



EMPHASIS RI
Socioeconomic impact
assessment



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Socioeconomic impact assessment EMPHASIS RI

HFFA Research GmbH

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List of Abbreviations

ELIXIR	–	European Life-Sciences Infrastructure
EMPHASIS	–	European Infrastructure for Multi-Scale Plant Phenotyping and Simulation for Food Security in a Changing Climate
EMPHASIS-GO	–	EMPHASIS Governance and Operations project
EMPHASIS-PREP	–	Preparatory Phase Project for EMPHASIS
EPPN	–	European Plant Phenotyping Network
ESFRI	–	European Strategy Forum on Research Infrastructures
FAIR	–	Findable, Accessible, Interoperable, Reusable (data principles)
MIAPPE	–	Minimum Information About a Plant Phenotyping Experiment
NPEC	–	Netherlands Plant Eco-phenotyping Centre
RI	–	Research Infrastructure
RI-PATHS	–	Research Infrastructure Impact Pathways project

Executive Summary

Plant phenotyping has become a critical driver of innovation in agriculture, enabling deeper understanding of plant–environment interactions and supporting the development of resilient, resource-efficient and sustainable crops. Over the past two decades, Europe has seen rapid growth in phenotyping research, technologies and investment. Scientific publications have expanded sharply since the early 2010s, innovation is reflected in rising patent activity and new technology companies, and public funding at both EU and national levels has increased significantly. This expanding landscape provides the context in which EMPHASIS has emerged as a unifying European research infrastructure.

Building on the foundations laid by EPPN and EPPN2020, EMPHASIS has progressively strengthened European phenotyping capacity. Through its preparatory and implementation projects, EMPHASIS has mapped over 200 installations, supported access and training activities, advanced data standards and methods, and fostered collaboration across countries. Stakeholders consistently highlighted its role in connecting national infrastructures, supporting emerging facilities, and helping the field speak with a more coordinated voice.

The socioeconomic assessment confirms clear contributions across four key impact areas. In **human resources**, EMPHASIS-linked activities have improved technical skills, supported a new generation of researchers and technologists to understand and confidently deploy plant phenotyping approaches, delivered career development for early-career researchers, and enabled access to advanced facilities for scientists from underrepresented regions. In **economy and innovation**, EMPHASIS has facilitated practical technical exchange, early-stage co-development of tools and methods with industry, and improvements in operational efficiency across research infrastructures. Plant phenotyping itself is already enabling faster breeding cycles, better resource-use efficiency and data-driven innovation. In **societal and environmental terms**, phenotyping contributes to climate resilience, sustainable farming, and smarter use of water and nutrients. Finally, in **policy**, EMPHASIS has strengthened national phenotyping communities, improved their ability to engage ministries, and contributed to European strategy discussions on RI, agriculture and climate.

At the same time, the study identifies several areas for further development. Many EMPHASIS services remain distributed across EU projects and are not yet visible as part of a coherent, central offer. Industry collaboration is growing but still fragmented, and stakeholders called for clearer communication of EMPHASIS's unique value. A more systematic approach to tracking impacts is also needed as the infrastructure moves into its next phase.

Overall, EMPHASIS is recognised as an essential enabler of European plant phenotyping. Its next challenge—and opportunity—lies in translating its strong foundations into a fully operational ERIC that provides clear, accessible services; strengthens collaboration across countries and sectors; and supports Europe's long-term goals in sustainable agriculture, climate resilience, and plant-based innovation.

1. Context and Purpose of the Study

Plant phenotyping has become a central driver of innovation in agriculture, supporting progress in basic plant science, breeding, sustainable farming, digital agriculture and emerging bio-based sectors. Its applications extend from crop improvement and resource efficiency to functional foods, nutrition, and plant-based pharmaceuticals. Against this backdrop, EMPHASIS—the European Infrastructure for Multi-Scale Plant Phenotyping and Simulation—was created to coordinate and strengthen European capabilities in this rapidly expanding field.

Building on more than a decade of earlier initiatives such as EPPN, EPPN2020 and EMPHASIS-PREP, the infrastructure aims to make phenotyping resources more accessible, interoperable, and impactful. As EMPHASIS prepares for full legal and operational status and future ERIC establishment, assessing its broader socioeconomic contributions has become important. This study, conducted within the Horizon Europe project EMPHASIS-GO, evaluates both the achievements to date and the future potential of EMPHASIS for research, industry, and society.

The assessment examines how EMPHASIS supports scientific collaboration, knowledge exchange, technology development and capacity building across Europe. It also investigates where EMPHASIS has already influenced the field and where further development is needed. Three main objectives guide the study:

- **Documenting the growth of plant phenotyping in Europe** since the early 2010s, using data-driven indicators.
- **Mapping the activities of EPPN, EPPN2020 and EMPHASIS**, and how they contribute to training, infrastructure development and methodological improvement.
- **Assessing medium- and long-term benefits**, including impacts on human capital, innovation, the economy, society and policy.

By providing this evidence base, the study positions EMPHASIS as an important European asset for advancing plant phenotyping and contributing to wider goals in sustainability, innovation and resilience.

2. Methodological Framework of the Study

2.1 Study design

The assessment is structured into three components:

1. **Phenotyping Landscape Analysis** – A quantitative overview of how plant phenotyping has developed in Europe, using indicators such as scientific publications, patents, start-ups, and public funding.
2. **Activities and Achievements** – A factual summary of the actions undertaken by EMPHASIS and its predecessors since 2012, based on project reports and documentation.
3. **Impact Analysis** – The core component, based on 23 stakeholder interviews across research, industry, and policy. It examines EMPHASIS's contributions to human resources, innovation and

the economy, society, and policy, including both observed impacts and expected future benefits.

