions has decreased over time, moving from 37% for 2010-2013 to 25% for 2018-2021. This is mainly due to the increase of startups focused on energy storage solutions, wind energy and hydrogen.

Wind energy focused startups have been increasingly relevant, accounting for 31% of the sample from 2018-2021. The type of services offered by startups under this category ranges from less capital-intensive companies that mainly focus on developing wind projects, to more innovative companies using advanced digital technologies. For instance, Gevi is a developer of high-performance wind turbines with active blade pitch and an Artificial Intelligence software self-specialising in multiple places and wind conditions[53].

Figure 18: Distribution of startups based on the energy field they tackle



Source: Technopolis Group based on Crunchbase and NetZero Insights, 2023

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[51] https://www.enerbrain.com/
[52] https://www.enerbrain.com/en/enerbrain_services/energy_monitoring/
[53] https://www.geviwind.com

Startups focused on the field of **hydrogen** have also notably increased in the last years, with an average year growth of 25% since 2017. For example, the company H2Greem develops and manufactures hydrogen generators based on Proton Exchange Membrane (PEM) technology[54].

Digital tech startups

Digital tech startups and tech firms offer a range of analytical and other digital technology-based services for the energy transition. Many companies are leveraging big data analytics to improve energy efficiency by predicting energy demand, optimising grid operations, and enable predictive maintenance of energy assets. By analysing data such as weather forecasts and human behaviour captured by sensors and smart meters and updated in real-time, these startups optimise energy consumption, identify anomalies, inform users of potentially greener behaviour, and enhance overall energy management. In many cases, companies using big data also use AI to support and improve their predicting capabilities and cloud-based platforms to process and visualise the collected data. Moreover, IoT-powered sensors are key in the data collection phase.

Big data and data analytics represent a key segment notably 32.6% of the energy startups established since 2015 as illustrated in Figure 19. For instance, the Bulgarian company GridMetrics[55] is an analytics firm that uses self-learning algorithms to improve the processes of companies with grid-like infrastructure.

Artificial Intelligence is increasingly used to address clean energy challenges as already described above. Specialised digital tech firms include for example Accure[56] that is a battery analytics company with software and AI-driven solution assisting the monitoring of battery systems. Another example is Dexter[57] that offers forecasting and dispatching solutions based on AI and cloud-based technology. It provides load and imbalance time-series forecasting throughout the trading cycles by combines large amounts of different external data sources (such as weather data) with customer data (historic time-series).

Figure 19: Type of digital technologies that energy startups can be linked with

Technology	
Big Data	32,6%
Artificial Intelligence	22,0%
Internet of Things	21,7%
Cloud technologies	10,6%
Robotics and automation	9,6%
Blockchain	3,5%

Source: Technopolis Group based on Crunchbase and NetZero Insights, 2023

Startups are leveraging **the Internet of Things** for the purposes of energy optimisation and grid integration, remote monitoring and management, predictive maintenance, and energy trading (21%). IoT devices and sensors provide real-time data on energy consumption, equipment performance, and environmental conditions, enabling efficient energy usage, predictive maintenance, and demand response capabilities. This is the case of Sferalab, an Italian 2016 startup[58], developing control panels for energy management

[54] http://h2greem.com
[55] https://www.gridmetrics.co
[56] https://www.accure.net/
[57] https://dexterenergy.ai/
[58] https://www.sferalabs.cc/energy-management/

for renewable energy generation, such as photovoltaics. To monitor and control energy generation/management systems, Sferalab uses Sigfox's IoT sensors and communication systems. Sigfox is a French 2010 startup in the IoT and wireless developer for industrial applications.[59]

Robotics and automation are also relevant and can play a significant role in various aspects, with inspection being the most relevant among European startups. For instance, drones and robotic systems are employed in wind energy and solar plants for turbine and panels inspection, reducing the need for manual and potentially risky maintenance tasks. For example, the Spanish company Alerion[60] has developed fully autonomous and intelligent drones that enable real-time infrastructure inspections of offshore windfarms, including the treatment of the monitored data and processing to digital twins.

