European Commission

Mapping of Technology Infrastructures supporting **Clean and Renewable Energy Industries in Europe**

Independent Expert Report

Research and Innovation

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Mapping of Technology Infrastructures supporting **Clean and Renewable Energy Industries in Europe**

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2024 Directorate-General for Research and Innovation

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EXECUTIVE SUMMARY

The European Union has set ambitious targets to become a climate-neutral economy by 2050. The clean and renewable energy industries (CREI) sector is crucial for achieving these targets. This report, based on a data-driven approach and using a web scraping methodology, provides a mapping of nearly 1400 technology centres, and the Technology Infrastructures they host, supporting the development of seven CREI technologies (solar photovoltaics, wind energy, heat pumps, batteries, electrolysers, advanced biofuels and CCS/CCU) and the corresponding ecosystem of around 16.000 companies in the CREI sector across the EU. These technology centres, thanks to the Technology Infrastructures they host, play a crucial role in advancing CREI technologies, particularly at later stages of their development. They provide support for technology validation, prototype demonstration, and system integration, which are critical for the commercialization of new technologies.

The analysis shows that **there is a very strong correlation at regional level between the number of technology centres and companies active in CREI technologies**, highlighting the importance of technology centres in supporting the development of industries and companies in the CREI sector. This suggests that technology centres play a key role in supporting the development of industries and companies in the CREI sector by providing access to facilities, expertise, networks, and resources. However, all types of Technology Infrastructures show a significant level of concentration in a limited number of regions.

Concentration and colocation patterns indicate specific European hotspots with a high concentration of industries and companies as well as technology centres active in CREI technologies, such as the metropolitan areas of Germany, Italy, Spain, France and Sweden. Some concentration, though at a much smaller scale, is also observed in metropolitan areas of Poland, Czechia, Romania and Bulgaria. At the same time, in many EU regions, the presence of technology centres and the related companies is marginal, showing an important innovation divide in CREI technologies.

The report highlights that **the distribution of technology centres also depends on the specific CREI technology considered**. Some countries established themselves as leaders in the development of specific CREI technologies, such as solar photovoltaics and wind energy in Germany, and advanced biofuels in Spain. Such a specialization pattern can also be identified at a regional level.

The analysis shows that **the technology readiness levels (TRLs) supported by technology centres vary across CREI technologies.** While most technology centres are active in TRL 5-6-7, some technologies such as advanced biofuels and CCS/CCU have a higher share of technology centres active in lower TRLs. As these are the least advanced among the CREI technologies, this suggests that technology centres and their technology infrastructures adapt their services to the general maturity level of a specific technology in order to better support the user needs.

Among the different categories of Technology Infrastructures identified, **the study showed that the most frequent type available in the EU are testbeds** (1027), followed by digital infrastructures (654), pilot plants (616) and demonstrators (537). The count is significantly lower for living labs (267) and cleanrooms (166) as they require extensive partnerships with communities, businesses, and governments for the significant investments needed to design, construct, and maintain them. In particular, the latter two types of infrastructures are only available in very few EU regions, which poses particularly important questions on their **accessibility for companies based in other parts of the EU**.

The report also highlights **the importance of regional innovation ecosystems**. A high concentration of technology centres and companies active in CREI technologies is often found in regions with a higher level of innovation and entrepreneurship, which is critical for the development of new technologies.

Overall, this report demonstrates the importance of technology centres in advancing CREI technologies and supporting the development of industries and companies in the CREI sector. With regard to the **significant imbalance in the availability of the Technology Infrastructures in the EU**, it suggests the need for a coordinated approach to support the development of such infrastructures across the EU, and to facilitate access for companies to their resources, expertise and networks.

At methodological level, this report successfully tested an effective operational framework to conduct a comprehensive mapping of Technology Infrastructures across the EU that could be replicated for other types of technologies.

1. Study approach and methodology

This report is part of the framework of the "Support to Assessment and Monitoring of Industrial Research, Innovation and Technologies in the field of clean/renewable energy industries (CREI) and of other industries in relation to the European Green Deal and the green transition".

This study aims to map technology centres that provide advanced technology infrastructures and their services for industry across the 27 EU Member States, encompassing the seven key technology domains of Clean and Renewable Energy Industries (CREI).

Through a data-driven approach and using a web scraping methodology, the study team presents the distribution of the different technology centres, including their respective Technological Readiness Levels (TRLs). In addition, it gives an estimation number of different types of technology infrastructures available in the EU, such as testbeds, pilot lines, or cleanrooms, active in the CREI technologies.

This analysis is intended to inform policymakers about potential gaps, and to compare the provision of technology infrastructures in technology centres active in Clean and Renewable Energy Industries (CREI) technologies among the EU Member States.

The results of this pilot exercise demonstrate the added-value and feasibility of using web scraping approaches to map the activities of technology centres. The same methodology can be used to map activities of technology centres in other sectors or industrial domains.

1.1. Methodology and data sources

In order to map and count technology infrastructures of technology centres active in Clean and Renewable Energy Industries (CREI) across the 27 EU Member States, the study team **compiled a database of technology centres** active in the European Union. It includes the following data sources:

- Technology centres that are part of the **European Monitor of Industrial Ecosystems (EMI)**[1]**:** Technology centres in this database are public or private organisations carrying out applied research and close-to-market innovation in digital, green and other advanced technologies. It contains 394 centres which comply with three qualitative criteria for inclusion to the database: 1) providing services to industry and SMEs, 2) being active in at least one of the Advanced Technologies for Industry, and 3) being active in the higher Technology Readiness Levels (TRL5, TRL6, TRL 7 or TRL 8); and with at least 2 quantitative criteria[2].

- Active members of the **European Network of Living Labs (ENOLL)**[3]**:** ENoLL is the international, non-profit, independent association of benchmarked Living Labs. The members of this network are living labs, which provide real-life test and experimentation environments that foster co-creation and open innovation. The study team included in the database of technology centres the full set of 119 living labs that are part of this network, and located in one of the EU-27 Member States.

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1 https://monitor-industrial-ecosystems.ec.europa.eu/technology-centre/mapping

2 See https://monitor-industrial-ecosystems.ec.europa.eu/about/what-is-emi

3 https://enoll.org/network/living-labs/

- Catalogue of the **European Digital Innovation Hubs (EDIH)**[4]: European Digital Innovation Hubs (EDIHs) are one-stop shops supporting companies and public sector organisations to respond to digital challenges and to become more competitive. EDIHs support companies to improve business/production processes, products, or services using digital technologies by providing access to technical expertise and testing, providing innovation services, and helping companies tackle environmental issues. At time of extraction, the catalogue contained 405 EDIHs.

- EU-funded projects on **Open Innovation Test Beds (OITBs)**[5]: The study team takes into account 28 EU-funded projects that serve as open innovation test beds in various fields related to advanced materials, such as climate neutral and circular innovative materials, nano-enabled bio-based materials, nano-enabled multifunctional composite materials, and nano-enabled surfaces and membranes. The study team identified 312 public organisations that participated in these projects.

- **In-house database of technology centres**: the study team also relied on a database of technology centres that has been compiled through desk research within the framework of the Advanced Technologies for Industry[6] project commissioned by the Directorate-General on Internal Market, Industry, Entrepreneurship and SMEs (DG GROW). This database contains more than 2000 technology centres in EU Member States that are active in advanced technologies such as Advanced materials, Advanced manufacturing Technologies, Artificial Intelligence, Augmented and Virtual Reality, Big data, Blockchain, Cloud technologies, Connectivity, Biotechnology, the Internet of Things, Micro- and nanoelectronics, IT for Mobility, Nanotechnology, Photonics, Robotics and Security.

After removing duplicates within and across these data sources, a **final list of 2885 potential technology centres** was compiled. Starting from this potential list, the study team aimed to identify which of these centres are active in CREI technologies and have technology infrastructures. A second objective consisted of counting the number of technology infrastructures per centre. Finally, the technology centres were located as to analyse their distribution at NUTS-2 region level and discern colocation patterns with CREI companies. As none of this information is codified in existing databases, the study team exploited information on the technology centres' websites using web scraping tools and advanced data analytics.

Figure 1 presents the steps that have been taken to identify, count and geolocate technology infrastructures of technology centres active in CREI technologies.

4 https://digital-strategy.ec.europa.eu/en/activities/edihs

5 https://op.europa.eu/en/publication-detail/-/publication/bc29de66-7586-11eb-9ac9-01aa75ed71a1/language-en

6 https://op.europa.eu/en/publication-detail/-/publication/5976f0f1-308a-11ec-bd8e-01aa75ed71a1/language-en

Figure 1: Methodology to map and count technology infrastructures of technology centres active in clean and renewable energy industries

Step 1: Identify technology centres that have technology infrastructures

Objective: Obtain an overview of technology centres that mention technology infrastructures on their website.

Methodology: Web scraping of technology centres' website in search for "technology infrastructure" related keywords (see Section 1.2.1 for more information).

Step 2: Categorise which of the technology centres with infrastructures are active in CREI technologies

Objective: Obtain an overview of technology centres that have technology infrastructures and that are active in CREI technologies.

Methodology: Web scraping of technology centres' website in search for "CREI technology" related keywords (see Section 1.2.2 for more information).

Step 3: Count how many infrastructures technology centres mention on their websites

Objective: Obtain an overview of the number of technology infrastructures per technology centres (for those that are active in CREI technologies and mention technology infrastructures on their websites).

Methodology: Advanced data analytics with ChatGPT to count the number of technology infrastructures on technology centres' website (see Section 1.3 for more information).

Step 4: Locate technology centres at NUTS-2 region level

Objective: Map technology centres at regional level in order to compare their colocation with CREI companies.

Methodology: Geolocation of technology centres using Google Places API and Google Geocoding API (see Section 1.4 for more information).

Source: Compiled by the authors.

1.2. Technology centres with technology infrastructures and active in CREI technologies

1.2.1. Technology infrastructures

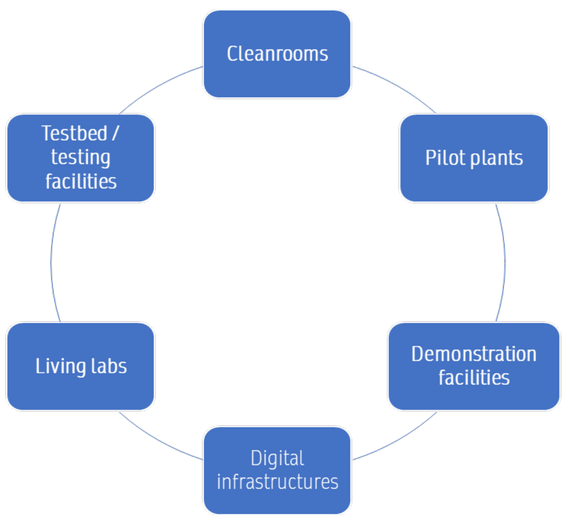
The presence of advanced technology infrastructures is crucial for the creation of innovative technology-driven products and services. Such infrastructures play a pivotal role in mitigating risks associated with testing the feasibility of new concepts and in reducing the time it takes to bring products to market. Furthermore, they facilitate access to external expertise, enhance the ability to evaluate growth prospects in emerging product and service offerings, and catalyse efforts towards compliance with standards and the development of new testing and certification protocols.

Technology infrastructures are defined as "*facilities, equipment, capabilities, and support services required to develop, test and upscale technology to advance from validation in a laboratory up to higher TRLs prior to competitive market entry. They can have public, semi-public or private status. Their users are mainly industrial players, including SMEs, which seek support to develop and integrate innovative technologies towards commercialisation of new products, processes and services, whilst ensuring feasibility and regulatory compliance*" (European Commission, 2019, p. 5).

In line with this definition, Viscido et al. (2022) describe technology infrastructures as (physical or virtual) facilities and equipment, such as demonstrators, testbeds, piloting facilities and living labs, capable of building bridges between science and the market. They are mostly created, managed, maintained and upgraded by Research Performing Organisations (mainly Research and Technology Organisations – RTOs, and Technical Universities – TUs), which require dedicated and significant resources and competences.

Taking stock of the above policy reports as well as analytical reports on the role of technology centres in the context of Advanced Technologies for Industry (Van de Velde et al., 2021) and the European Monitor of Industrial Ecosystems (Van de Velde & Boschmans, 2023; Van de Velde et al., 2023), the study team classified the technology infrastructures in six categories for the purpose of this study as depicted in Figure 2.

Figure 2: Types of technology infrastructures



Source: Compiled by the authors based on literature review.

The six categories can be defined as follows:

- Testbeds or test facilities: “Testbeds can be described as experiments to develop, test and upscale a product or service in a dedicated environment. The focus of the experiment is mostly technical. It is common for testbeds to feature access to dedicated research and technology infrastructures, and to support and advise. Funding is also often provided in order to support experimentation.”[7]

- Cleanrooms: “A cleanroom is a room in which the concentration of airborne particles is controlled, and which is constructed and used in a manner to minimize the introduction, generation, and retention of particles inside the room, and in which other relevant parameters, for example, temperature, humidity, and pressure, are controlled as necessary”.[8]

- Pilot plants: “A pilot plant is a small-scale, operational system or facility that is designed to replicate and simulate key aspects of a larger industrial process. It serves as an intermediate step between laboratory-scale research and full-scale commercial production, and focuses on process development and optimization. The primary purpose of a pilot plant is to gather valuable data, assess the feasibility and efficiency of a process, and identify potential challenges before committing to large-scale implementation.”[9]

- Demonstration facilities: “A demonstration plant or facility is a scaled-up, operational unit designed to showcase and test a particular industrial process or technology before full-scale commercial implementation. It serves as an intermediate step between laboratory-scale research and full-scale production, and aims to demonstrate the commercial viability of a new technology and/or process. The primary purpose of a demonstration plant is to validate the feasibility, efficiency, and practicality of a new technology or process in real-world conditions.”

- Digital infrastructures: Digital infrastructures are digital environments designed for conducting experiments, tests, or simulations in various fields, including technology, science and engineering. They provide researchers and developers with a platform to explore and validate hypotheses, prototype new technologies, or assess the performance of systems in a controlled and reproducible manner.

- Living labs: “Living labs are a widespread experimentation tool to co-create, prototype, test and upscale innovative solutions to (local) needs in real-life settings. One of their distinguishing features is the involvement of citizens as well as several other stakeholders and the end-users as co-creators during the entire experimentation process. The type of evidence generated by living labs is socio-technical and makes it possible to explore the effect of an innovation on users and society, thus leading to better calibration of requirements”.[10]

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[7] Commission Staff Working Document, 2023, Regulatory learning in the EU: Guidance on regulatory sandboxes, testbeds, and living labs in the EU, with a focus section on energy, https://data.consilium.europa.eu/doc/document/ST-12199-2023-INIT/en/pdf

[8] https://www.sciencedirect.com/topics/engineering/cleanroom

[9] Hellsmark, H., Frishammar, J., Söderholm, P., & Ylinenpää, H. (2016). The role of pilot and demonstration plants in technology development and innovation policy. Research Policy, 45(9), 1743-1761.

[10] See also the European Network of Living Labs (ENoLL): https://enoll.org/about-us/

Based on the above definitions and desk research on policy reports[11], the study team has produced a list of 109 technology infrastructure keywords to be used in step 1 of the project. This list is as comprehensive as possible, in order to define and capture the different labels of technology infrastructures. The list of keywords is presented in Table 1, by category of technology infrastructures (in bold).

Table 1: Keywords related to technology infrastructures

Technology infrastructure keywords		
Test bed / testing facilities	test centre	demonstration facility
test bed	test environment	demo
test room	test equipment	demonstration site
innovation test bed		demonstrator
open innovation test bed	**Cleanrooms**	
testing capability	cleanroom	Living labs
testing equipment		Living lab
testing facility	**Pilot plants**	living test bed
testing room	pilot plant	innovation lab
technology lab	pilot capability	
R&D facility	pilot centre	**Digital infrastructures**
experimentation facility	pilot facility	online test bed
experimenting facility	pilot line	virtual test bed
hub	piloting facility	virtual environment
validation facility	prototyping lab	virtual testing
key technology facility		simulated environment
open innovation facility	**Demonstration facilities**	digital laboratory
physical facility	demonstration plant	virtual experimentation
technology infrastructure	demonstration capability	virtual prototyping system
technology platform	demonstration environment	virtual facility

Note: Spelling variants and plural forms are also included as keywords. They are not displayed in the table for space-saving purposes.
Source: Compiled by the authors based on literature review.