The study follows the principle that EMPHASIS activities lead to outputs and outcomes, which then contribute to longer-term impacts. Because EMPHASIS is still in a preparatory phase, many impacts are emerging rather than fully measurable.

2.2 Conceptual background of the *Impact Analysis*

The impact assessment uses the **RI-PATHS** framework¹ (<https://ri-paths-tool.eu/en>) which traces impacts along a pathway from inputs, to outputs, to outcomes, and finally to long-term effects. Impacts are grouped into four areas: **Human Resources, Economy & Innovation, Society, and Policy**.

Since several EMPHASIS services are still under development, some impact pathways are currently theoretical. The analysis therefore includes both **actual** and **expected** impacts. It also recognises that the wide ecosystem of plant phenotyping itself delivers societal and economic benefits, which EMPHASIS indirectly enables.

Seven key impact pathways are considered:

Impact Area: Human Resources

Pathway 1 — Learning and training through use of infrastructure

Access to phenotyping installations and training activities improves skills, builds collaborations, and enhances career development, especially for researchers from underrepresented regions.

Impact Area: Economy & Innovation

Pathway 2 — Joint development of instruments and tools

Collaborative technical development drives innovation and spreads new technologies.

Pathway 3 — Science–industry partnerships

Better connections between academia and industry support technology uptake, co-development, and economic growth.

Pathway 4 — Provision of curated/FAIR data

Standardised data systems enable broader data reuse, support discovery, and increase efficiency in research and breeding.

Impact Area: Society

Pathway 5 — Addressing societal challenges

Phenotyping supports climate resilience, sustainable agriculture, and the bioeconomy through improved plant traits and resource-efficient technologies.

¹ RI-PATHS provides funders and managers of research infrastructures the tools to assess their impact on the economy and contribution to society.

Impact Area: Policy

Pathway 6 — Engaging science, society and policy

EMPHASIS contributes to evidence-based policy through participation in committees, consultations and networks.

Cross-cutting Pathway

Pathway 7 — Publications and scientific recognition

EMPHASIS-supported research generates scientific outputs that feed into further research, policy, and innovation.

2.3 Data sources

The analysis integrates quantitative and qualitative data. Publication, patent and funding trends were gathered through open databases and literature review. Activity summaries draw on project documents. Impact findings are based on 23 interviews across research, industry and policy, providing diverse perspectives from different regions and roles (see Table 1).

Table 1: List of interview partners

Research (10 interviewees)	Politics (5 interviewees)	Private Sector (8 interviewees)
Rick van de Zedde, NPEC2 / WUR (The Netherlands)	Mihaela Constantin & Pierre-Mathieu Pelissier, DG RTD (EU)	Ludo van Put, WIWAM (Belgium)
Francesco Loreto, Michelina Ruocco PHEN-Italy (Italy)	José Luis Martínez Peña, ESFRI (Spain)	Vincent Jalink, Phenovation (The Netherlands)
François Tardieu & Cyril Pommier, INRAE (France)	Philipp von Gillhaussen, IPPN (Germany)	Alexis Comar, Hiphen (France)
Pedro Barros, ITQB (Portugal)	Tim Shuttleworth, BBSRC UKRI (Great Britain)	Robert Tietz, LemnaTec (Germany)
Márcia Raquel Gomes de Carvalho, UTAD-University (Portugal)		Udo Seiffert, Compolytics (Germany)
Morten Lillemo, NMBU (Norway)		Viktor Korzun, Gemma Molero & Dirk Wiechers, KWS (Germany)
Photini Mylona, Hellenic Agricultural Organisation (Greece)		
Karim Ammar, CIMMYT (Global)		

2.4 Limitations of the study

The study faces attribution challenges: developments in plant phenotyping cannot be directly linked to EMPHASIS alone. Since EMPHASIS is still evolving, many services are not fully operational, making long-term impacts difficult to observe. Qualitative interview data introduce subjectivity, though efforts were

² Netherlands Plant Eco-phenotyping Centre

made to standardize interview protocols, ‘verify’ individual statements in other interviews (triangulate perspectives) and ensure balanced representation.

3. Phenotyping Landscape Analysis

The Phenotyping Landscape Analysis examines how plant phenotyping has evolved in Europe over the past two decades. Three types of indicators were analysed: **scientific output**, **innovation and commercial uptake**, and **public investment**. Although this is not an exhaustive set of metrics, the selected indicators provide a robust overview of growth trends in the field.