[59] https://www.sigfox.com/use-cases/utilities-energy/
[60] https://aleriontec.com

5. Venture capital investment into energy startups

Venture capital investment into clean energy startups has sharply increased in recent years[61]. The analysis of Net Zero Insights and Crunchbase allows to capture investment information and funding rounds of startups and innovative companies developing solutions for the energy transition. The investment figures presented in this section refer only to the funding rounds where a value has been disclosed.

The last few years have been a period of extreme disruption for the energy sector. The global energy crisis in parallel to the increased scientific evidence of the climate emergency can justify the sharp increase in investments across different energy subsectors[62].

There is consensus among recent studies that global clean energy investments are on the rise, having reached USD 1600 bn in 2022, led by renewables and energy efficiency technologies (ibid). Venture Capital has also boom, especially since 2021, when a sharp increase happened both in early and late stages. According to the same study, most of the global VC funding for energy technologies has flowed to US-based start-ups, with Europe holding a strong presence in hydrogen and China active in mobility and batteries.

As depicted in Figure X, also European Early investment stages including Seed and Early VC and Late development has been on the raise since 2010, booming in 2021 and 2022. This sharp increase is led by alternative and advanced biofuels/alternative fuels, photovoltaics, and hydrogen focused startups.

Early investment in companies developing **advanced biofuels/alternative fuels** grew 228% on average during the period 2017 to 2022. For instance, Ineratec is a German startup founded in 2016 that provides sustainable fuels, gas-to-liquid, power-to-gas and power-to-liquid application products. In 2022, it raised EUR 21 m through a Series A round. Late investment has also been consistently increasing since 2019, reaching a total of €449 m in 2022.

Seed and Early development investment towards companies developing solutions around the **hydrogen** field had a sharp increase since 2019, with an average year growth of 330% from 2019 to 2022 and gathering a total of €567 m by 54 companies. Some of these companies started gathering Late development investments as of 2020, what points out to a positive evolution. Looking at the top areas of focus of the invested hydrogen companies include electrolysis and hydrogen production, hydrogen-powered mobility solutions for commercial vehicles, and design and manufacturing of fuel cell systems and power generators that use hydrogen as a clean source of electricity.

As an example of funding progression, founded in 2017, Lhyfe[63] is a provider of production units for hydrogen production, distribution, and storage by utilizing locally available renewable energy sources, such as wind and solar power, to produce hydrogen through electrolysis. It has been hydrogen produced is then used in industrial sector and fuel cell vehicles, providing a clean and efficient source of energy for transportation. It has been involved in four funding rounds since 2020, gathering a total of €85 m in early VC and went public through and IPO of €110 m in the second quarter of 2022.

Startups developing **energy storage technologies**[64] also show a positive market acceptance having increased their annual early funding 83% on average since 2017. Late investments have been increasing sharply 2018, reaching a total of €1.84 bn in 2022.

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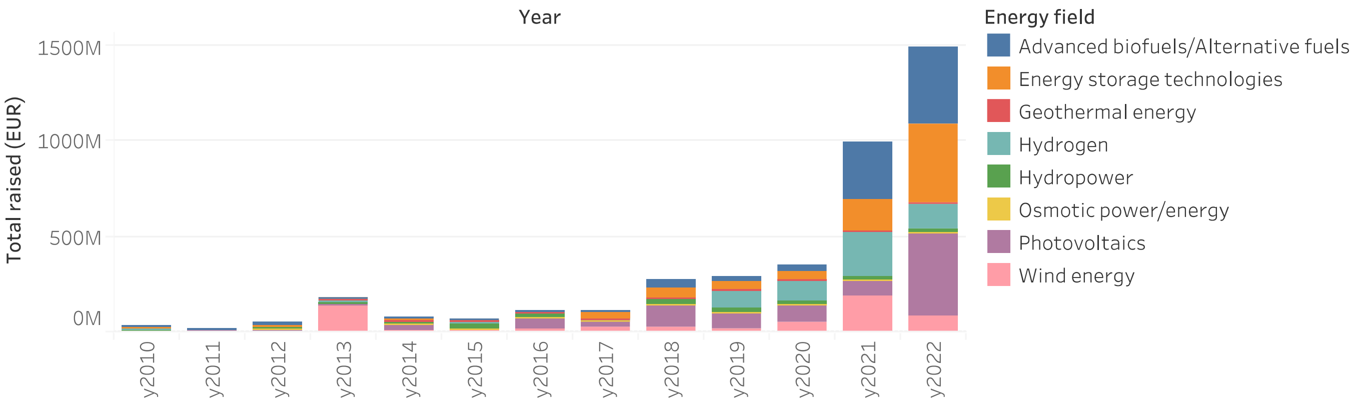
[62] https://iea.blob.core.windows.net/assets/8834d3af-af60-4df0-9643-72e2684f7221/WorldEnergyInvestment2023.pdf

[63] http://www.lhyfe.com

[64] Within this category we include any company developing solutions related to power storage systems, batteries, advanced and efficient materials, high-performance ultracapacitors, etc,.