At first instance, only keywords in English have been produced. However, not all websites of technology centres could be found in English. Therefore, in order to be able to scrape those websites, ChatGPT was used to translate technology infrastructure keywords in the 10 most frequent European languages of the non-English websites (i.e. Spanish, French, German, Italian, Swedish, Polish, Dutch, Portuguese, Finnish and Danish). As such, around 85% of the websites in foreign languages could be added to the web scraping. Members of the study team who have a native language other than English, made a validity check of the translation (e.g., Dutch, French, Italian and Portuguese).

1.2.2. CREI technologies

For the demarcation of CREI technologies, the study team takes stock of the definitions used in the Clean Energy Technology Observatory (CETO)[12], a joint initiative between the

[11] EARTO, 2022, EARTO Case Studies on Technology Infrastructures https://www.earto.eu/earto-case-studies-on-technology-infrastructures/

[12] https://energy.ec.europa.eu/topics/research-and-technology/clean-energy-competitiveness_en

European Commission's Joint Research Centre, implementing the observatory, the Directorate-General for Research and Innovation and the Directorate-General for Energy, which offer their support on the policy side. In addressing the Net-Zero industry, seven categories of clean/renewable energy technologies are identified:

- Solar photovoltaics
- Wind energy
- Heat pumps
- Batteries
- Electrolysers
- Advanced biofuels
- CCS/CCU

The study team followed a keyword-based approach to define CREI technologies in line with a prior study of Van de Velde et al. (2023), compiling a list of around 30,000 CREI technology related keywords from patent titles and abstracts with CREI-related CPC codes. While this extensive list of keywords is highly relevant to identify companies active in CREI technologies based on their patenting activities, it remains too technology-specific for web scraping purposes, with the first results showing that many technology centres were active in CREI technologies. This is caused by the fact that if one of the 30,000 keywords was found on a website, the corresponding technology centre was classified as active in CREI. For this reason, the study team opted for a more restricted and targeted **list of 32 CREI keywords** depicting the most relevant technologies in each CREI category, using a more user-centred approach. The new compilation was based on desk research through the analysis of prior studies in this domain such as the CETO reports mentioned above, as well as the use of recurrent terms mentioned on the websites of some of the largest technology centres in Europe such as VTT, Tecnalia, CEA and TNO. The list of CREI-related keywords is presented in Table 2.

Table 2: Keywords related to clean and renewable energy technologies

Keywords related to clean and renewable energy technologies		
Solar photovoltaics	**Batteries**	**CCS/CCU**
photovoltaics	battery	carbon storage
solar PV	batteries	carbon capture utilisation and storage
solar energy	electric vehicle charging	CO2 capture utilisation and storage
		CO2 storage
Wind energy	**Electrolysers**	CCU
wind energy	electrolysis	CCS
wind offshore	electrolyser	
wind power	hydrogen	**Generic keywords**
wind turbine		fuel cell
	Advanced biofuels	energy storage
Heat pumps	biofuels	biorefinery
heat pump	bioenergy	renewable energy
air capture	biogas	electrification
heating and cooling network	sustainable fuels	
heating network		

Note: Spelling variants and plural forms are also included as keywords. They are not displayed in the table for space-saving purposes. Keywords are presented by CREI technology as highlighted in bold. The category Generic keywords contains keywords that can be attributed to multiple CREI technologies.
Source: Compiled by the authors based on literature review.

As for the technology infrastructure keywords, the study team also translated the CREI-specific keywords in 10 other European languages in order to be able to scrape non-English websites. For the ease of presentation, results for non-English websites are converted back to English keywords.

1.3. Count of technology infrastructures

The study team used advanced data analytics through ChatGPT to prompt the AI-enhanced tool to count the number of technology infrastructures of a technology centre from its website information. The main home page as well as well as all subpages of a technology centre were analysed by ChatGPT if they contain technology infrastructure related keywords. For each subpage, ChatGPT provided a counting result for each of the six types of technology infrastructures as presented in Figure 2. Summing up the counts over all subpages would lead to overestimating the number of infrastructures as they are often repeated across subpages. Hence, to avoid such double containing, the study team retained the maximum count by infrastructure type over all subpages.

1.4. Geolocation of technology centres and companies

In order to analyse the geographical distribution of technology centres as well as of companies active in CREI technologies, the study team has identified the geolocation of both.

The CREI companies database has been built using multiple sources (Orbis, Dealroom, Technote). Orbis is a source for company financials data such as turnover, employment, profitability and other data derived from company financial statements; while Technote provides data on technologies, investment and collaborations between companies; and Dealroom provides data on start-ups and capital raised.

For CREI companies, the study team has first exploited the address information provided by the different sources employed to construct the database (Orbis, Dealroom, Technote) and used Google Geocoding API[13] to retrieve latitude and longitude based on this information. If a company has no address information, the study team has used Google Places API[14], a textual identifier that uniquely identifies the location of a place based on its name. Google Places API has also been used by the study team to identify the location of technology centres.

1.5. Quality control

Due to the exploratory character of the methodology used, the study team carried out several quality control analyses to check the robustness and to improve the methodology, which resulted, for instance, in the refinement of the list of keywords used in the web scraping.

Several robustness checks took place such as:

- Checking for false negatives and false positives by looking at the list of webpages with only 1 technology infrastructure keyword occurrence
- Checking the list of webpages that failed to be scraped
- Checking potential outliers related to the count of the number of technology infrastructures, using ChatGPT

The various checks allowed the team to better train ChatGPT in order to provide more accurate counts.

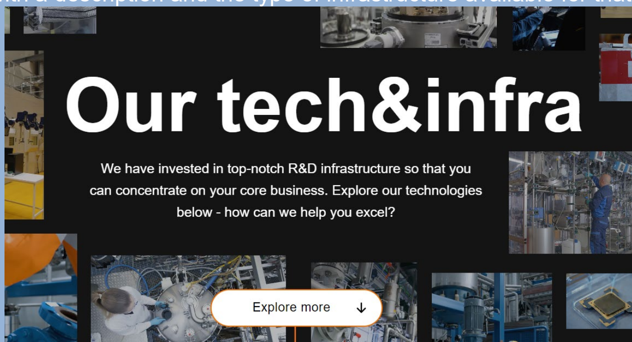
In addition, the study team analysed several technology centres such as VTT, Tecnalia, TNO, RISE, CEA, Fraunhofer, imec, with the objective of assessing how the tool was able to effectively scrape some of the well-known technology centres in Europe. Box 1 and box 2 present two examples of the technology centres analysed.

[13] https://developers.google.com/maps/documentation/geocoding/start

[14] https://developers.google.com/maps/documentation/places/web-service/overview

Box 1: Example of VTT

VTT[15], one of Europe's leading research institutions, is a limited liability company that is fully owned by the Finnish state and operates under the ownership steering of the Ministry of Economic Affairs and Employment. The special duty of VTT as an independent and impartial research centre is to promote the wide-ranging utilisation and commercialisation of research and technology in commerce and society. In addition to the parent company, VTT Group consists of three fully-owned subsidiaries: VTT Holding Oy, VTT International Ltd, VTT Ventures Ltd. VTT has several locations across Finland.
During the analysis, the study team found that the list of all technology infrastructures offered by VTT are listed in the main website in one single link: https://www.vttresearch.com/en/technology-infrastructures. However, the infrastructures are divided by type of technologies and by clicking on each technology, another page opens with a description and the type of infrastructure available for that technology.



The first wave of web scraping **identified 16 websites linked to VTT.** Those websites were from the different data sources used by the study team. The scraping of all the websites was able to identify several technology infrastructure keywords, with an **average of 13 keywords.** An example is shown below:

Examples of infrastructures
VTT IntelligentEnergy testbed
Cleanroom facility
Lab to bench scale facilities for CO2 utilisation
Battery laboratory
VTT Bioruukki Pilot Centre
In-house pilot lines

The scraping was also able to identify many CREI keywords (using the initial list of more than 30,000 keywords), with an **average of 116 keywords,** covering all CREI technologies.

The example shows that the initial list of technology infrastructure keywords effectively captured the correct type of infrastructures, such as **testbed, cleanroom**, **laboratory or pilot line,** while the long list of CREI keywords was too broad. In addition, it helped the team to proceed with the cleaning of the databases. As the different VTT webpages did not correspond to different technology centres, the study team decided to delete all the websites, except the one corresponding to the list of technology infrastructures (mentioned above). This website was then used for the subsequent wave of web scraping.

Source: Compiled by the authors.

[15] https://www.vttresearch.com/en

Box 2: Example of CEA

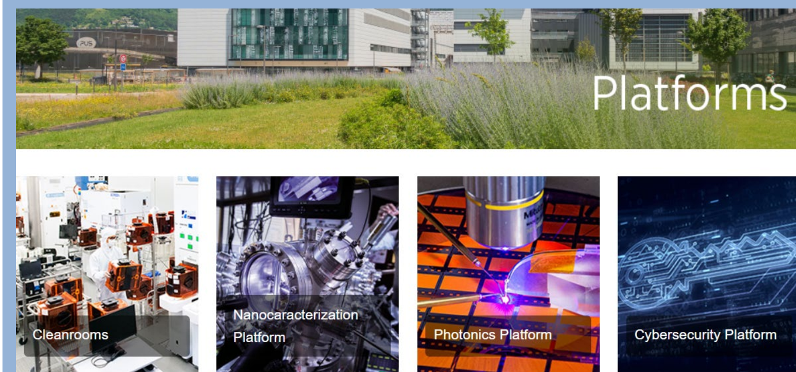
The CEA[16] is a major French research organisation, with 9 research centres and 16 institutes across France and strong partnerships with many other research organisations, regional authorities and universities. CEA is able to provide tangible solutions in four key fields:

- Low-carbon energy (nuclear and renewable)
- Digital technology
- Technology for medicine of the future
- Defence and national security

The CEA features four operational divisions tasked with carrying out its research:

- Energy Division
- Military Applications Division
- Technological Research Division
- Fundamental Research Division

Unlike the example of VTT, CEA does not have a single webpage with all the different technology infrastructures available. Instead, the various infrastructures are mentioned in the different webpages corresponding to the CEA Institutes. A few challenges such as the fact that some links did not have an English version (challenge that was resolved after the translation process took place), and one case where the list of infrastructures were mentioned in a PDF document, show the difficulty in using web scraping approaches.



Example from the CEA-Leti institute (https://www.leti-cea.com/cea-tech/leti/english/Pages/Applied-Research/Facilities/research-facilities.aspx)

The first wave of web scraping **identified 29 websites linked to CEA.** Those websites originated from the different data sources used by the study team. The scraping of all the websites was able to identify several technology infrastructure keywords, with an **average of 11 keywords.** An example is shown below:

Examples of infrastructures
Robot qualification and tool integration platform
Fuel Cell Platform
Solar Photovoltaics Platform
Industrial-scale pilot lines
High activity hot laboratory
Clean rooms

The scraping was also able to identify many CREI keywords (using the initial list of more than 30,000 keywords), with an average of **153 keywords**, covering all CREI technologies.

The example shows that the initial list of TI keywords effectively captured the correct type of infrastructures, such as **pilot lines, clean rooms**, **laboratory or platform.** However, as with VTT, there were several webpages that did not correspond to different technology centres. For this reason, the study team decided to keep only the webpages that corresponded to 9 CEA institutes (excluding those focused on fundamental research and one that did not have any information on technology infrastructures).

Source: Compiled by the authors.

The qualitative analysis and the examples above showed a high degree of variability across the EU in how the technology centres and their corresponding webpages are organised and structured, in particular the exact location of the technology infrastructures offered by each technology centre.

Based on the qualitative and robustness analysis, the study team was able to clean the initial database of technology centres, by removing duplicates, correcting wrong websites and finetuning technology centres. The study team was also able to use the qualitative analysis to improve the final list of technology infrastructure and CREI keywords used. This led to an improvement of the overall approach and to effectively be able to use web scraping techniques to capture and map technology infrastructures active in different sectors across Europe.

1.6. Benefits and limitations of the methodology

Using web scraping methodologies to map the landscape of technology infrastructures in Europe has proven to be advantageous, entailing several benefits:

- Large-scale data collection: Web scraping is a cost-effective technique allowing to gather data from websites at scale. Given the large number of technology centres in Europe, it would take a lot of time and human resources to screen all the websites manually.

- Automation: Web scraping is time-saving technique because it uses an automated data collection process.

- Customisation and accuracy: Web scraping techniques used for this report have shown to provide accurate and up-to-date data, hence successfully helping to support policymakers and decision-making. At the same time, it is a very flexible and customised method, enabling scalability for projects and the screening of different sectors or topics of research.

In what concerns the use of ChatGPT to count the number of technology infrastructures from a website, there are also a few benefits. Similar to web scraping, it is a cost-effective and time-saving technique because it can generate responses to queries in seconds, hence reducing the use of manual work and time-consuming screening tasks. In addition, since it is possible to train the model, one is able to provide more accurate information in successive queries.

While the above techniques offer a powerful means of extracting data from the web, it is essential to recognize their inherent limitations and challenges. By understanding the technical and practical challenges, web scraping strategies can be further improved in the future. Some limitations include:

- Technical challenges: Websites may implement rate-limiting mechanisms or block IP addresses engaging in excessive scraping activity. This can hinder the scraping process, slow down data extraction, or lead to temporary or permanent bans from accessing the website. Another issue may relate to the failure of accessing a webpage that does not exist or cannot be found on the server. Around 12% of websites in the sample could not be scraped due to technical challenges (see Table 11 in Annex).

- Dependency on website structure: Web scraping heavily relies on the structure and layout of target websites. While some technology centres present all infrastructure on one dedicated web page, other centres present them on multiple pages (see examples above). In addition, it is challenging to determine the extent to which the technology infrastructures mentioned on various web pages are referring to the same entities or distinct ones. To address this issue, the study team opted to retain the maximum count of technology infrastructures found across all webpages of a technology centre to prevent double counting.

- Data quality and consistency: Another limitation lies in the quality and consistency of the scraped data. Websites may frequently update their structure or content, leading to data inconsistencies or errors in the scraping process. Additionally, variations in formatting or encoding can affect the accuracy of the extracted data. Another issue relates to hallucinations with ChatGPT referring to instances where the AI-generated responses may include content that is not factually accurate, coherent, or contextually appropriate. Hence, the study team conducted quality controls (see Section 1.5) and removed outliers from statistical results.

- Significant resource intensity: The computational resources required for parsing and processing HTML, extracting data, and storing it can accumulate rapidly when scraping many subpages. Therefore, the study team chose to scrape all subpages accessible within one click from the initial webpage of the technology centre. This implies that the findings presented in this report may not be entirely accurate for websites where technology infrastructures are spread across numerous subpages at deeper levels of the website structure. Hence, expanding the scope of web scraping to include additional subpages could improve the accuracy of results in the future.

2. Technology centres and their technology infrastructures in EU Member States

This section presents the current landscape of technology centres and their infrastructures across EU Member States and regions in the seven key domains of CREI technologies. Technology centres are defined as in Van de Velde and Boschmans (2023) and refer to public or private organisations carrying out applied research and close-to-market innovation (technology readiness levels 3 to 9). The definition of technology infrastructures is provided in Section 1.2.1. The analysis in this section is based on a **sample of 1396 technology centres** and their technology infrastructures. More information on how this sample has been obtained can be found in Annex. To better understand the role and positioning of technology centres in the industrial landscape, we compare their distribution with companies active in CREI technologies. The industry sample accounts for **16029 CREI companies**. Both samples are restricted to technology centres and companies active in EU Member States.