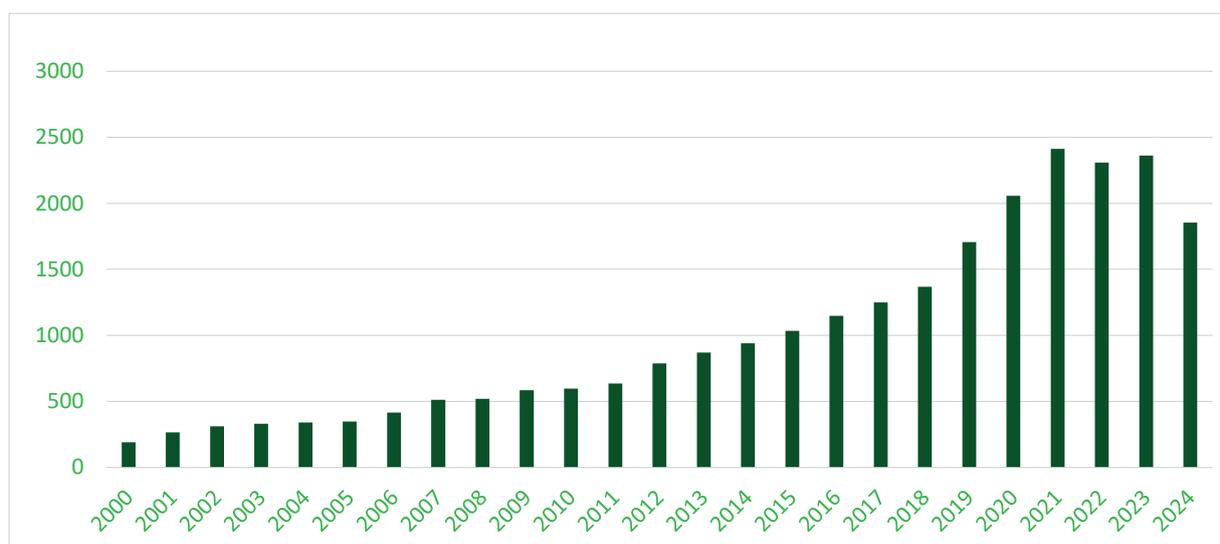
3.1 Scientific output

The scientific output was measured by looking at the number of publications related to plant phenotyping. Different open-source databases were used to triangulate the results. OpenAlex (www.openalex.org) and BASE (www.base-search.net) were used to track the plant phenotyping related publications in Europe and for reasons of comparability Google Scholar (<https://scholar.google.com/>) was used to capture the global coverage.

The search queries were standardized across databases to capture all relevant literature on plant phenotyping while ensuring that only plant-related publications were included. We developed a Boolean search query that retrieved results containing any of the terms *phenotyping*, *imaging*, *multispectral*, or *high-throughput* in combination with *plant*. To further refine the results, we excluded publications related to animals or humans.

As displayed in the figures below, since 2000 there has been a steady increase in the number of relevant publications at European as well as international level. Based on OpenAlex (Figure 1), from 2018 onwards, the number of publications increases significantly from year to year. However, in 2024, the number dropped compared to previous years. One reason could be that not all publications published in 2024 have been included in the database yet.

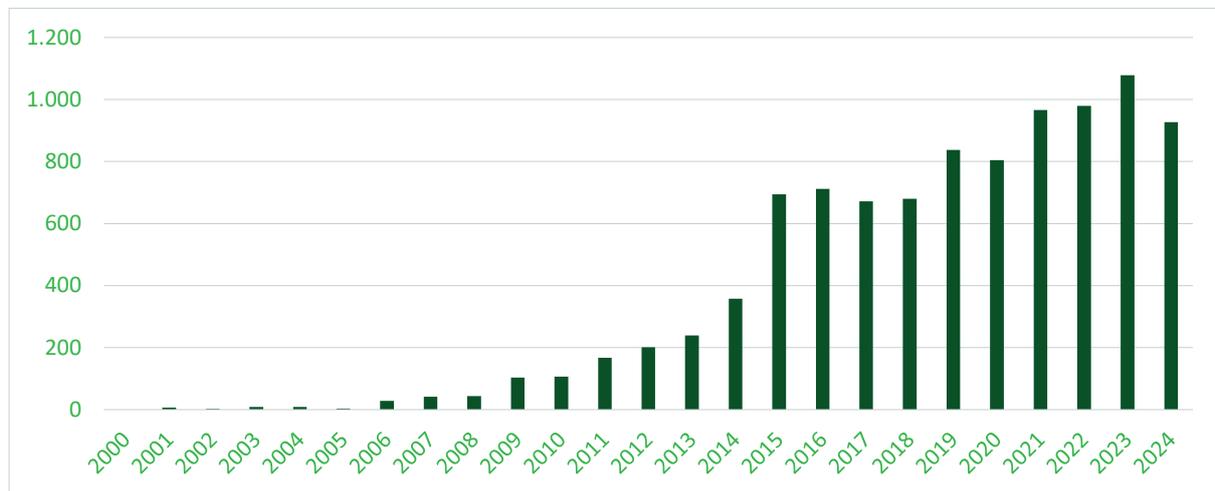
Figure 1: Number of publications in the field of plant phenotyping published in Europe since 2000 (I)



Source: openalex.org

The figures based on BASE (Figure 2) show a similar picture: a steady increase since the early 2010s and a significant jump in 2015 compared to 2014. From then until 2023, the number of publications has increased by approximately 50 percent. There is again a visible drop in 2024, however, presumably due to the same lag-factors explained above.

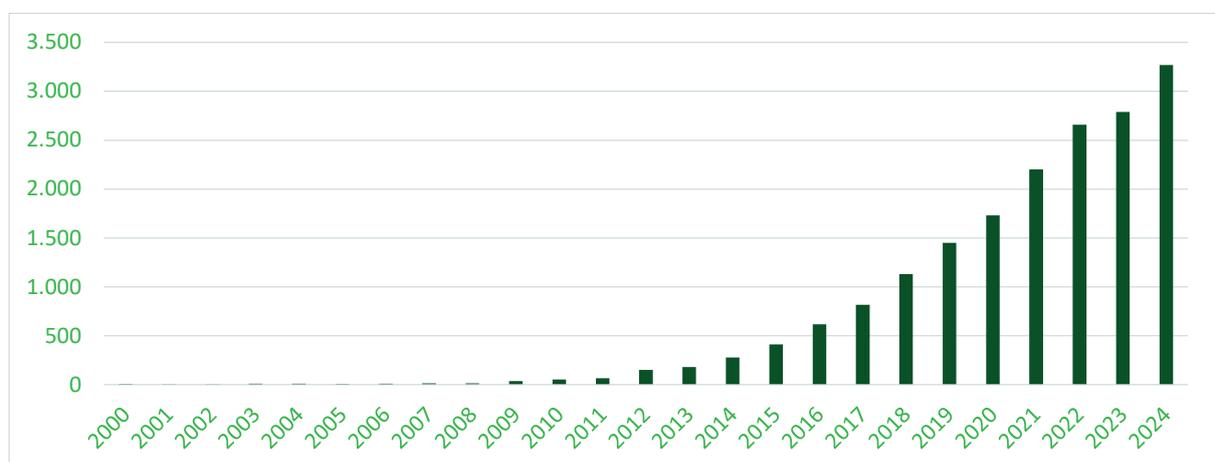
Figure 2: Number of publications in the field of plant phenotyping published in Europe since 2000 (II)