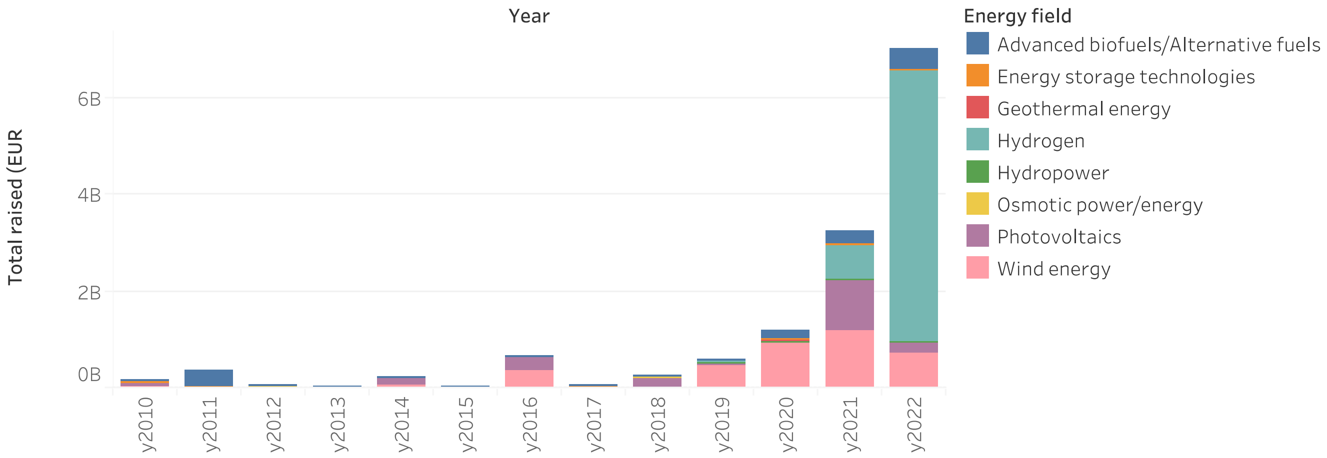
Early investments into companies developing **photovoltaics** services or solutions have been consistent although with fluctuations over time, having a sharp increase in 2022 reaching €431 m. An interesting observation that emerges looking at the type of companies behind this field is the increasing presence of providers of off-grid solar solutions for residential applications. Since 2015, a total of €1.67 bn was invested in these companies type of companies, with an average annual growth of 234%. An example of this is the German producer of solar-hydrogen rooftop system Home Power Solutions[65], which has participated to six founding rounds since 2018, absorbing a total of €69 m.

Table 6 Evolution of seed and early development investments into clean energy companies



Source: Technopolis Group based on Crunchbase and NetZero Insights, 2023

Table 7 Evolution of late and exit investment into clean energy companies



Source: Technopolis Group based on Crunchbase and NetZero Insights, 2023

[65] https://www.homepowersolutions.de

Appendix A: References

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Appendix B: Methodological notes

FDI analysis

Table 8: Selected sectors included in the FDI analysis

Sector	Sub-sector
Renewable energy	Other electric power generation (Renewable Energy)
	Solar electric power
	Wind electric power
	Biomass power
	Hydroelectric power
	Geothermal electric power
	Marine electric power

List of energy fields and digital technologies in the scope of the Startup and VC analysis

Energy fields	Digital transition
Advanced biofuels and alternative fuels	Artificial Intelligence
Energy storage technologies	Big Data
Geothermal energy	Blockchain
Hydrogen	Cloud and other software
Hydropower (including tidal/wave energy)	Internet of Things
Osmotic power/energy	Robotics and automation
Photovoltaics	
Energy management technologies	

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