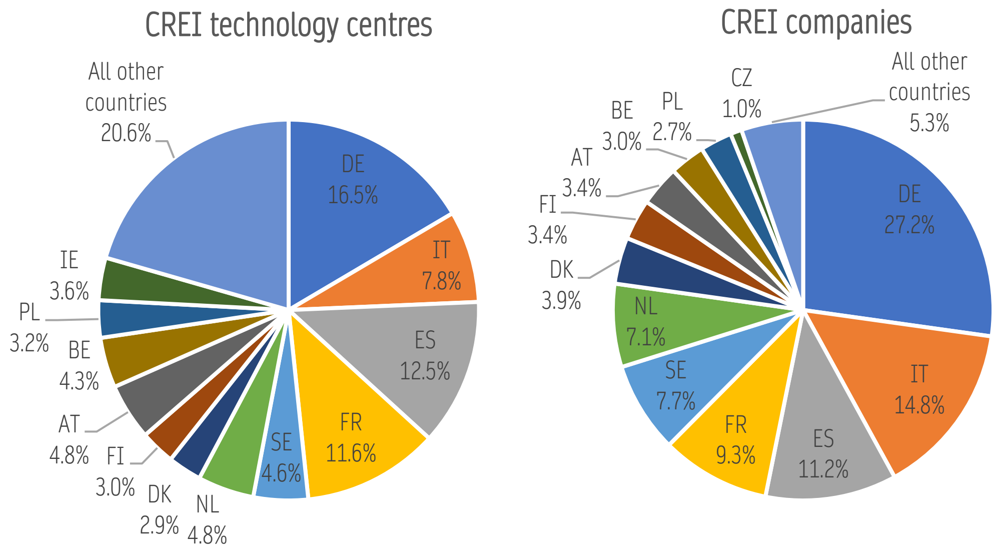
2.1. Landscape and distribution of technology centres

Figure 3 presents the distribution of CREI technology centres and companies by Member State. In both samples, the most represented countries are Germany, Italy, Spain and France. While the latter two countries account for a similar part in both samples, the shares for Germany and Italy are remarkably higher within the distribution of CREI companies. In the industrial landscape, Germany and Italy account for 42% of the sample, while for technology centres they take up around 24% of the sample. This points at the significant progress of both Germany and Italy in advancing the clean energy adoption and transitioning towards more sustainable and environmentally friendly industrial practices (Van de Velde et al., 2023).

Other relevant countries in the ranking of both samples include the Netherlands and Scandinavian countries such as Sweden, Denmark, and Finland. These countries host important technology centres such as RISE Research Institutes of Sweden (SE), Danish Technological Institute (DK), and VTT Technical Research Centre of Finland (FI).

Lastly, the other countries segment in the distribution of CREI technology centres is relatively large (20.6% compared to 5.3% for CREI companies), pointing at a diversified array of countries that host technology centres in the field of clean and renewable energy. Most of these countries are East-European ones, which exhibit higher shares in terms of CREI technology centres compared to CREI companies. While being less industrialised, the presence of technology centres in these countries is important to reinforce industries with access to cutting-edge innovations, research facilities, and skilled talent pools.

Figure 3: Distribution of CREI technology centres and companies by Member State

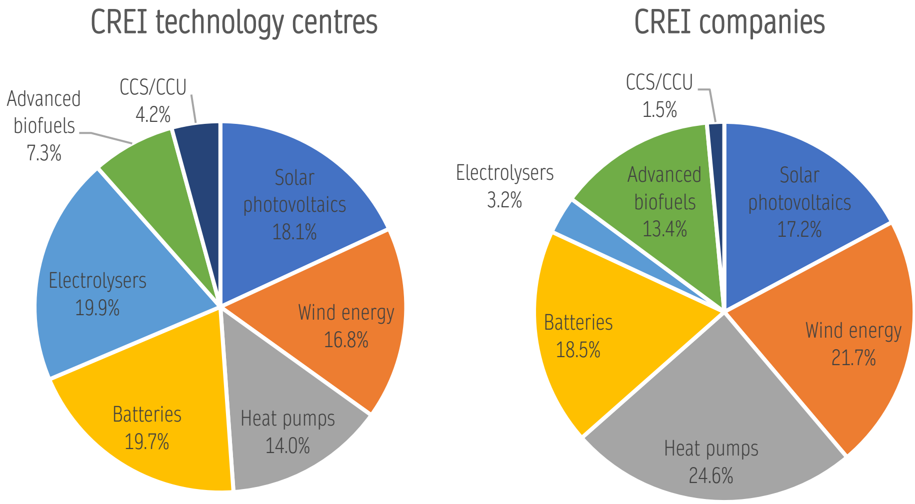


Note: The distributions are based on 1357 CREI technology centres (39 centres have missing information for the country) and 16029 CREI companies.
Source: Compiled by the authors based on web scraping of technology centres' websites and a database of CREI companies collected by Van de Velde et al. (2023).

Turning to the distribution of CREI technology centres and companies by technology in Figure 4, it can be noted that the shares of solar photovoltaics, wind energy and batteries are similar across both samples. This similarity is driven by the fact that these are widely deployed and economically viable technologies and hence the landscape of companies and technology centres is relatively balanced. It also constitutes a large segment of the market as together they account for 60% in each sample. Other examples of mature technologies are advanced biofuels and heat pumps. For these technologies, the share in the industrial landscape is relatively high (25% for heat pumps and 13% for advanced biofuels) compared to the more modest segment in the technology centres distribution (14% and 7% respectively). In sharp contrast, 20% of technology centres are active in the field of electrolysers compared to only 3% of CREI companies in this domain. This can be explained by the fact that hydrogen is still in its infancy and hence many technology centres are active in this field in order to support the emerging industry.

Table 12 presents the distribution of technology centres across technology for each Member State (see annex). It can be noted that in most Member States, technology centres are active in batteries and electrolysers, in line with the results of Figure 4. However, some differences can be observed. In Denmark, the majority of technology centres are active in wind energy while in Hungary, Malta, and Romania, most technology centres are active in solar photovoltaics. Finally, Table 13 presents the distribution of technology centres across Member States for each technology (see annex). Germany has the highest share of technology centres active in all CREI technologies with the exception of advanced biofuels and CCS/CCU. For the latter, Sweden has the highest share of technology centres active in that technology while for advanced biofuels, Spain accounts for the highest share of technology centres active in it.

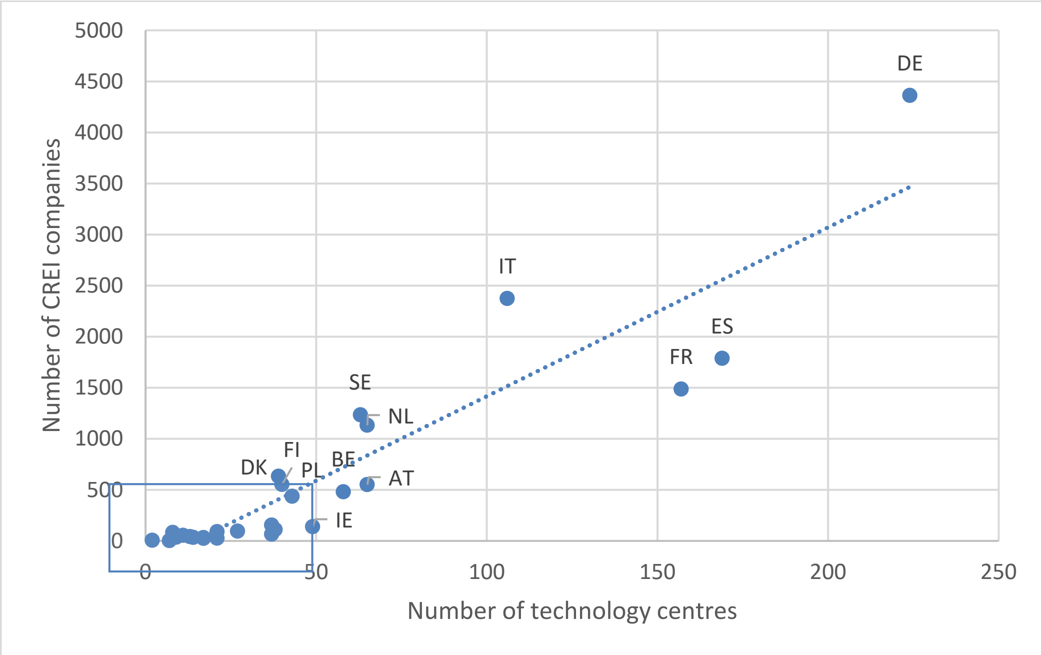
Figure 4: Distribution of CREI technology centres and companies by technology



Note: The distributions are based on 1396 CREI technology centres and 16029 CREI companies. CREI technology centres and companies can be active in various technologies.
Source: Compiled by the authors based on web scraping of technology centres' websites and a database of CREI companies collected by Van de Velde et al. (2023).

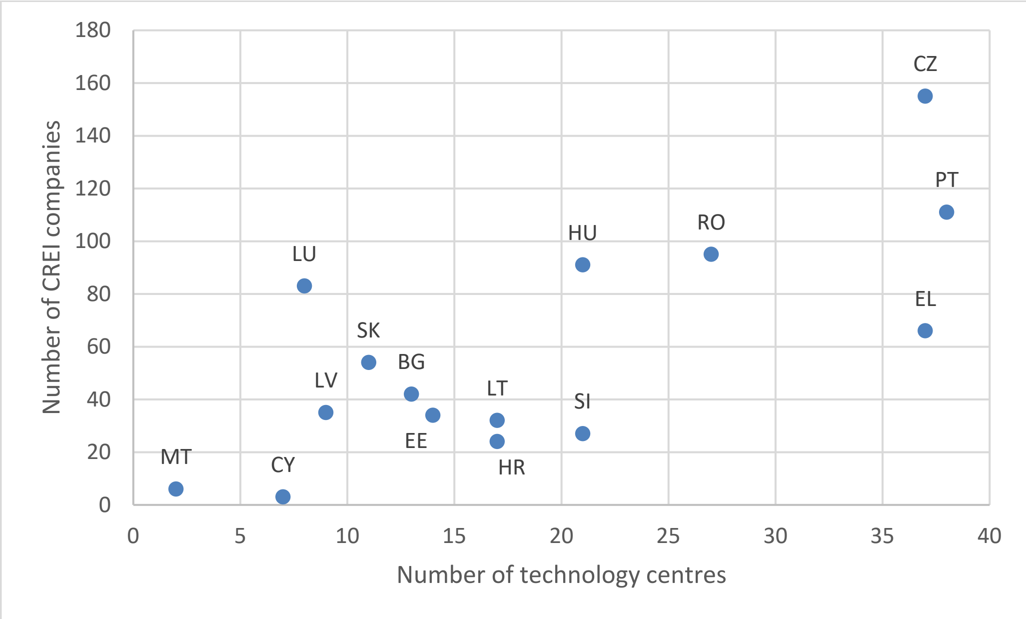
Figure 5 presents the relationship between the number of companies active in CREI technologies and the number of technology centres active in CREI technologies. For ease of representation, the lower end of the distribution of the countries as highlighted in the blue rectangle are displayed in Figure 6. It can be noted that there is a positive association between the number of technology centres active in CREI technologies and the number of companies active in these technologies, in line with expectations. More specifically, the correlation between the two variables is 0.92 which indicates a high level of correlation. Germany clearly stands out as the Member State hosting the majority of technology centres as well as companies active in CREI technologies. It has large institutions as Fraunhofer that owns an extensive network of technology centres, while the industrial landscape includes many subsidiaries of large conglomerates as Siemens, BASF, and Schenker, Other countries such as Poland or Portugal have fewer technology centres which is also aligned with fewer CREI companies.

Figure 5: Relationship between companies and technology centres active in CREI technologies by Member State, in total numbers



Note: The distributions are based on 1357 CREI technology centres (39 centres have missing information for the country) and 16029 CREI companies.
Source: Compiled by the authors based on web scraping of technology centres' websites and a database of CREI companies collected by Van de Velde et al. (2023).

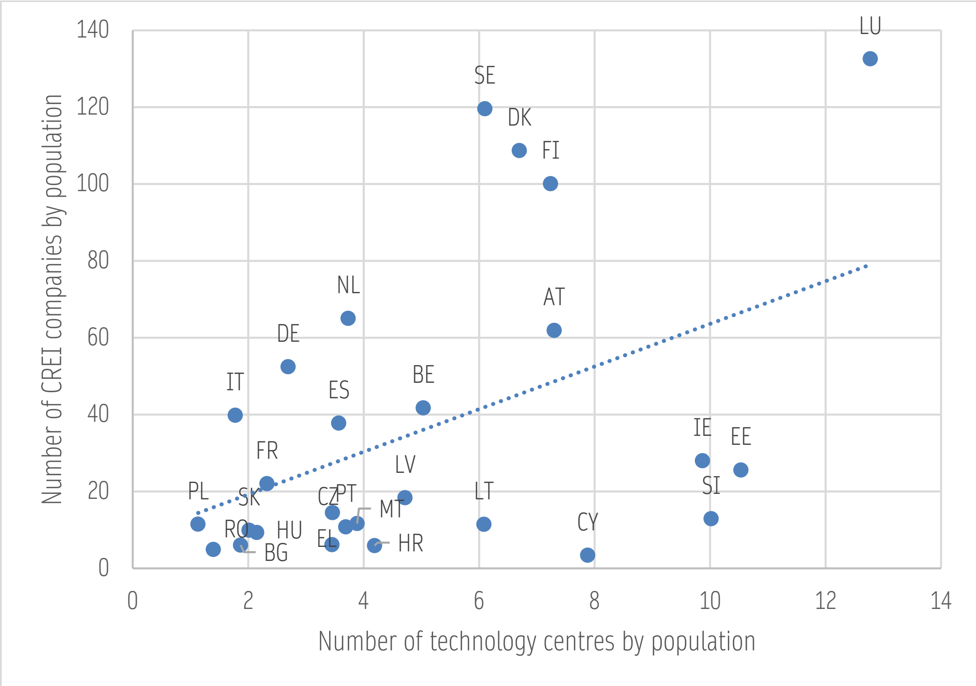
Figure 6: Relationship between companies and technology centres active in CREI technologies by Member State, in total numbers



Note: The distributions are based on 1357 CREI technology centres (39 centres have missing information for the country) and 16029 CREI companies.
Source: Compiled by the authors based on web scraping of technology centres' websites and a database of CREI companies collected by Van de Velde et al. (2023).

Figure 7 examines the relationship between companies and technology centres active in CREI technologies by Member State in relation to the population. It plots the number of technology centres and CREI companies as per capita measures (i.e. by million inhabitants), allowing for a normalised comparison across countries with different population sizes. Distinct groups of countries emerge in the figure. Luxembourg stands out for having a high density of CREI companies and technology centres relative to its population size. Also, Scandinavian countries (Denmark, Finland and Sweden) demonstrate a strong industrial base and high density of technology centres per capita. By contrast, Ireland, Estonia and Slovenia exhibit a noteworthy performance in terms of technology centres per capita but display relatively lower figures on CREI companies per capita. Most of the West European countries exhibit around 40 to 60 CREI companies per million inhabitants (with the exception of France and Ireland with around 20 and 27 CREI companies per million, respectively), while their density in technology centres is more diverse. It ranges from 2 technology centres per million inhabitants in Italy to close to 10 in Ireland. In general, East European countries display a relatively weak industrial base per capita in CREI technologies (around 10 CREI companies per million inhabitants on average with the exceptions of Estonia and Latvia which both have around 20 CREI companies per million inhabitants), while their score on technology centre density varies between around 2 centres per million inhabitants (Poland, Romania, Bulgaria) and around 10 centres per million inhabitants (Estonia and Slovenia).

Figure 7: Relationship between companies and technology centres active in CREI technologies by Member State, in total numbers by population



Note: The distributions are based on 1357 CREI technology centres (39 centres have missing information for the country) and 16029 CREI companies.
Source: Compiled by the authors based on web scraping of technology centres' websites and a database of CREI companies collected by Van de Velde et al. (2023).