Source: base-search.net

At the international level, the number of publications is growing exponentially (Figure 3). Here, the significant upturn from the early 2010s is particularly evident. Unlike at the European level, the number of publications is by far the highest in 2024. The difference between EU-level and global publications in 2024 is likely due to the use of different data sources. Open-source databases as used for the EU often depend on metadata updates from individual institutions, meaning many 2024 publications may not yet be indexed. In contrast, Google Scholar crawls a wide range of sources continuously and captures new publications much faster. This discrepancy in indexing speed likely explains why the EU count appears to dip in 2024 while the global count reaches its highest point. Unfortunately, at Google Scholar it is impossible to filter by region, which is why we cannot verify whether the difference is only methodological.

Figure 3: Number of publications published globally since 2000

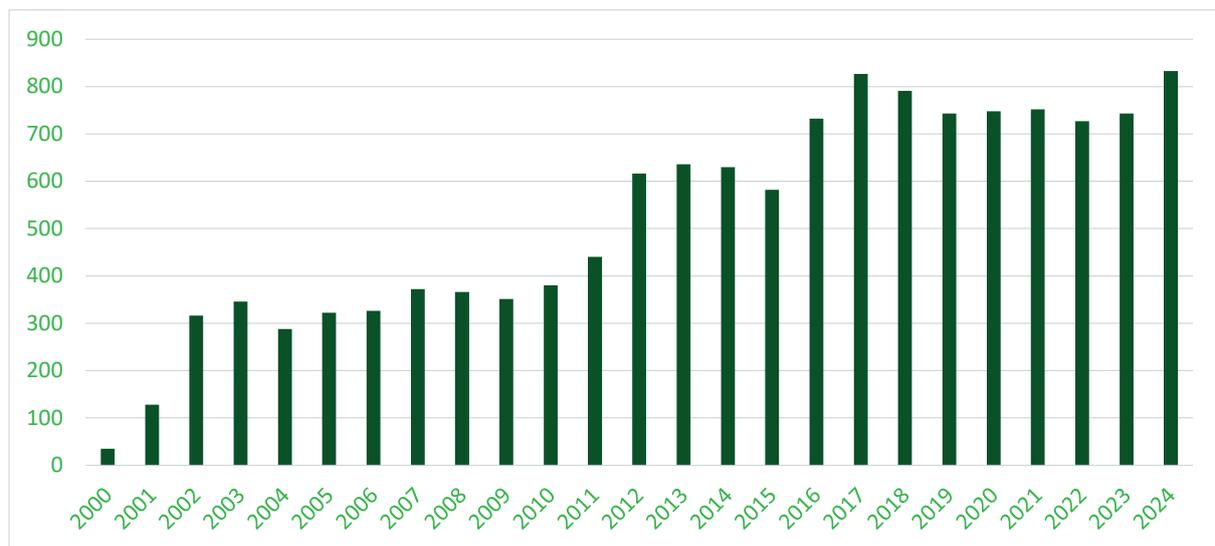


Source: scholar.google.com

3.2 Innovation output and commercial uptake

Innovation output was measured by counting the number of patents that European inventors have applied for in plant phenotyping since 2000 based on www.lens.org. As for the publications, the search is based on a Boolean search query³. There has been a steady but slight increase since 2002 with a sharper increase in 2012 (Figure 4). Since lens.org database contains also scholarly research, we ran a test of how plant phenotyping research impacted patent applications. Of the 11,026 plant phenotyping publications identified at lens.org, over 1,000 have been cited in patents, linking them to nearly 4,000 individual patents. This shows how plant phenotyping research is not only advancing science but also driving real-world innovation.

Figure 4: Number of patent applications from European inventors in the plant phenotyping domain