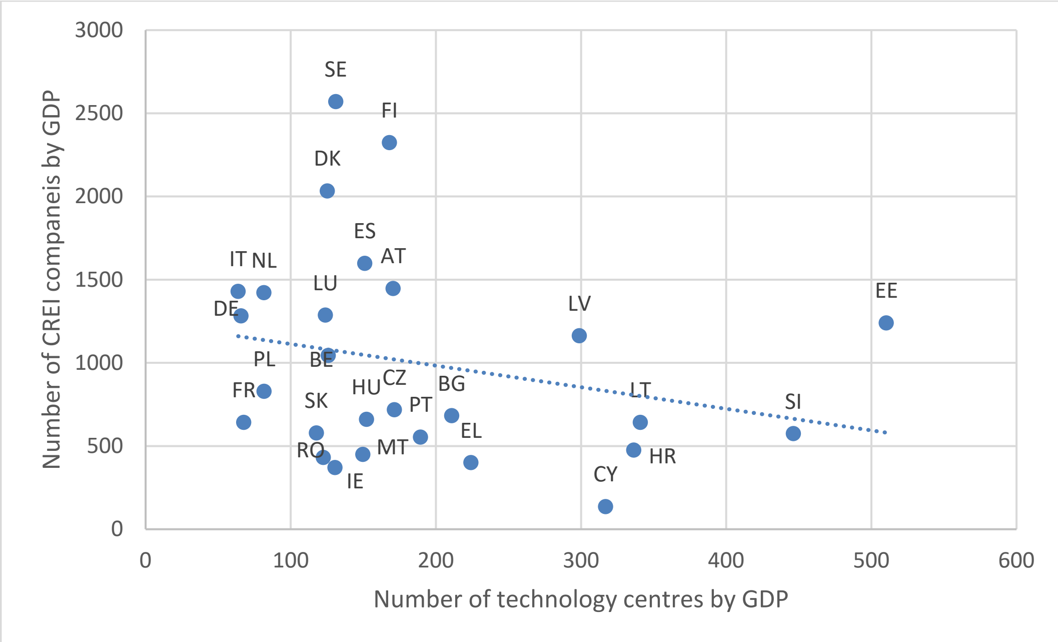
A different pattern emerges when analysing the relationship between companies and technology centres active in CREI technologies by gross domestic product as presented in Figure 8. Differences arise from the fact that the population size does not necessarily reflect the economic performance of a country. For instance, Luxembourg, given its small size, demonstrates a notable presence in the analysis when population size is accounted for. However, this observation contrasts with its relatively robust GDP. Consequently, Luxembourg finds itself positioned at the lower spectrum of the distribution depicted in Figure 8.

Overall, East European countries (Estonia, Slovenia, Latvia, and Lithuania) stand out with relatively high densities of technology centres per GDP. This showcases the importance of technology centres in these countries to fostering innovation and research in clean and renewable energy technologies. At the same time, they lack a solid industrial base in CREI technologies. This discrepancy may point to opportunities for enhancing entrepreneurial ecosystems and further incentivizing the commercialisation and scaling of CREI innovations in these countries.

While Scandinavian countries still exhibit a strong industrial base in CREI technologies when controlling for the economic activity in these countries, their density of technology centres per million GDP is now comparable to other West European (e.g. Ireland and Belgium) and East European (e.g. Hungary and Czechia) countries.

Despite their strong positions in absolute numbers (see Figure 5), France and Germany appear at the lower end of the distribution when taking into account GDP.

Figure 8: Relationship between companies and technology centres active in CREI technologies by Member State, in total numbers by gross domestic product (GDP)



Note: The distributions are based on 1357 CREI technology centres (39 centres have missing information for the country) and 16029 CREI companies.
Source: Compiled by the authors based on web scraping of technology centres' websites and a database of CREI companies collected by Van de Velde et al. (2023).

2.1.1. Analyses of technology centres active in particular CREI technologies

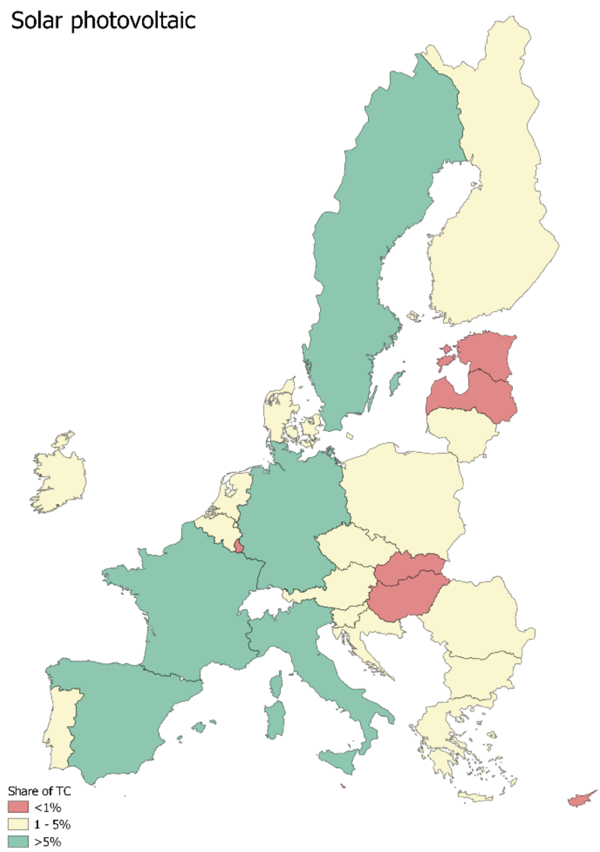
In this section, we examine in more detail technology centres that are active in four CREI technologies: Solar photovoltaics, batteries, advanced biofuels, and CCS/CCU. Solar photovoltaics and batteries have been selected due to the significant presence of technology centres and companies actively engaged in these technologies while advanced biofuels and CCS/CCU have been selected as a more limited number of technology centres and companies are actively engaged in these two technologies.

For solar photovoltaics, Germany is the Member State with the highest number of technology centres (15.9%). In 2021, Germany accounted for about 6.9% (59 Gigawatt-peak) of the cumulative PV capacity installed worldwide (848 Gigawatt-peak) with about 2.2 million PV systems installed in Germany[17]. The country hosts the largest solar technology centre in Europe, the Fraunhofer Institute for Solar Energy Systems ISE, with a staff of about 1400 employees. The centre is active in four main research areas: energy provision, energy distribution, energy storage and energy utilization. The centre also has three external branches in Germany which carry out work on solar cell and semiconductor material development: the Laboratory and Service Centre (LSC) in Gelsenkirchen, the Technology

[17] Fraunhofer Institute for Solar Energy Systems, ISE with support of PSE Projects GmbH (2023). Photovoltaics report.

Centre of Semiconductor Materials (THM) in Freiberg, and the Fraunhofer Centre for Silicon Photovoltaics (CSP) in Halle. As shown in Figure 9, other Member States with a high share of technology centres active in solar photovoltaics are Spain (13.0%), France (9.3%), Italy (8.5%), and Sweden (5.3%).

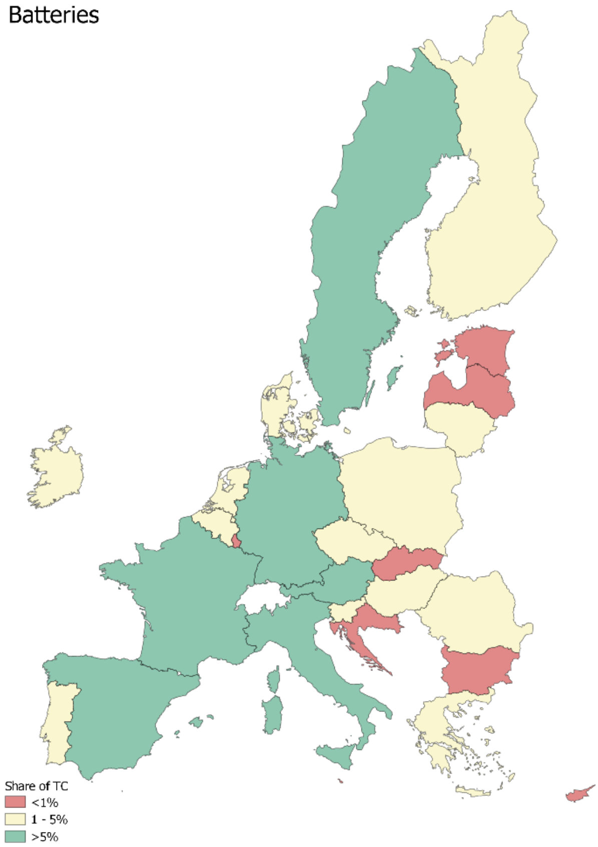
Figure 9: Distribution of technology centres active in solar photovoltaics by Member State



Note: The distribution is based on 1012 CREI technology centres.
Source: Compiled by the authors based on web scraping of technology centres' websites and a database of CREI companies collected by Van de Velde et al. (2023).

Germany is also the Member State with the highest number of technology centres active in batteries (15.8%). The most prominent technology centre in the batteries' technology is Fraunhofer ISI which has been active in this field for over ten years. The centre has specialised in lithium-ion batteries covering the entire value chain, i.e. from raw materials, components, the battery cell, battery markets and recycling. The centre is also actively engaged in the monitoring of alternative battery chemistries and systems that could reach market maturity in the next few years and provides support for companies that wish to operate in this market by organizing technology- and application-specific expert workshops to calculate the effects of technological developments or substitutes at the material, battery cell or system level. As shown in Figure 10, other Member States with a high share of technology centres active in batteries are Spain (12.7%), France (10.5%), Italy (8.4%), Austria (5.4%), and Sweden (5.3%).

Figure 10: Distribution of technology centres active in batteries by Member State

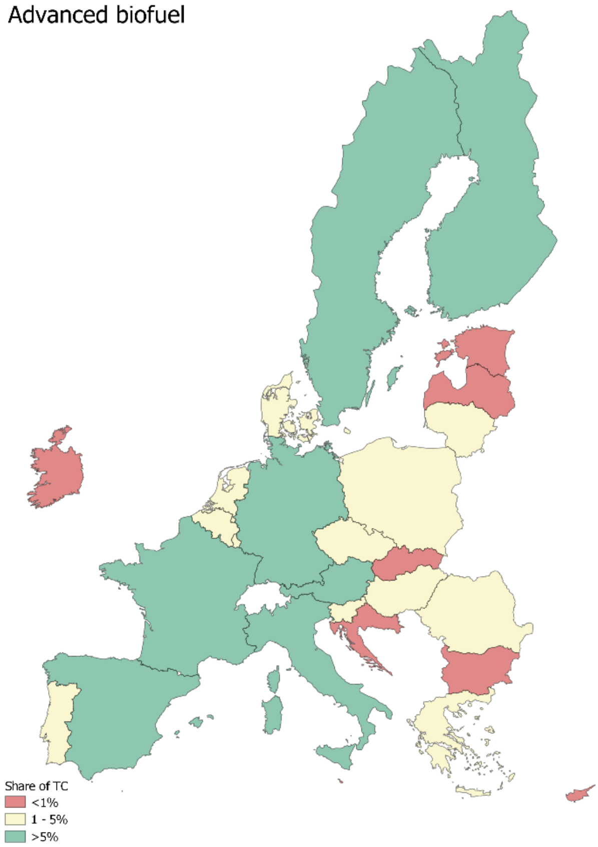


Note: The distribution is based on 1113 CREI technology centres.
Source: Compiled by the authors based on web scraping of technology centres' websites.

Spain, one of the Member States with the highest biofuel production capacity in the EU[18], is also one of the Member States with the highest number of technology centres active in this technology. Among others, one of the most prominent technology centres active in advanced biofuels is the National Renewable Energy Centre of Spain (CENER) which develops applied research in renewable energies, and provides technological support to companies and energy institutions. The centre is specialized in the development and optimization of production processes of bioproducts, solid biofuels, advanced liquid or gaseous biofuels, as well as biorefinery concepts. Another technology centre particularly active in this technology and based in Spain is TECNALIA which is engaged in various initiatives aimed at promoting efficient technological solutions for the production of biofuels for aviation and for the marine sector through biorefinery and biological processes, from the organic fraction of solid urban waste. As shown in Figure 11, other Member States with a high share of technology centres active in advanced biofuels are Germany (12.8%), Sweden (11.1%), France (7.5%), Finland (5.8%), Austria (5.6%), and Italy (5.6%).

[18] Hurtig, O., Buffi, M., Scarlat, N., Motola, V., Georgakaki, A., Letout, S., Mountraki, A. and Joanny Ordonez, G., Clean Energy Technology Observatory: Advanced Biofuels in the European Union – 2022 Status Report on Technology Development, Trends, Value Chains and Markets, EUR 31287 EN, Publications Office of the European Union, Luxembourg, 2022, ISBN 978-92-76-58806-1, doi:10.2760/938743, JRC130727.

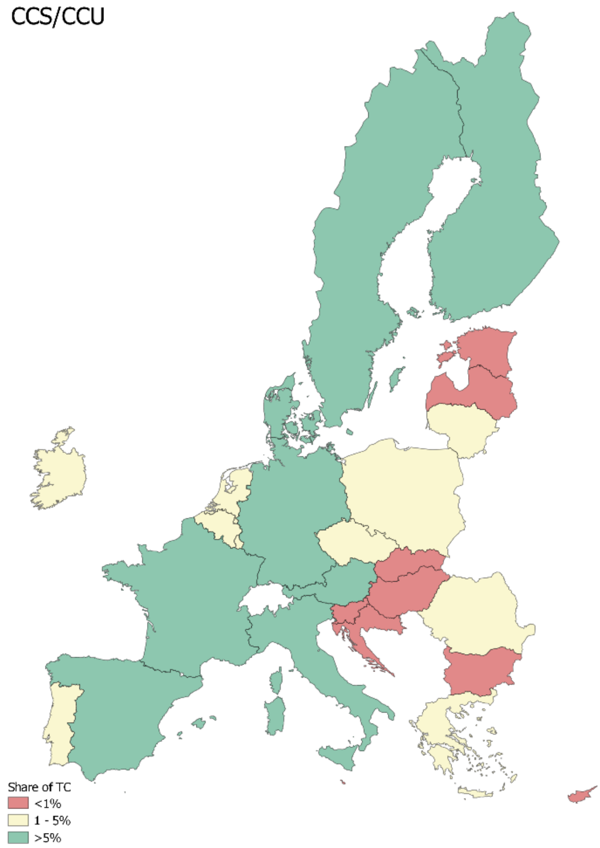
Figure 11: Distribution of technology centres active in advanced biofuels by Member State



Note: The distribution is based on 413 technology centres.
Source: Compiled by the authors based on web scraping of technology centres' websites.

For CCS/CCU, Sweden is one of the Member States with the highest number of technology centres active in this technology (15.4%). Most of these centres belongs to RISE which, over time, has gone through a consolidation phase becoming an umbrella organisation for several technology centres across Sweden. RISE provides expertise in CCS/CCU covering the entire value chain of this technology. Its services encompass capture, purification, processing, storage and the transformation of carbon dioxide into various products for industrial and transport applications. These services are offered to actors in both the private and public sector through efforts such as knowledge overviews, technology comparisons, economic evaluations, sustainability assessments, as well as the opportunity to demonstrate carbon capture, processing, and conversion using RISE pilot plants. As shown in Figure 12, other Member States with a high share of technology centres active in CCS/CCU are Germany (11.6%), Spain (11.6%), France (10.0%), Austria (6.2%), Finland (6.2%), Denmark (5.4%), and Italy (5.4%).

Figure 12: Distribution of technology centres active in CCS/CCU by Member State



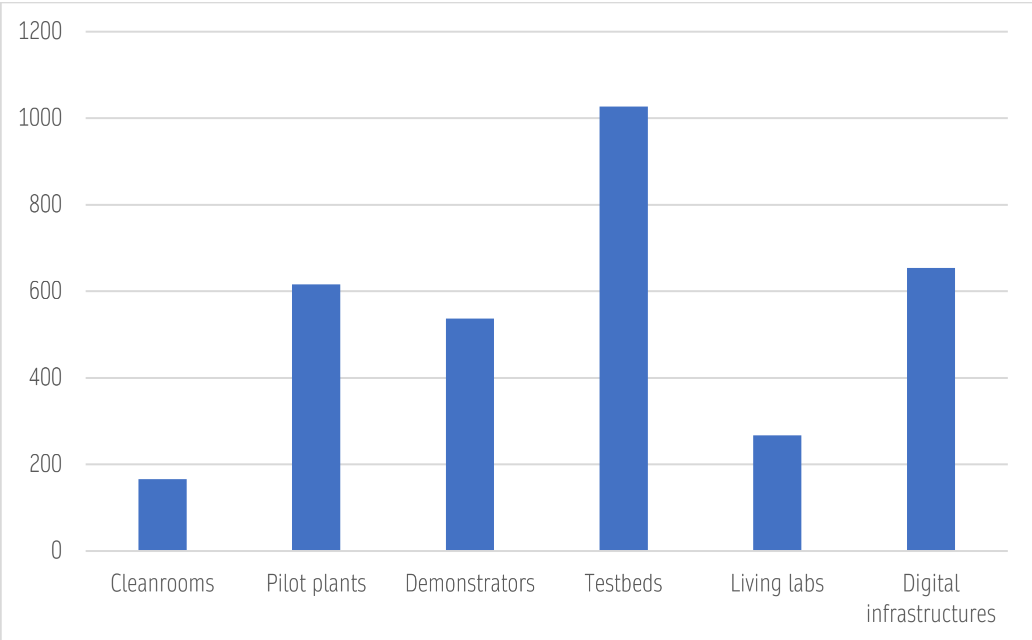
Note: The distribution is based on 241 technology centres.
Source: Compiled by the authors based on web scraping of technology centres' websites.

Despite differences in the total number of technology centres active in each of the above-mentioned technologies, no major differences can be identified in terms of their geographical distribution. In fact, Germany, France, Spain, Italy, and Sweden host a considerable share of technology centres in both solar photovoltaics, batteries, advanced biofuels and CCS/CCU. Other Member States like Austria, Finland and Denmark are well positioned in a more limited number of technologies (Austria in batteries, advanced biofuels, and CCS/CCU; Finland in advanced biofuels and CCS/CCU; Denmark in CCS/CCU). Easter European countries are instead less well represented in terms of technology centres active in these four technologies. Among them, Poland, Czechia, and Romania are the Member States that host the highest number. Poland hosts 3.1% of technology centres active in solar photovoltaics and in batteries, 4.4% active in advanced biofuels, and 2.1% active in CCS/CCU. It is the Easter European country that hosts the highest number of technology centres (3.2%) and the highest number of technology centres active in a certain technology (4.4% of all technology centres active in advanced biofuels). Czechia hosts 2.4% of technology centres active in solar photovoltaics and in advanced biofuels, 2.3% of those active in batteries, and 1.7% of those active in CCS/CCU. Technology centres located in Easter European countries tend to be more active in solar photovoltaics, batteries and electrolysers and less in advanced biofuels and CCS/CCU, a distribution that mirrors the one displayed in Figure 4 where all Member States are considered.

2.2. Landscape and distribution of technology infrastructures

Figure 13 shows the count of technology infrastructures by type of infrastructure. The most frequent type of infrastructure available in the EU are testbeds (1027), followed by digital infrastructures (654), pilot plants (616) and demonstrators (537). The count is significantly lower for living labs (267) and cleanrooms (166). The lower number of living labs might be due to the fact that while these infrastructures offer unique opportunities for user-centred innovation and co-creation, they may require extensive partnerships with communities, businesses, and governments, which could limit their proliferation compared to other types of infrastructure. For cleanrooms, the low number can be motivated by the significant investments needed to design, construct, and maintain them.

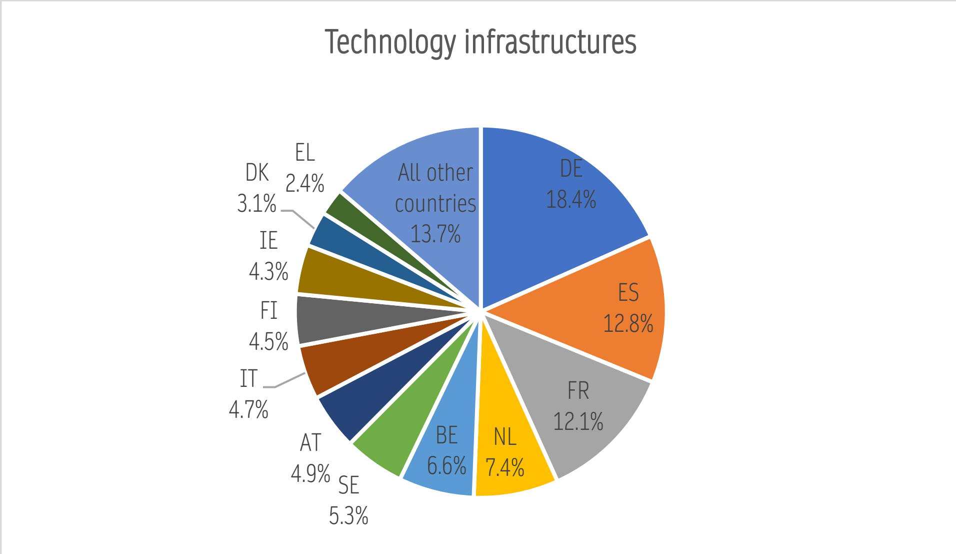
Figure 13: Number of technology infrastructure by type



Source: Compiled by the authors based on web scraping of technology centres' websites.

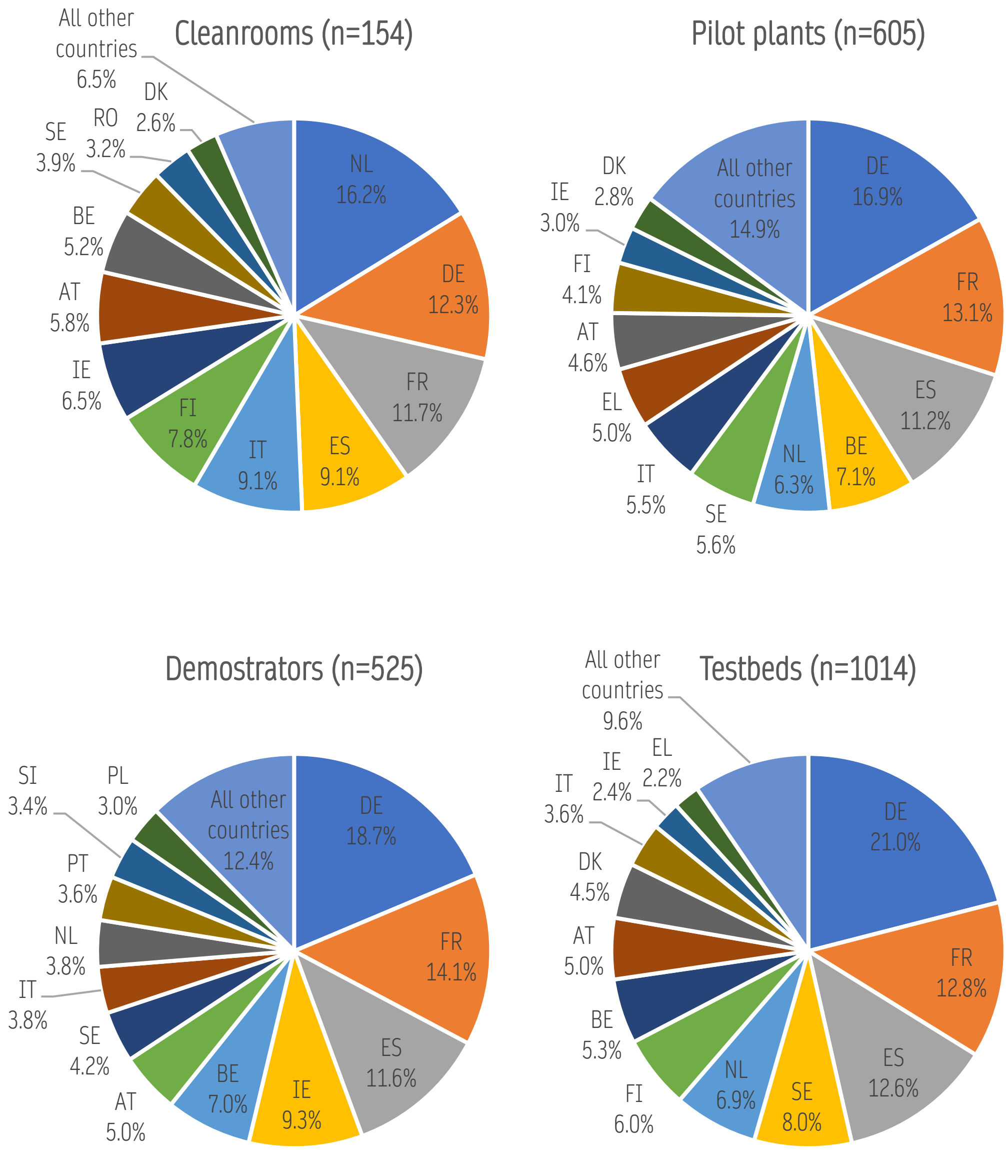
Figure 14 presents the distribution of technology infrastructures by Member State. The most represented countries are Germany, Spain, France, and the Netherlands. Together, these countries account for around 50% of all technology infrastructures present in the EU. Figure 15 further breaks down the geographical distribution of technology infrastructures by type. Germany and France host the majority of pilot plants (29.9%), testbeds (33.8%), and demonstrators (32.8%). Germany and the Netherlands hosts the majority of cleanrooms (28.6%) while for living labs, the majority is concentrated in Spain and Belgium (30.4%). Finally, 33.8% of all digital infrastructures are located either in Spain or Germany. Table 14 presents the distribution of technology infrastructures across type of infrastructure for each Member State (see annex). It can be noted that in most Member States, testbeds are the most common type of infrastructure, in line with the results of Figure 13. However, some differences can be observed. In Greece and Hungary, the most common type of infrastructure are pilot plants. In Bulgaria, Ireland, Lithuania, Portugal and Slovenia, the most common type of infrastructure are demonstrators. In Estonia, living labs are the most common, while in Italy and Poland, digital infrastructures are the most common.

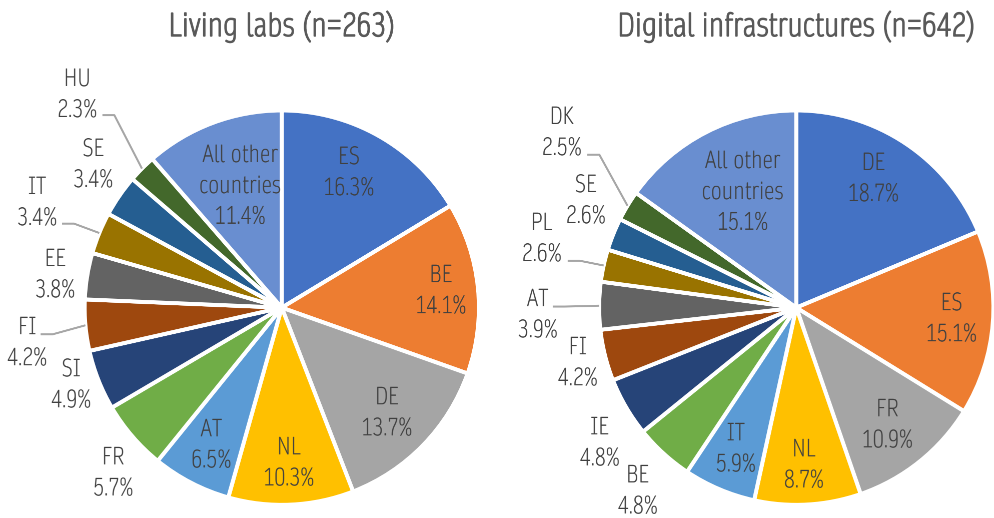
Figure 14. Distribution of technology infrastructures by Member State



Note: The distributions are based on 3203 technology infrastructures (64 technology infrastructures have missing information for the country).
Source: Compiled by the authors based on web scraping of technology centres' websites.

Figure 15. Distribution of technology infrastructures by type of infrastructure and by Member State





Note: The distributions are based on 3203 technology infrastructures (64 technology infrastructures have missing information for the country).
Source: Compiled by the authors based on web scraping of technology centres' websites.

2.3. Technology readiness levels of technology centres

Technology Readiness Levels (TRLs) are a systematic metric used to assess the maturity of a technology or innovation. They provide a common framework for evaluating the progress of a technology from its conceptual stage to its deployment in practical applications. The TRL scale typically consists of nine levels. However, as the technology centres analysed in this report are active at later stages of an innovation, we classify their activities from TRL 3 to TRL 9 as presented in Table 3.

Table 3: Technology readiness levels analysed in this report

Technology readiness levels	
TRL 3 – Proof of Concept Validate	Experimental or analytical studies are conducted to demonstrate the feasibility of the technology concept. This often involves laboratory testing or small-scale prototype development.
TRL 4 - Technology Validated in Lab	The technology is tested and validated in a laboratory environment to simulate real-world conditions.
TRL 5 - Technology Validated in Relevant Environment	The technology is tested in a relevant environment or prototype system to assess its performance under realistic conditions.
TRL 6 - Technology Demonstrated in Relevant Environment	A prototype or model of the technology is demonstrated in a relevant operational environment to showcase its functionality and effectiveness.
TRL 7 - System Prototype Demonstrated in Operational Environment	A fully functional prototype or model of the system incorporating the technology is demonstrated in an operational environment.
TRL 8 - System Complete and Qualified	The technology is integrated into a complete system or product, and it undergoes testing and qualification to ensure compliance with relevant standards and requirements.
TRL 9 - Actual System Proven in Operational Environment	The technology has been successfully deployed and proven to work as intended in operational environments.

Source: Compiled by the authors based on https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf.

We take stock of the technology infrastructure keywords to identify in which TRLs technology centres are active. To do so, we classify keywords within their respective TRL activities in line with the definitions of Table 3. Technology readiness levels are grouped in three categories: TRL 3-4, TRL 5-6-7 and TRL 8-9. Keywords related to laboratory testing for the validation of proof of concepts and technologies (e.g. test centre, test equipment and testing room) are classified in TRL 3-4. Keywords related to prototyping and demonstrations (e.g. demonstration plant, cleanroom, pilot plant) are linked to TRL 5-6-7. Lastly, keywords related to operational environments (e.g. living lab, innovation lab) are linked to TRL 8-9. The full list of keywords and their association with TRL levels is presented in Table 4. A technology centre is categorised to one or more TRL classification if its website mentions one of the keywords related to the TRL category.

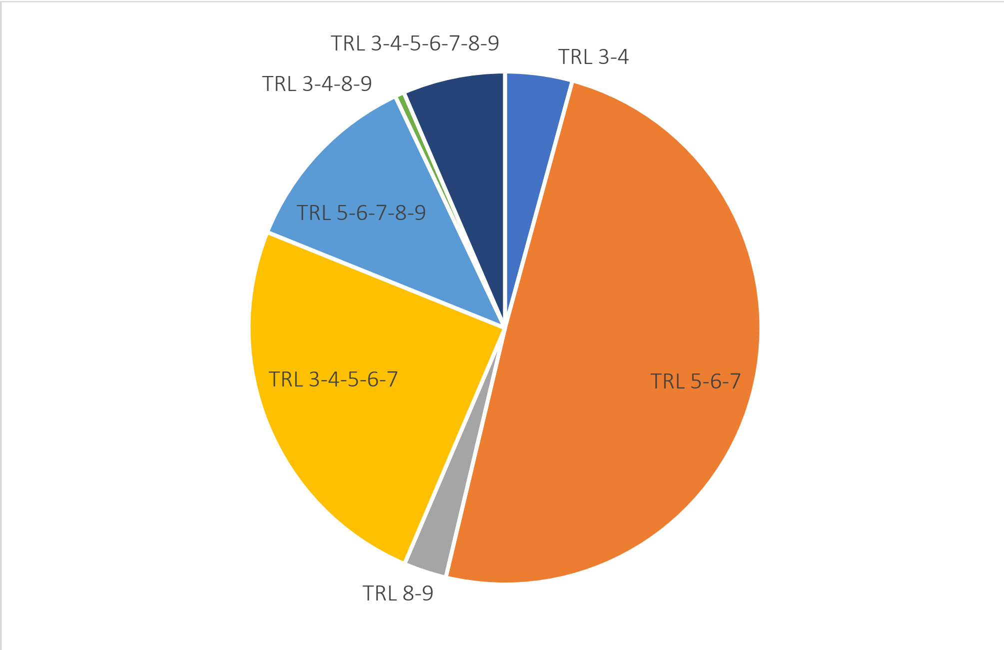
Table 4: Classification of technology infrastructure keywords to technology readiness levels

Technology readiness level classification			
TRL 3-4	**TRL 5-6-7**		**TRL 8-9**
Proof of concept / lab testing	**Pilot plants**	**Cleanrooms**	**Living labs**
test centre	pilot plant	cleanroom	living lab
test environment	pilot capability		living test bed
test equipment	pilot centre	**Demonstration facilities**	innovation lab
testing capability	pilot facility	demonstration plant	
testing equipment	pilot line	demonstration capability	
testing facility	piloting facility	demonstration environment	
testing room	prototyping lab	demonstration facility	
technology lab		demo	
R&D facility	**Test bed / testing facilities**	demonstration site	
	test room	demonstrator	
	innovation test bed		
	open innovation test bed		

Note: Spelling variants and plural forms are also included as keywords. They are not displayed in the table for space-saving purposes. Keywords are presented by type of technology infrastructures as highlighted in bold. They correspond to the ones presented in Figure 2, except for the Proof of concept / lab testing category.
Source: Compiled by the authors based on literature review.