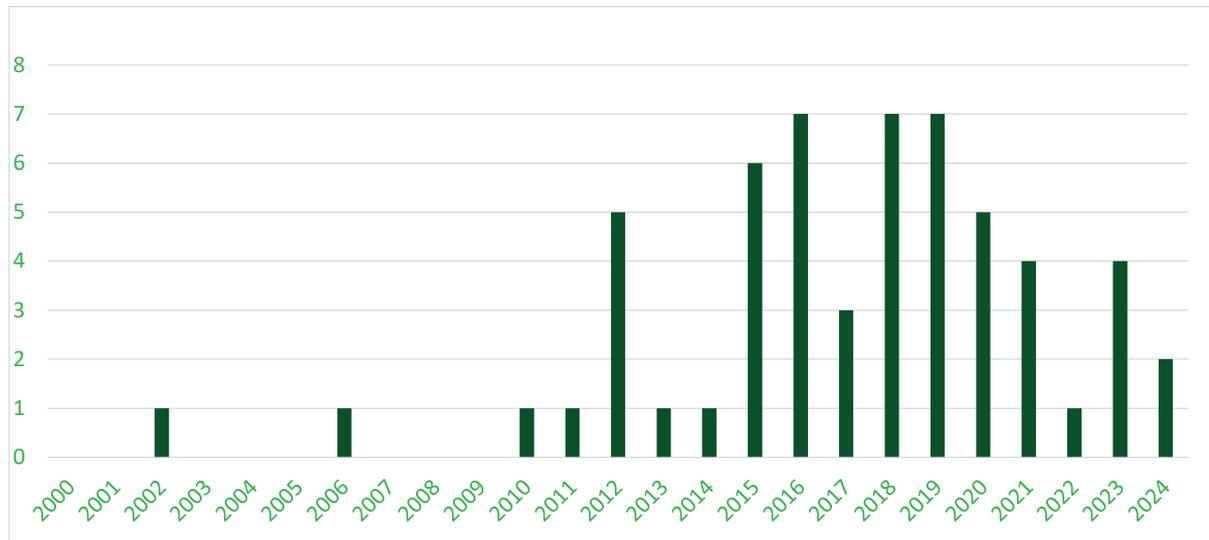
Source: lens.org

While the growing relevance of plant phenotyping is well documented in scientific publications and patent applications, we also aimed to assess its commercial use and impact by analyzing companies that have successfully built a business case around it. Figure 5 shows the number of startups in plant phenotyping founded in Europe since 2000. It is evident that, while between 2000 and 2011 only four companies were established, this number increased sharply from 2012 onwards, with 50 companies founded between 2012 and 2024. The majority of companies included in the statistics are technology providers, often active in the fields of imaging and sensor systems, as well as data analytics and management. The results are based on searches conducted on relevant portals and via Google.

A couple of things must be noted: since all listed companies have active websites, we assume they are still in operation. However, this approach cannot accurately capture the founding activity in earlier years, as companies that have since ceased to exist are not represented. This may distort the picture, given that some of the recently founded companies may also no longer be in business in the coming years. In addition, although we conducted an intensive search, we do not claim to be exhaustive, and it is possible that some relevant companies have been overlooked.

³ multispectral plant imaging) OR (high-throughput plant imaging) OR (plant trait measurement) OR (hyperspectral plant sensor) OR (crop phenotyping) NOT (human) NOT (mammal) NOT (animal) NOT (mouse)

Figure 5: Number of European plant phenotyping technology companies founded between 2000 and 2024



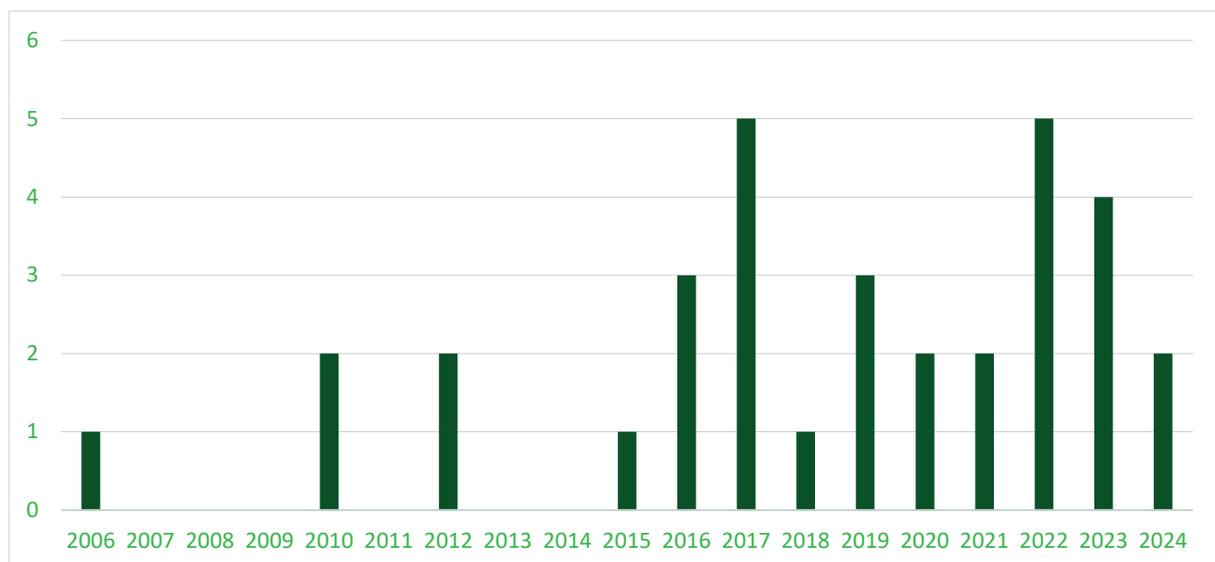
Source: eu-startups.com, Google.com, LinkedIn.com, Crunchbase

3.3 Research expenditure for plant phenotyping related projects

3.3.1 Expenditures at EU level

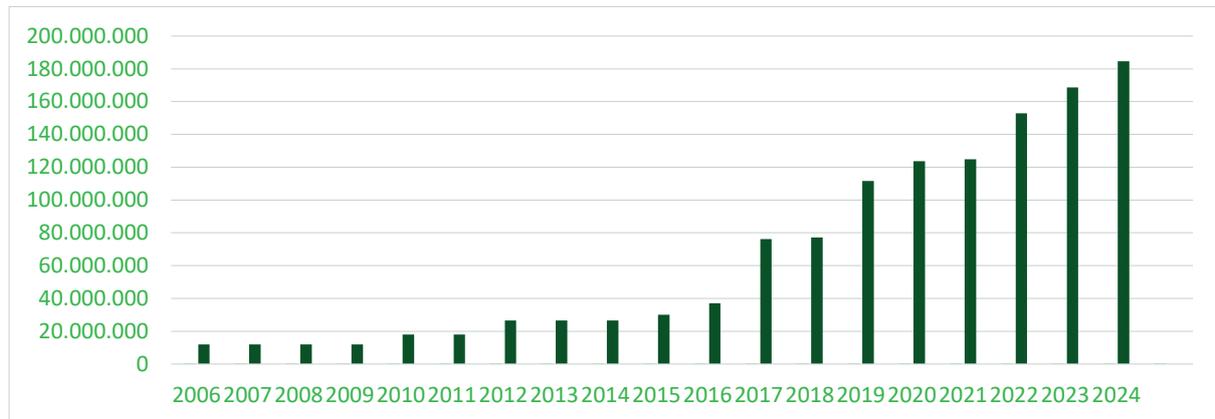
Public spending on research in the field of plant phenotyping at EU level has increased significantly in recent years. Figure 6 shows the number of projects launched each year. The statistics include projects explicitly dedicated to plant phenotyping; however, in most cases, plant phenotyping is not the primary focus but rather just one aspect of the project. Aggregate expenditure from 2006 to 2024 amounts to almost 187 million Euros (see Figure 7).