Turning to the distribution of technology readiness levels of technology centres in Figure 16, it can be noted that technology centres play a vital role in advancing emerging CREI technologies, in particular at later stages of their development. Just 4% of technology centres are active in TRL 3-4 only, i.e. providing support on the proof of concept validation and lab testing. Most technology centres are active in TRL 5-6-7, either alone (49%) or in combination with TRL 3-4 (25%) or TRL 8-9 (12%). Hence, the majority of technology centres provide support on technology validation in relevant environments as well as prototype demonstration. Around 6% of the technology centres are active across the whole range of technology readiness levels, while 3% is only active at the final deployment stage (TRL 8-9).

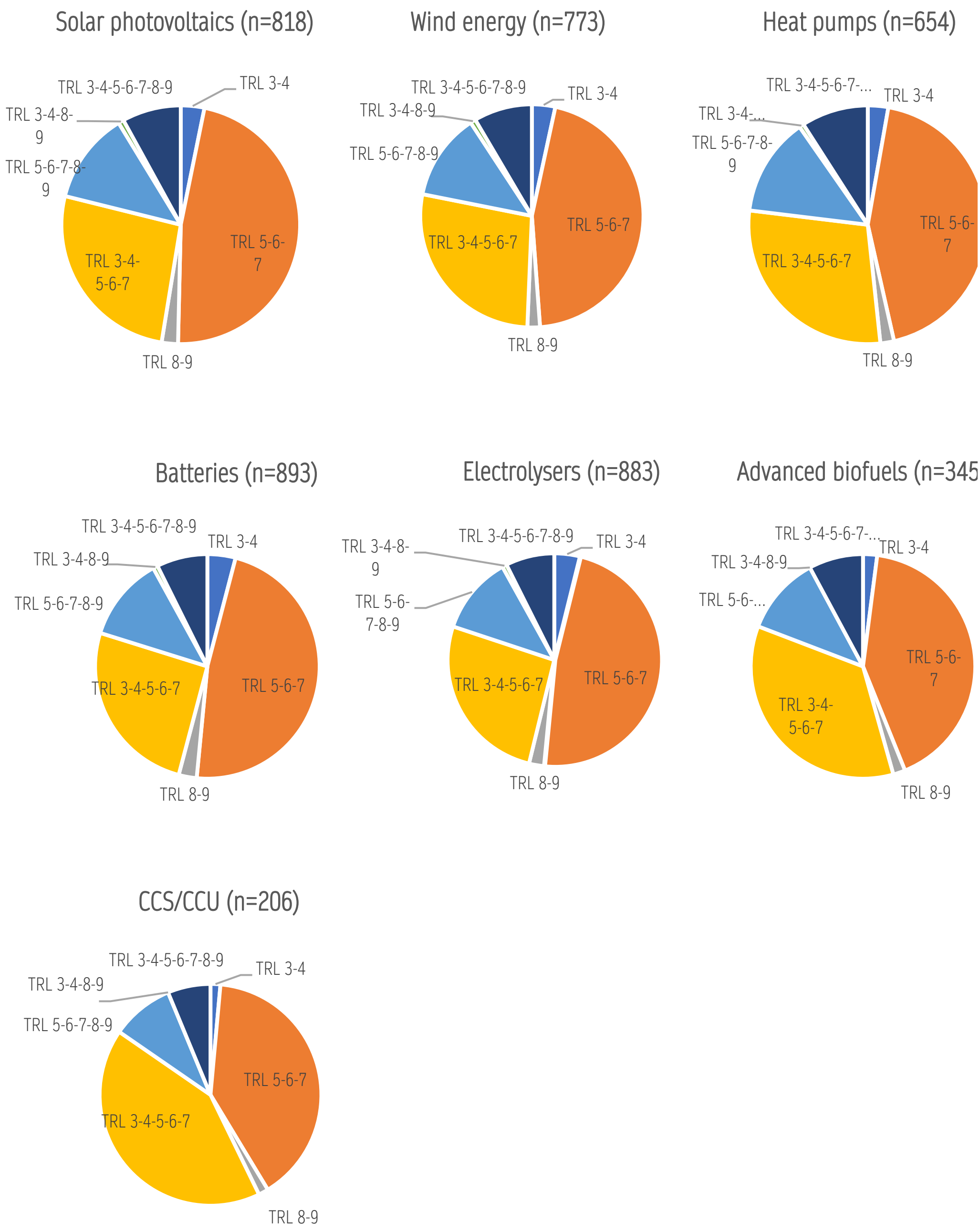
Figure 16: Distribution of technology readiness levels of technology centres



Note: The distribution of TRLs is based on a sample of 1044 CREI technology centres.
Source: Compiled by the authors based on web scraping of technology centres' websites.

Looking at the distribution of TRLs by CREI technologies, it can be noted that the shares remain virtually unchanged, except for advanced biofuels and CCS/CCU. The difference in distribution may by driven by their maturity levels. While advanced biofuels and CCS/CCU can be considered maturing technologies, they may not yet be fully mature. Despite significant progress made in demonstrating the effectiveness of both technologies, challenges still exist in terms of scalability, cost-effectiveness, and commercial viability. This may explain the higher share of technology centres active in TRL 3-4-5-6-7 in these technologies (i.e. around 35-42% compared to 26-29% in other technologies). In addition, these technologies exhibit a different sample size. The sample sizes for other technologies oscillate around 700 to 900 technology centres, while the number of technology centres in advanced biofuels and CCS/CCU is significantly lower (around 200 to 300).

Figure 17: Distribution of technology readiness levels of technology centres by CREI technology



Note: Samples for CREI technologies on solar photovoltaics, wind energy, heat pumps, batteries and electrolysers are relatively similar, while the samples of advanced biofuels and CCS/CCU are remarkably smaller.

Source: Compiled by the authors based on web scraping of technology centres' websites.

3. The regional landscape of technology centres and technology infrastructures

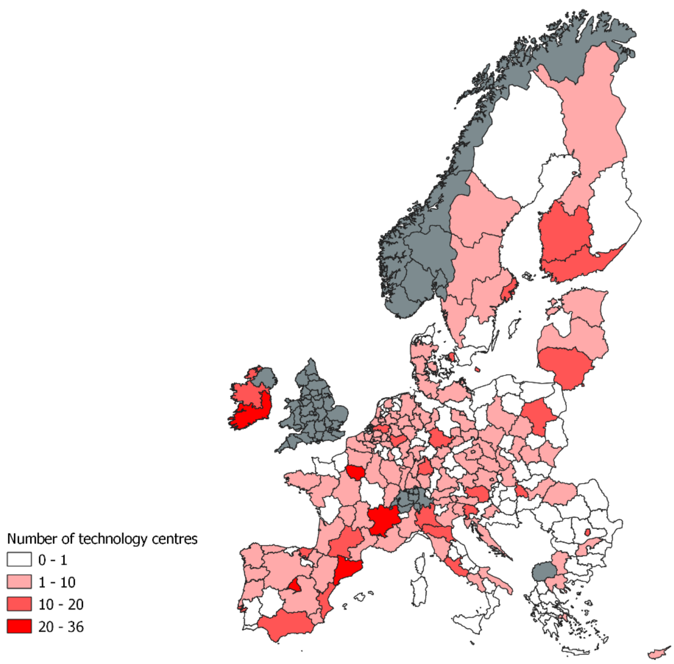
3.1. The regional landscape of technology centres

In step 4, the study team performed a mapping of the technology centres and companies active in CREI technologies at the regional level using a geolocation methodology described above. The results are presented in Figure 18 and Figure 19, respectively.

Figure 18 shows that the highest concentrations of technology centres occur mostly in metropolitan or very industrialised regions such as Ile de France (FR), Nordrhein-Westfalen (DE), Madrid (ES), Catalonia (ES), Lombardy (IT) and Emilia-Romagna (IT). This is not surprising given the fact that technology centres tend to be located close to their main users, which are companies, or located close to universities and research institutions.

Another interesting finding is the high concentration of technology centres in countries with a lower share of technology centres overall, such as South Finland (FI), Southern region of Ireland (IE), or Lithuania (LT). Part of the explanation is statistical and relate to how the regions are divided, as in the case of Lithuania (no NUTS-2 region). Another explanation is that some technology centres like VTT in Finland, which is one of the leading technology centres in Europe, has several locations in the south of Finland.

Figure 18: Distribution of CREI technology centres by NUTS-2 region

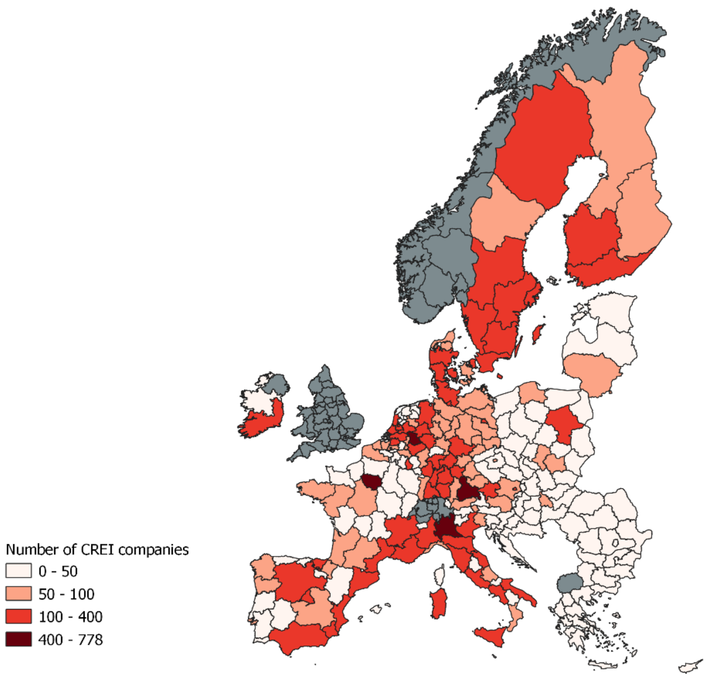


Source: Compiled by the authors based on web scraping of technology centres' websites.

Figure 19 presents the distribution of CREI companies by NUTS2 region. Regions with the highest concentration of CREI companies include Ile de France (FR), Nordrhein-Westfalen (DE), Madrid (ES), Castille and Léon (ES), Valencia (ES) and several Italian regions, such as Lombardy, Liguria and Emilia-Romagna. In Scandinavia, CREI companies are concentrated in southern regions such as Stockholm (SE), West Sweden (SE) and South Finland (FI).

These findings showcase clear colocation patterns between CREI technology centres and CREI companies, where concentrations are clustered in similar regions or adjacent regions in close proximity to one another.

Figure 19: Distribution of CREI companies by NUTS-2 region



Source: Compiled by the authors based on a database of CREI companies collected by Van de Velde et al. (2023).

3.2. The regional landscape of technology infrastructure

Total infrastructures

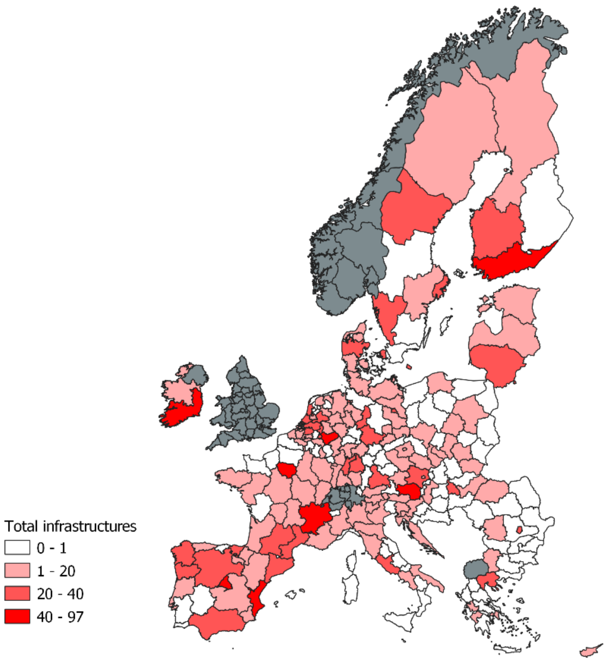
Apart from big metropolitan regions like the Paris region in France, or very industrialised regions like Cologne in Germany, the results show some interesting hotspots in the EU for technology centres with technology infrastructures active in CREI technologies.

One example is the region of Styria in the Southeastern area of Austria, which includes the second largest Austrian city – Graz and an industrial area Linz. The region is also known for being a cluster of cleantech with many companies located in the area[19]. Among the technology centres from our database, testbeds are the type of technology infrastructures mostly represented. Examples of TCs include Magna Engineering Center Steyr[20] in the field of batteries and electrical vehicles, Virtual Vehicle Research[21] also in the field of batteries, and the AEE - Institute for Sustainable Technologies[22] focusing on renewable energy and resource efficiency.

Another example is the Valencian Community with two important technology centres: the Instituto Tecnológico de la Energía[23] and the ITENE research centre[24], both with a large number of pilot plants and testbeds, mainly in the fields of batteries and renewable hydrogen.

The region of Southern Finland is another interesting example. Although the region includes the capital city Helsinki, the results are driven mostly by the presence of VTT Technical Research Centre of Finland, which is one of the largest technology centres in Europe, with a large number of infrastructures and very active in CREI technologies.

Figure 20: Distribution of total infrastructures by NUTS-2 region



Source: Compiled by the authors based on a sample of 2503 total infrastructures.

[19] More information here: https://www.greentech.at/en/uber-das-valley/

[20] https://engineering.mpt.magna.com/

[21] https://www.virtual-vehicle.at/

[22] https://www.aee-intec.at/

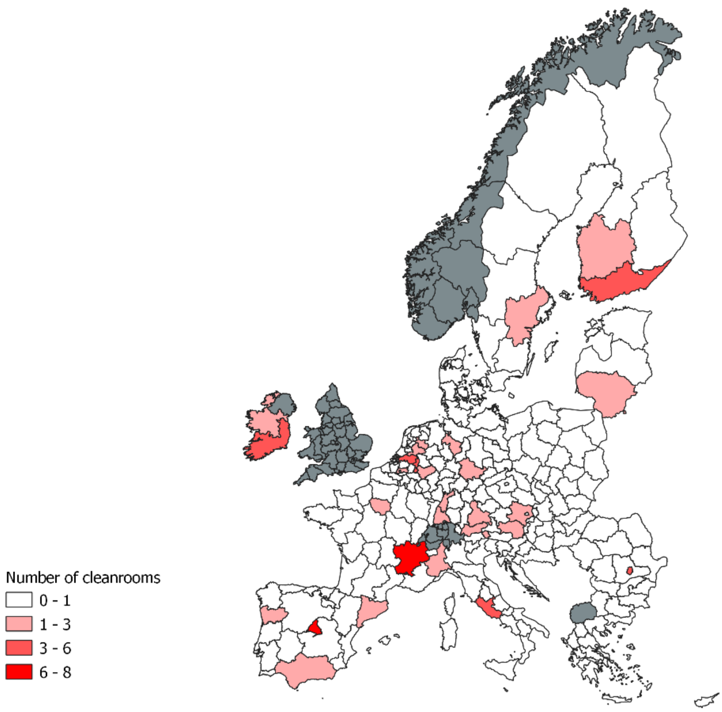
[23] https://www.ite.es/en/planta-piloto/

[24] https://www.itene.com/en/

Cleanrooms

Cleanrooms necessitate meticulous design, construction, and maintenance to meet stringent cleanliness standards. These requirements encompass specialized materials, advanced filtration systems, stringent monitoring, and precise temperature and humidity control, all of which contribute to substantial initial and ongoing expenses. Consequently, despite their importance, the prevalence of cleanrooms in Europe remains relatively low as presented in Figure 21. The technology centres host a total of 166 cleanrooms from which 125 could be allocated at NUTS-2 region.