Figure 6: Number of EU Projects started between 2006 and 2024



Source: cordis.europa.com

Figure 7: Aggregated investments in plant phenotyping and related projects at EU level in €



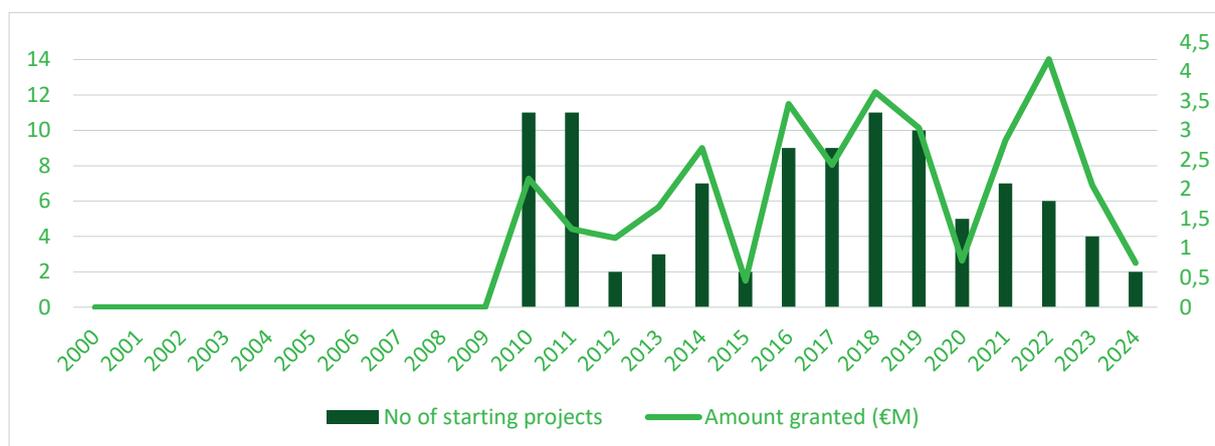
Source: cordis.europa.com

3.3.2 Expenditures at national level

In addition to European investment trends in plant phenotyping, we also conducted an analysis at national level using two countries as example. In order to do so, we used an automated process to search the national research funding databases in France and the United Kingdom.

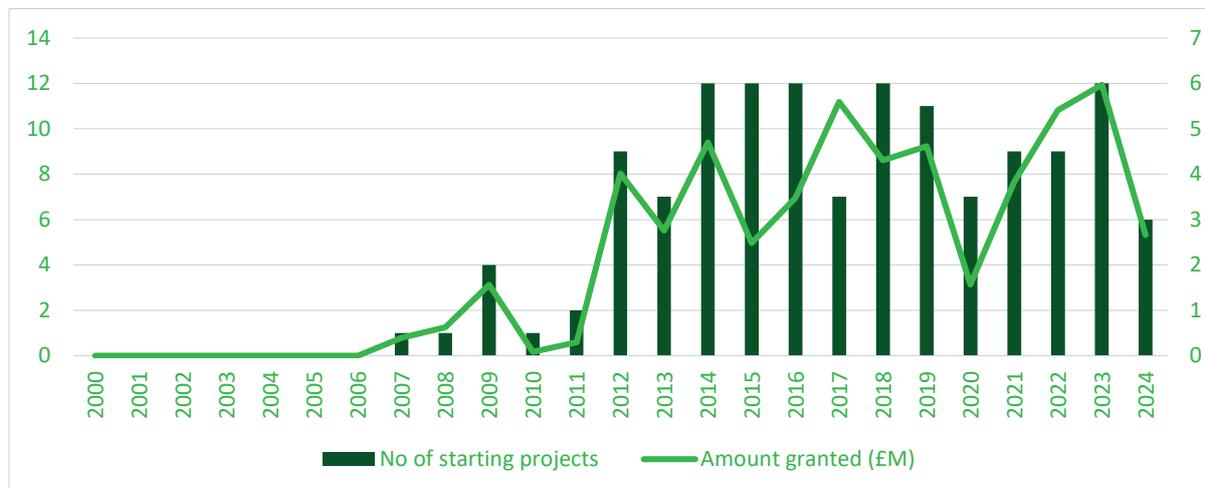
A similar picture emerges for both countries. In both countries, funding for plant phenotyping is detected in 2010, which is in line with developments at European level, where the first projects specifically addressing plant phenotyping were launched in 2010. While the number of projects started in France and the United Kingdom has fluctuated over the years without a clear trend, the amount of funding approved has increased over the years, with significant declines in 2020 in both countries (possibly due to the pandemic) and a peak in 2022/2023. Between 2010 and 2024, France financed 99 projects with a total budget of €33 million, and the United Kingdom financed 128 projects with a total budget of €56 million.