Figure 21: Distribution of cleanrooms by NUTS-2 region



Source: Compiled by the authors based on a sample of 125 cleanrooms.

Table 5 illustrates the distribution of cleanrooms for the top 5 NUTS-2 regions. These regions are situated in Spain, France, Finland, and the Netherlands. Notably, the first three regions are highlighted in other sections due to their strong rankings in various types of technology infrastructures (see the section on testbeds). However, Lazio (IT) and Limburg (NL) represent distinct regions deserving attention. In Limburg, the Brightlands Chemelot Campus25 is driving the results. This technology centre is specialised in chemicals, plastics and biobased materials. It conducts research and development on performance materials in such a way that it contributes to the use of less material, energy or other resources. In Noord-Brabant,

[25] https://www.brightlands.com/en/brightlands-chemelot-campus/performance-materials/materials-sustainable-applications

IBS Precision Engineering26 constitutes an interesting example. It delivers ultra-precision machines which can be used in new energy production technologies.

Table 5: Top 5 NUTS-2 regions on number of cleanrooms

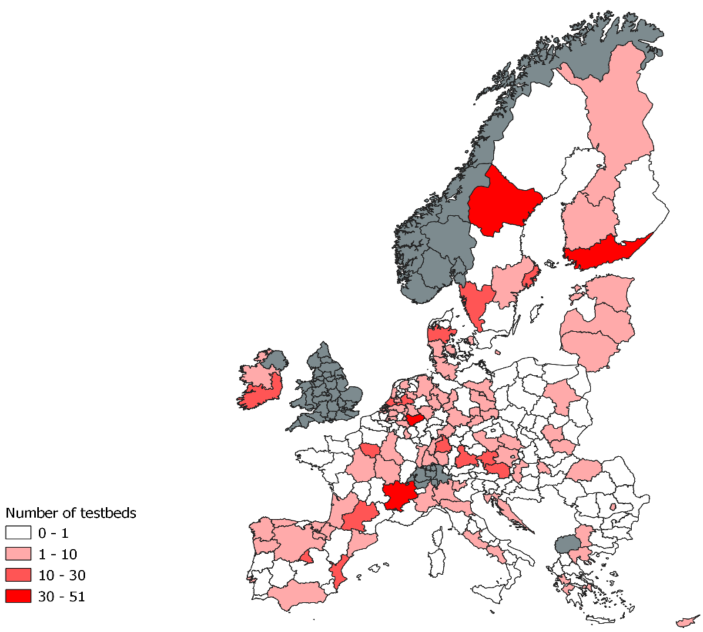
NUTS 2 code	Region name	Country	Number of cleanrooms
ES30	Comunidad de Madrid	Spain	8
FR71	Rhône-Alpes	France	8
FI18	Etelä-Suomi	Finland	6
NL42	Limburg	Netherlands	6
NL41	Noord-Brabant	Netherlands	5

Source: Compiled by the authors based on a sample of 125 cleanrooms.

Testbeds

The distribution of testbeds across NUTS-2 regions is presented in **Figure 22**. The distribution of testbeds is spread across Europe. While Western Europe is hosting a large part of testbeds, many regions in Eastern Europe (in particular in the Baltic countries, Poland and Romania) seem also well populated.

Figure 22: Distribution of testbeds by NUTS-2 region



Source: Compiled by the authors based on a sample of 834 testbeds.

[26] https://www.ibspe.com/

Five regions stand out for their high concentration of testbeds as presented in Table 6. Each of the top 5 regions hosts more than 27 testbeds: Köln (DE), Etelä-Suomi (FI), Rhône-Alpes (FR) and Mellersta Norrland (SE), and Comunidad Valenciana (ES). The robust presence of testbeds in Finland and Sweden can be attributed to the VTT Technical Research Centre of Finland and the Rise Research Institutes of Sweden, respectively. Rhône-Alpes distinguishes itself with three prominent technology centres housing numerous testbeds: CEA-Liten[27], Centre Scientifique et Technique du Bâtiment[28], and Supergrid[29]. These centres are dedicated to advancing the energy transition and actively engage in various domains such as solar energy, smart grid management, battery storage, and hydrogen technologies, all aimed at enhancing energy efficiency. Lastly, Comunidad Valenciana scores well due to the presence of the Technological Institute of Energy[30] which aims to guide companies towards technological innovation in all areas of energy transition.

Table 6: Top 5 NUTS-2 regions on number of testbeds

NUTS 2 code	Region name	Country	Number of testbeds
DEA2	Köln	Germany	51
FR71	Rhône-Alpes	France	49
FI18	Etelä-Suomi	Finland	48
SE32	Mellersta Norrland	Sweden	35
ES52	Comunidad Valenciana	Spain	28

Source: Compiled by the authors based on a sample of 834 testbeds.

Pilot plants

As illustrated in Figure 23, pilot plants are widespread across Europe. Most of the European regions have been 1 and 6 pilot plants. Higher concentrations can be observed in the capital and southern regions of France, Spain (with Valencia and Madrid as most prominent regions), Germany and Finland. As depicted in Figure 19, these regions are also highly populated with CREI companies, providing evidence for the colocation of CREI companies in regions where technology centres host many pilot plants. Proximity with these technology centres fosters collaboration, innovation, and knowledge exchange. It creates dynamic ecosystems for partnerships and breakthrough innovations in clean and renewable energies.

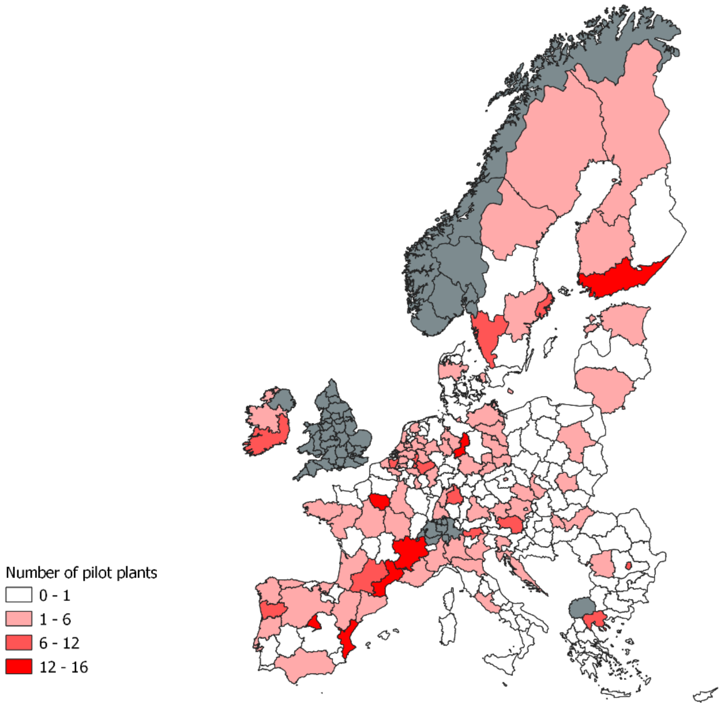
[27] https://liten.cea.fr/cea-tech/liten/english/Pages/Welcome.aspx

[28] https://recherche.cstb.fr/en/

[29] https://www.supergrid-institute.com/

[30] https://www.ite.es/en/

Figure 23: Distribution of pilot plants by NUTS-2 region



Source: Compiled by the authors based on a sample of 493 pilot plants.

Turning to the top 5 NUTS-2 regions on number of pilot plants in Table 7, two regions in Spain are top-ranked. Prominent technology centres with many pilot plants in these regions include ITENE research centre[31], the Spanish National Research Council (CSIC) and the previously mentioned Technological Institute of Energy.

Table 7: Top 5 NUTS-2 regions on number of pilot plants

NUTS 2 code	Region name	Country	Number of pilot plants
ES30	Comunidad de Madrid	Spain	16
ES52	Comunidad Valenciana	Spain	16
FI18	Etelä-Suomi	Finland	15
FR81	Languedoc-Roussillon	France	15
DE91	Braunschweig	Germany	14

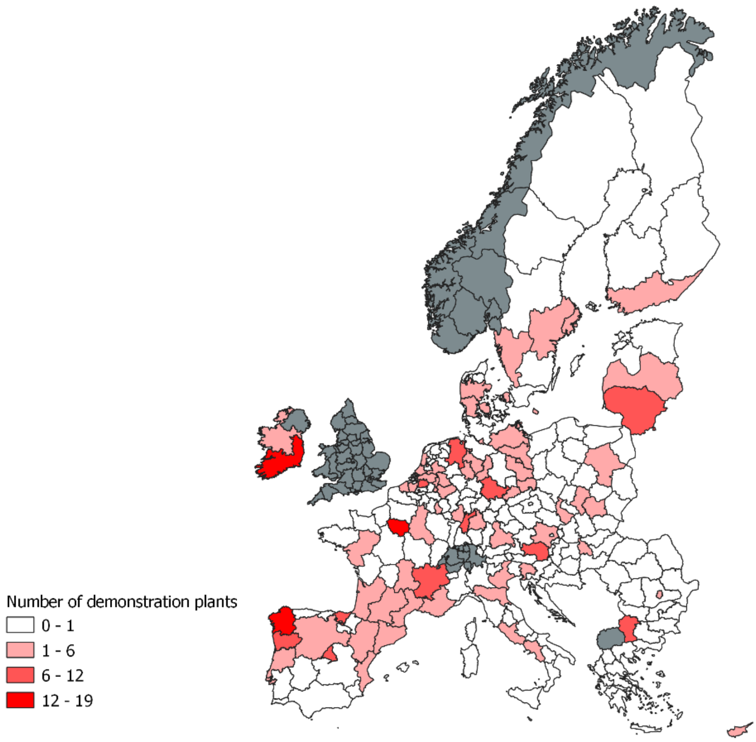
Source: Compiled by the authors based on a sample of 493 pilot plants.

[31] http://www.itene.com

Demonstration plants

Figure 24 illustrates the geographical distribution of demonstration plants across NUTS-2 regions. Consistent with patterns observed in earlier figures, these plants are spread across numerous regions, with notable clusters in Ireland, Spain, France, and Germany. The regions of Lietuva, encompassing Lithuania in its entirety, and Yugozapaden, the capital region of Bulgaria, stand out for their particularly high concentrations of demonstration plants. This prominence can be attributed to the Lithuanian Energy Institute[32] and the Bulgarian Academy of Sciences[33]. The former plays a pivotal role in hosting demonstration plants focusing on smart grids and renewable energy technologies. Conversely, the Bulgarian Academy of Sciences stands as Bulgaria's leading scientific and expertise hub, with a focus on renewable energy among its research areas.

Figure 24: Distribution of demonstration plants by NUTS-2 region



Source: Compiled by the authors based on a sample of 379 demonstration plants.

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[32] https://www.lei.lt/en/

[33] https://www.bas.bg/?page_id=11326&lang=en

Table 8 presents the top 5 NUTS-2 regions on number of demonstration plants. While the Southern and Eastern region of Ireland leads the ranking, Spain lists as most prominent country in the NUTS ranking, where concentrations of demonstration plants are mainly located in the north-west. The top rank for Ireland is driven by technology centres as Ireland's Centre for Applied AI[34] and Tyndall National Institute[35]. The latter institute is specialised in both electronics and photonics – materials, devices, circuits and systems which can be used in the research area of integrated energy systems and climate mitigation. Galicia's prominent place is driven by the EnergyLab Technology Centre[36], which focuses on the development of innovative solutions for the effective achievement and consolidation of the energy transition and the decarbonisation objectives of society. In País Vasco, the technology centre with the highest amount of demonstration plants is Koniker[37], scientific-technological agent specialised in research and development of new technologies related to machinery and industrial manufacturing processes. One of its research areas is solar photovoltaics. Finally, the Spanish National Research Council (CSIC) is the technology centre with the highest number of demonstrators in Madrid.

Table 8: Top 5 NUTS-2 regions on number of demonstration plants

NUTS 2 code	Region name	Country	Number of demonstration plants
IE02	Southern and Eastern	Ireland	19
ES11	Galicia	Spain	13
FR10	Île de France	France	13
ES21	País Vasco	Spain	11
ES30	Comunidad de Madrid	Spain	10

Source: Compiled by the authors based on a sample of 379 demonstration plants.

Living labs

The presence of living labs across Europe remains restricted. As illustrated in Figure 25, approximately 70 percent of NUTS-2 regions lack any living labs, with 24 percent hosting only 1 to 3 such facilities.

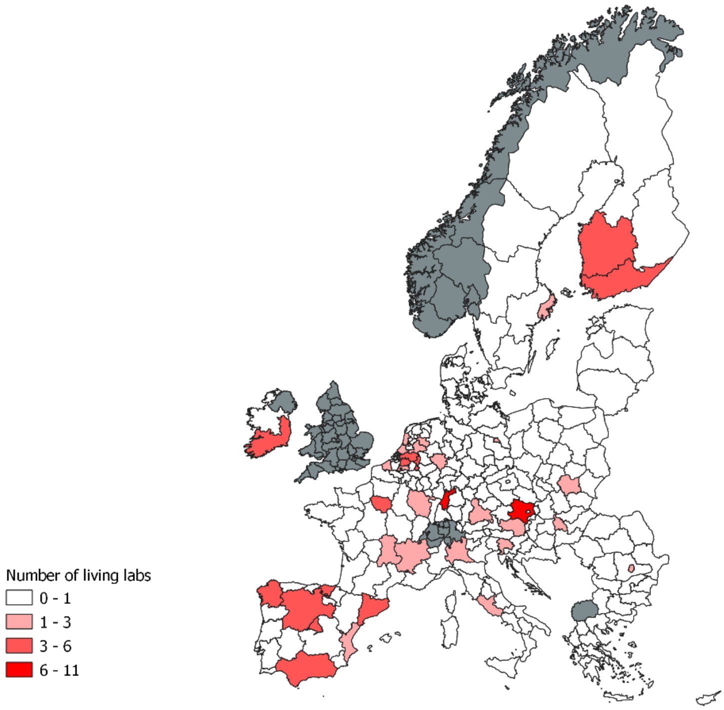
[34] http://ceadar.ie

[35] https://www.tyndall.ie/

[36] https://energylab.es/en/

[37] https://www.koniker.coop/en/ https://www.koniker.coop/en/

Figure 25: Distribution of living labs by NUTS-2 region



Source: Compiled by the authors based on a sample of 173 living labs.

Merely 10 regions have 5 or more living labs, and the top 5 among them are detailed in Table 9. In Lower Austria, which leads the ranking, living labs are mainly hosted at the AIT Austrian Institute of Technology38 and Business Intelligence & Innovation Hub39. The second top-ranked region is Karlsruhe with for instance the FZI Research Center for Information Technology40, hosting a living lab on smart energy, among others. Belgium is represented twice in the top ranking due to the presence of the technology centres of Actphast41 and the Offshore Wind Infrastructure Application Lab. Actphast is specially designed to support European companies who want to boost the innovation of their projects with photonics. The latter centre supports Belgian companies in the wind energy value chain and provides access to large climate test chambers and services. The last region in the top 5 is Galicia which scores well due to the presence of CETIM42, a private non-profit technology centre located in La Coruña, Spain, whose mission is to promote research, technological development and innovation in different economic sectors and economic activities. CETIM expertise covers three knowledge areas: eco bio technologies, advanced materials and digital industries.