Figure 8: Research grants in France



Source: <https://scanr.enseignementsup-recherche.gouv.fr>

Figure 9: Research grants in United Kingdom



Source: <https://qtr.ukri.org/>

The analysis shows that plant phenotyping has developed into a growing field in Europe over the past two decades. Scientific publications, patent activity, and the number of dedicated tech companies all point to increasing research and innovation efforts, particularly after 2010. Public investment at both EU and national levels has supported this growth. This coincides with the time when EPPN and EPPN2020 were launched at European level. However, as already observed, no causal link can be established. Despite some methodological limitations, the selected indicators offer a robust picture of how plant phenotyping is gaining scientific, technological, and economic relevance across Europe.

4. Pan-European Initiatives as Key Building Blocks for EMPHASIS' Maturity

4.1 Achievements of EPPN and EPPN2020

European and national initiatives such as EPPN, EPPN2020, Phen-Italy and DPPN provided the essential foundations for today's coordinated phenotyping landscape. EPPN (FP7, 2012–2015) unified a previously fragmented community by offering transnational access to 23 installations, supporting 66 access experiments and generating over 50 peer-reviewed papers (Pieruschka and Schurr, 2019). It advanced shared standards through protocols for trait measurement, environmental monitoring, and the MIAPPE standard, and strengthened community building via workshops, summer schools and exchanges, contributing to the formation of IPPN (European Commission, 2017).

EPPN2020 (H2020, 2017–2021) expanded access to 31 installations across 11 countries, enabling 144 access projects from 40 countries, with strong participation from new users, including 45% women and 19 non-European countries (Pieruschka and Schurr, 2019; European Commission, 2023). Its Joint Research Activities delivered major advances in sensor calibration, data analysis workflows (e.g. R-based tools), and FAIR-aligned data management implemented in 19 facilities. A trans-platform experiment involving 13 sites validated these methods. Networking activities reached >85,000 web visitors and trained ~1,100 participants in dedicated workshops (European Commission, 2023).

The projects also focused on data management, helping organize data in a way that follows FAIR principles, making data easy to find, access, and reuse. It introduced consistent ways to name measurements and track plant data. These systems were set up in 19 phenotyping facilities across Europe. A trans-platform experiment involving 13 platforms tested the developed methods and promoted exchanges with genomics and modelling communities. Networking activities reached over 85,000 web visitors (31,000 recurring), and nearly 10,000 scientists were informed through meetings and conferences. Around 1,100 participants were involved in dedicated workshops for the dissemination of methods (European Commission, 2023).

All these developments directly feed into, and now continue under, EMPHASIS, in its 'pre-ERIC' phase.

4.2 Key services and first achievements of EMPHASIS-PREP and EMPHASIS-GO

Recognized as a priority by the European Strategy Forum for Research Infrastructures (ESFRI), EMPHASIS was listed on the ESFRI roadmap in 2016 under the Health and Food thematic area.

EMPHASIS-PREP (2017–2021) established the foundations for a sustainable European RI, including a business plan, governance model, user strategy and cost framework. It mapped >200 installations across 24 countries and piloted early services in field access, best practices, data workflows, modelling and training (European Commission, 2022).

EMPHASIS-GO extends this work toward operational readiness for EMPHASIS-ERIC from 2027 (European Commission, 2023b). Key service areas include:

Service 1: User access

Access is mainly provided via EU-funded TNAs such as **AgroServ** (EMPHASIS, 2024a), **Microbes4Climate**, and previous schemes like EPPN2020. EMPHASIS's role is still not fully-fledged, as access is fragmented and tied to projects. Stakeholders stressed that centralised, stable EMPHASIS-ERIC services will simplify navigation and improve continuity. Users from established RI (e.g., NPEC) also noted technology adoption gaps in national communities (Interview with NPEC, 2025).

In addition, some countries operate national access programmes via calls, although their conditions and openness to international users vary. For instance, in some cases, funding is reserved for national researchers, while in others, consortia with international partners can apply (Interviews with Phen-Italy, 2025; and NPEC, 2025).

Service 2: Innovation partnerships

Industry engagement activities across EMPHASIS-GO partners included 133 interactions (workshops, collaborative projects, access by companies, training). Industry partners range from technology providers (68) to breeding companies (48) (Industry Engagement Survey, 2025). Detailed impacts are discussed in Chapter 5.

Service 3: Advancing phenotyping practices

Through PHENET (<https://www.phenet.eu>) and earlier work, EMPHASIS contributed innovations including digital sensor calibration via 3D reconstructions, deep-learning training datasets (>40,000 annotated images), and a catalogue of environmental sensors. Future plans include stabilising these as community services (Fahrner et al., 2023). Through PHENET's technology development work, EMPHASIS also accelerates AI-assisted sensing and low-energy sensor development (EMPHASIS, 2025).

Service 4: Data management and computational services

EMPHASIS-PREP advanced FAIR-aligned data practices, promoting Level 1 and Level 2 data management models from EPPN2020. It supported adoption of PHIS, GnpIS, MIAPPE, and BrAPI for semantic interoperability and machine-readable access (Tardieu et al., 2019). The Plant A+ tools released via EOSC-Life enable cross-domain data integration (EMPHASIS, 2025). Collaboration with ELIXIR enhances findability and links with genomics/modelling (Fahrner et al., 2023).

Service 5: Advocacy and convening

EMPHASIS strengthened national communities and supported infrastructure development (e.g., NordPlant, NPEC, NaPPI). It contributed to national roadmap positioning in Estonia and Poland and supported new national initiatives across many countries (Pieruschka and Schurr, 2019). EMPHASIS is active in European and global RI networks and partnerships (CORBEL, RI-VIS, EOSC-Life, AnaEE, ELIXIR, Metrofood, eLTER, ISBE) and Horizon Europe projects such as **AGroServ**, **AI4Life**, and **ALL-Ready**. Through these partnerships, EMPHASIS advances the integration of phenotyping technologies into broader research agendas, enabling solutions that span environmental monitoring, biodiversity, crop improvement, and AI-driven science.