[38] http://www.ait.ac.at/

[39] https://biih.labs.fhv.at/

[40] https://www.fzi.de/en/

[41] https://www.actphast.eu/en

[42] https://cetim.es/?lang=en

Table 9: Top 5 NUTS-2 regions on number of living labs

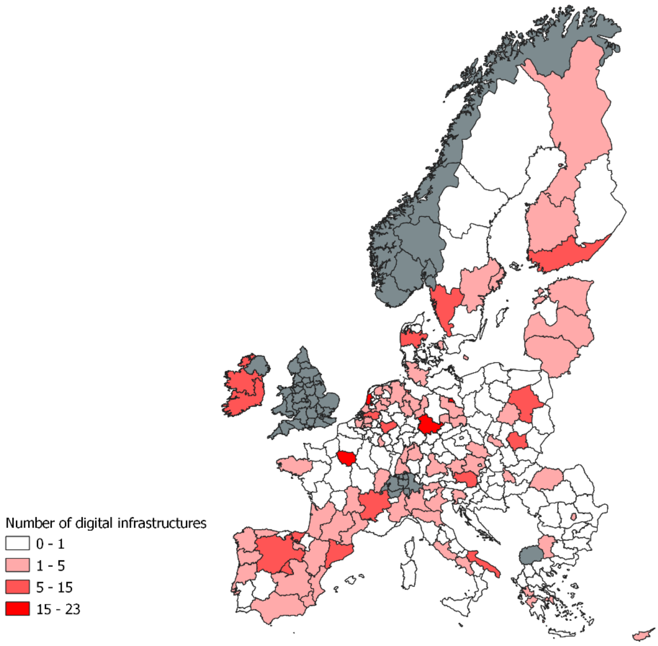
NUTS 2 code	Region name	Country	Number of living labs
AT12	Niederösterreich	Austria	11
DE12	Karlsruhe	Germany	8
BE10	Région de Bruxelles-Capitale	Belgium	8
BE21	Prov. Antwerpen	Belgium	5
ES11	Galicia	Spain	5

Source: Compiled by the authors based on a sample of 173 living labs.

Digital infrastructures

Digital infrastructures hosted by technology centres are widespread across European regions as illustrated in Figure 26. While the leading five regions are located in Germany, France, Netherlands and Finland as displayed in Table 10, it is interesting to see that several regions in East Europe also exhibit a high level of digital infrastructures. For instance, the region of Malopolskie (PL) is home to 10 digital infrastructure facilities, largely attributed to the Krakow Technology Park and the Solaris National Synchrotron Radiation Centre, both located in the outskirts of Krakow.

Figure 26: Distribution of digital infrastructures by NUTS-2 region



Source: Compiled by the authors based on a sample of 491 digital infrastructures.

In terms of digital infrastructure concentration, Berlin (DE), Île de France (FR), Noord-Holland (NL) and Thüringen (DE) feature among the top-ranked regions. Berlin's leading status is significantly influenced by the Helmholtz Centre Berlin for Materials and Energy43, whereas Thüringen hosts the Mittelstand 4.0 Competence Centre. In the Netherlands, the Future Internet Lab is an important player in terms of digital infrastructures. It conducts research and innovation development on big tech challenges, including the development of sustainable urban environments.

Table 10: Top 5 NUTS-2 regions on number of digital infrastructures

NUTS 2 code	Region name	Country	Number of digital infrastructures
DE30	Berlin	Germany	23
FR10	Île de France	France	20
NL32	Noord-Holland	Netherlands	17
DEG0	Thüringen	Germany	16
FI18	Etelä-Suomi	Finland	15

Source: Compiled by the authors based on a sample of 491 digital infrastructures.

[43] https://www.helmholtz.de/en/

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ANNEX

The web scraping has been performed on a potential list of 2885 technology centres. Around 13% of the websites of these technology centres could not be scraped due to blocked access from web servers preventing automated scraping or because website changed names and do no longer exist. From the 2516 successfully scraped technology centres, around 9% do not have technology infrastructure related keywords, while 44% do not mention any of the CREI technology related keywords on their websites. The relatively large fallout on CREI technology keywords is driven by the fact that the initial sample of technology centres is taken from various sources which includes a large variety of non-CREI related technologies associated with ICT, advanced manufacturing technology, micro- and nanoelectronics and photonics. The final sample of technology centres active in CREI technologies and having technology infrastructures includes 1396 centres as presented in Table 11.

Table 11: Final sample of CREI technology centres with technology infrastructures

Sample	Statistics	
	Number	Perc.
Initial sample of technology centres	2885	
Websites with web scraping errors	369	12,8%
Successfully scraped websites	2516	
Without technology infrastructure keywords	222	8,8%
Without CREI technology related keywords	1097	43,6%
Final sample of CREI technology centres with technology infrastructures	1396	

Table 12. Distribution of technology centres across technologies by Member State

	Solar photovoltaics	Wind energy	Heat pumps	Batteries	Electrolysers	Advanced biofuels	CCS/CCU	Total
AT	17.1%	16.4%	14.0%	20.5%	19.1%	7.8%	5.1%	100%
BE	17.5%	17.9%	14.8%	19.8%	19.8%	6.2%	3.9%	100%
BG	19.6%	17.9%	17.9%	19.6%	21.4%	3.6%	0.0%	100%
CY	19.4%	19.4%	19.4%	22.6%	19.4%	0.0%	0.0%	100%
CZ	18.9%	15.0%	11.8%	20.5%	22.8%	7.9%	3.1%	100%
DE	18.3%	17.6%	13.0%	20.0%	21.8%	6.0%	3.2%	100%
DK	15.5%	19.5%	15.5%	17.8%	15.5%	8.6%	7.5%	100%
EE	19.6%	17.6%	13.7%	19.6%	23.5%	3.9%	2.0%	100%
EL	16.7%	16.1%	15.6%	17.7%	18.8%	8.6%	6.5%	100%
ES	18.9%	16.3%	13.2%	20.2%	18.6%	8.7%	4.0%	100%
FI	16.7%	16.3%	14.4%	16.7%	17.2%	11.5%	7.2%	100%
FR	17.6%	15.9%	11.8%	21.9%	22.6%	5.8%	4.5%	100%
HR	23.7%	16.9%	16.9%	18.6%	23.7%	0.0%	0.0%	100%
HU	16.1%	17.9%	12.5%	23.2%	17.9%	8.9%	3.6%	100%
IE	19.4%	18.5%	17.1%	20.8%	20.4%	1.9%	1.9%	100%
IT	19.4%	16.7%	15.1%	20.9%	19.8%	5.2%	2.9%	100%
LT	16.7%	15.5%	15.5%	20.2%	17.9%	9.5%	4.8%	100%
LU	16.3%	14.0%	14.0%	14.0%	18.6%	11.6%	11.6%	100%
LV	17.2%	17.2%	13.8%	27.6%	24.1%	0.0%	0.0%	100%
MT	33.3%	16.7%	16.7%	16.7%	16.7%	0.0%	0.0%	100%
NL	18.4%	17.6%	16.8%	19.5%	20.7%	4.7%	2.3%	100%
PL	17.6%	15.9%	13.6%	19.3%	20.5%	10.2%	2.8%	100%
PT	17.1%	17.1%	14.3%	17.7%	18.3%	10.9%	4.6%	100%
RO	18.7%	17.9%	13.0%	18.7%	18.7%	10.6%	2.4%	100%
SE	15.3%	15.0%	13.8%	16.7%	15.8%	13.0%	10.5%	100%
SI	20.8%	15.3%	11.1%	22.2%	19.4%	8.3%	2.8%	100%
SK	17.9%	17.9%	12.8%	20.5%	23.1%	2.6%	5.1%	100%

Note: The distributions are based on 1357 CREI technology centres (39 centres have missing information for the country).
Source: Compiled by the authors based on web scraping of technology centres' websites.

Table 13. Distribution of technology centres across Member States by technology

	Solar photovoltaics	Wind energy	Heat pumps	Batteries	Electrolysers	Advanced biofuels	CCS/CCU
AT	4.9%	5.1%	5.2%	5.4%	5.0%	5.6%	6.2%
BE	4.4%	4.9%	4.8%	4.6%	4.6%	3.9%	4.1%
BG	1.1%	1.1%	1.3%	1.0%	1.1%	0.5%	0.0%
CY	0.6%	0.6%	0.8%	0.6%	0.5%	0.0%	0.0%
CZ	2.4%	2.0%	1.9%	2.3%	2.6%	2.4%	1.7%
DE	15.9%	16.4%	14.5%	15.8%	17.2%	12.8%	11.6%
DK	2.7%	3.6%	3.4%	2.8%	2.4%	3.6%	5.4%
EE	1.0%	1.0%	0.9%	0.9%	1.1%	0.5%	0.4%
EL	3.1%	3.2%	3.7%	3.0%	3.1%	3.9%	5.0%
ES	13.0%	12.1%	11.7%	12.7%	11.6%	14.8%	11.6%
FI	3.5%	3.6%	3.8%	3.1%	3.2%	5.8%	6.2%
FR	9.3%	9.0%	8.0%	10.5%	10.8%	7.5%	10.0%
HR	1.4%	1.1%	1.3%	1.0%	1.3%	0.0%	0.0%
HU	0.9%	1.1%	0.9%	1.2%	0.9%	1.2%	0.8%
IE	4.2%	4.2%	4.7%	4.0%	3.9%	1.0%	1.7%
IT	8.5%	7.8%	8.5%	8.4%	7.9%	5.6%	5.4%
LT	1.4%	1.4%	1.7%	1.5%	1.3%	1.9%	1.7%
LU	0.7%	0.6%	0.8%	0.5%	0.7%	1.2%	2.1%
LV	0.5%	0.5%	0.5%	0.7%	0.6%	0.0%	0.0%
MT	0.2%	0.1%	0.1%	0.1%	0.1%	0.0%	0.0%
NL	4.6%	4.8%	5.5%	4.5%	4.7%	2.9%	2.5%
PL	3.1%	3.0%	3.0%	3.1%	3.2%	4.4%	2.1%
PT	3.0%	3.2%	3.2%	2.8%	2.9%	4.6%	3.3%
RO	2.3%	2.3%	2.0%	2.1%	2.1%	3.1%	1.2%
SE	5.3%	5.6%	6.2%	5.3%	5.0%	11.1%	15.4%
SI	1.5%	1.2%	1.0%	1.4%	1.3%	1.5%	0.8%
SK	0.7%	0.7%	0.6%	0.7%	0.8%	0.2%	0.8%
Total	100%	100%	100%	100%	100%	100%	100%

Note: The distributions are based on 1357 CREI technology centres (39 centres have missing information for the country).
Source: Compiled by the authors based on web scraping of technology centres' websites.

Table 14. Distribution of technology infrastructures across type of infrastructure by Member State

Country	Clean rooms	Pilot plants	Demonstrators	Testbeds	Living labs	Digital infrastructures	Total
AT	5.8%	17.9%	16.7%	32.7%	10.9%	16.0%	100%
BE	3.8%	20.5%	17.6%	25.7%	17.6%	14.8%	100%
BG	0.0%	6.3%	43.8%	12.5%	0.0%	37.5%	100%
CY	0.0%	10.5%	15.8%	36.8%	5.3%	31.6%	100%
CZ	0.0%	22.0%	4.9%	39.0%	0.0%	34.1%	100%
DE	3.2%	17.3%	16.7%	36.2%	6.1%	20.4%	100%
DK	4.1%	17.3%	14.3%	46.9%	1.0%	16.3%	100%
EE	0.0%	11.1%	3.7%	25.9%	37.0%	22.2%	100%
EL	3.9%	39.5%	5.3%	28.9%	5.3%	17.1%	100%
ES	3.4%	16.5%	14.8%	31.1%	10.5%	23.6%	100%
FI	8.3%	17.4%	5.6%	42.4%	7.6%	18.8%	100%
FR	4.7%	20.5%	19.2%	33.7%	3.9%	18.1%	100%
HR	0.0%	33.3%	0.0%	33.3%	16.7%	16.7%	100%
HU	2.2%	31.1%	20.0%	17.8%	13.3%	15.6%	100%
IE	7.2%	13.0%	35.5%	17.4%	4.3%	22.5%	100%
IT	9.3%	21.9%	13.2%	24.5%	6.0%	25.2%	100%
LT	5.9%	23.5%	35.3%	11.8%	0.0%	23.5%	100%
LU	0.0%	16.7%	16.7%	25.0%	25.0%	16.7%	100%
LV	0.0%	9.1%	18.2%	45.5%	9.1%	18.2%	100%
MT	0.0%	33.3%	33.3%	0.0%	0.0%	33.3%	100%
NL	10.6%	16.1%	8.5%	29.7%	11.4%	23.7%	100%
PL	0.0%	22.4%	27.6%	17.2%	3.4%	29.3%	100%
PT	6.0%	22.4%	28.4%	14.9%	9.0%	19.4%	100%
RO	10.4%	27.1%	8.3%	33.3%	4.2%	16.7%	100%
SE	3.6%	20.1%	13.0%	47.9%	5.3%	10.1%	100%
SI	1.9%	15.1%	34.0%	1.9%	24.5%	22.6%	100%
SK	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	100%

Note: The distributions are based on 3203 technology infrastructures (64 technology infrastructures have missing information for the country).
Source: Compiled by the authors based on web scraping of technology centres' websites.

Table 15. Distribution of technology infrastructures across Member States by type of infrastructure

	Cleanrooms	Pilot plants	Demonstrators	Testbeds	Living labs	Digital infrastructures
AT	5.8%	4.6%	5.0%	5.0%	6.5%	3.9%
BE	5.2%	7.1%	7.0%	5.3%	14.1%	4.8%
BG	0.0%	0.2%	1.3%	0.2%	0.0%	0.9%
CY	0.0%	0.3%	0.6%	0.7%	0.4%	0.9%
CZ	0.0%	1.5%	0.4%	1.6%	0.0%	2.2%
DE	12.3%	16.9%	18.7%	21.0%	13.7%	18.7%
DK	2.6%	2.8%	2.7%	4.5%	0.4%	2.5%
EE	0.0%	0.5%	0.2%	0.7%	3.8%	0.9%
EL	1.9%	5.0%	0.8%	2.2%	1.5%	2.0%
ES	9.1%	11.2%	11.6%	12.6%	16.3%	15.1%
FI	7.8%	4.1%	1.5%	6.0%	4.2%	4.2%
FR	11.7%	13.1%	14.1%	12.8%	5.7%	10.9%
HR	0.0%	0.3%	0.0%	0.2%	0.4%	0.2%
HU	0.6%	2.3%	1.7%	0.8%	2.3%	1.1%
IE	6.5%	3.0%	9.3%	2.4%	2.3%	4.8%
IT	9.1%	5.5%	3.8%	3.6%	3.4%	5.9%
LT	0.6%	0.7%	1.1%	0.2%	0.0%	0.6%
LU	0.0%	0.7%	0.8%	0.6%	2.3%	0.6%
LV	0.0%	0.2%	0.4%	0.5%	0.4%	0.3%
MT	0.0%	0.2%	0.2%	0.0%	0.0%	0.2%
NL	16.2%	6.3%	3.8%	6.9%	10.3%	8.7%
PL	0.0%	2.1%	3.0%	1.0%	0.8%	2.6%
PT	2.6%	2.5%	3.6%	1.0%	2.3%	2.0%
RO	3.2%	2.1%	0.8%	1.6%	0.8%	1.2%
SE	3.9%	5.6%	4.2%	8.0%	3.4%	2.6%
SI	0.6%	1.3%	3.4%	0.1%	4.9%	1.9%
SK	0.0%	0.0%	0.0%	0.5%	0.0%	0.0%
Total	100%	100%	100%	100%	100%	100%

Note: The distributions are based on 3203 technology infrastructures (64 technology infrastructures have missing information for the country).
Source: Compiled by the authors based on web scraping of technology centres' websites.

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The report presents a mapping of technology centres that provide advanced technology infrastructures and their services for industry across the 27 EU Member States, encompassing the seven key technology domains of Clean and Renewable Energy Industries (CREI). The analysis shows that significant concentration patterns emerge where industrial entities cluster their operations near technology centres offering support services through various types of infrastructures. Germany and Italy emerge as the Member States where both technology centres and companies active in CREI technology are significantly concentrated. Other Member States hosting several technology centres as well as numerous companies active in CREI technologies include the Netherlands, Spain and the Nordic. Eastern European countries are instead characterized by the presence of a relatively high number of technology centres compared to the number of companies active in this sector.

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