Policy engagement includes contributions to the Life Science RIs FP10 Position Paper (<https://emphasis.plant-phenotyping.eu/european-life-science-ris-position-paper-on-fp10/>, 2024), RI-VIS white papers (<https://ri-vis.eu/network/rivis/white-papers>) on Africa-Europe, Latin America-Europe, and Australia-Europe cooperation (<https://zenodo.org/records/4475595>, <https://zenodo.org/records/4544374>, <https://zenodo.org/records/4546173>), with >4,000 views and >2,800 downloads, and EU consultations on RI strategy and GreenData4All.

EMPHASIS actively supports events that bring together researchers, infrastructure managers, funders, and policymakers. At conferences such as the International Plant Phenotyping Symposium (IPPS), or the European Plant Phenomics Symposium 2025 (https://epps2025.plant-phenotyping-network.de/EPPS_Home) EMPHASIS is present and involved and does not only showcase scientific results but also facilitates discussions on the future of research infrastructure governance, the role of plant phenotyping in global food systems, infrastructure user needs and technology adoption gaps.

Within EMPHASIS-PREP eight peer reviewed articles were published (EMPHASIS-PREP, 2021).

Service 6: Training and education

Training and education have emerged as one of the most visible and valued services of EMPHASIS. Training demand has consistently focused on data and AI skills. EMPHASIS has delivered short courses, hands-on workshops, and online sessions in affordable phenotyping (Matera–Metaponto, 2023), FAIR data and MIAPPE (remote 2023; Paris 2024), with 25–40 participants per session. EMPHASIS is emerging as a key coordinator of training efforts across Europe.

5. Impact Assessment by Thematic Area

This chapter summarises a qualitative assessment of the impacts of EMPHASIS and its associated activities across the key thematic areas of human resources, innovation and the economy, society, and policy, drawing primarily on 23 stakeholder interviews (2025). Findings reflect both observed impacts and expected future benefits as EMPHASIS moves toward ERIC establishment.

5.1 Impacts on Human Resources

5.1.1 Improved professional skills for users of EMPHASIS services

Users of EMPHASIS have consistently reported skill gains through EMPHASIS-linked exchanges, transnational access, and technical workshops—though not always recognised as “EMPHASIS-branded.” Knowledge transfer between established and emerging infrastructures helped new national nodes develop management routines, experimental design practices, imaging workflows, and data documentation approaches. Annual FAIR/data workshops since 2018 (funded under EMPHASIS-PREP and related projects) increased uptake of coherent data management practices. However, the absence of a clearly visible, unified EMPHASIS training programme means learning is often attributed to individual EU projects or national platforms rather than to EMPHASIS itself. As one interviewee summarized, *“We learned a lot through these exchanges, but you have to know where to look.”* Some interviewees expressed a desire for more clearly structured and continuous training, and it can be said that there is general support for expanding and structuring these skill-building opportunities under a more visible and accessible EMPHASIS framework.

5.1.2 Career development for individual researchers and young scientists

Transnational access and supporting services of EMPHASIS have enabled PhD students and postdocs to conduct otherwise impossible experiments, advance publications, and shape long-term research agendas. Engagement with experienced facility staff improved experimental design and protocol development. EMPHASIS-related coordination roles (facility management, data stewardship, project administration) have also created new professional pathways. However, access often depends on institutional networks, not transparent opportunities for junior researchers; interviewees suggested more structured mentorship, clearer pathways to connect with facilities, or even practical support like travel funding for training.

5.1.3 Access to EMPHASIS facilities by underrepresented or economically disadvantaged regions

EPPN2020 and subsequent EU projects opened doors to researchers from Southern and Eastern Europe to advanced phenotyping tools that were not otherwise available. Stakeholders in countries with limited infrastructure stressed the importance of fully funded mobility schemes. Providers in central and northern Europe confirmed hosting increasing numbers of users from these regions. Remaining challenges include limited awareness of how to apply, fragmented access routes, and low visibility of EMPHASIS as the “gateway” to opportunities.

In summary, while there are clear cases where EMPHASIS-linked programs have enabled access for researchers from less advantaged regions, the system relies heavily on EU project funding and is not yet consistently available or well-known to all potential users.

5.1.4 Transnational collaboration and mutual learning

Collaboration impacts were the most widely acknowledged. Working groups on data standards, ontology development, access models and platform design supported meaningful cross-border problem-solving and adoption of shared workflows. Facilities adjusted their infrastructure investment and operational plans based on peers' experiences, improving operational choices, saving time and money and avoiding duplication. While these effects were often tied to specific projects, they were seen as part of a broader environment that EMPHASIS helped to structure. There is also a visible increase in the usage of national plant research facilities over the years, particularly from users embedded in EU project consortia, which is probably at least partly caused by EMPHASIS activities.

Momentum slowed somewhat during delays in EMPHASIS establishment (including the period around Germany's withdrawal), and stakeholders noted the absence of a central community-building event in recent years (aside from the European Plant Phenotyping Symposium, which whilst closely connected to EMPHASIS, is not an EMPHASIS event, although it will become so after the ERIC establishment).

While newly established national infrastructures are seeing a clear value in having this transnational exchange in order to learn from other national nodes in building a functioning infrastructure in their own country, well-established infrastructures cautioned about the need for clear added value from EMPHASIS as a coordinating actor.

Nevertheless, many interviewees expected EMPHASIS to play a bigger role in the future. They valued the idea of building a shared platform of services, aligning methods and data across nodes, and pooling resources where possible. A European Commission official reflected that such collaboration is more sustainable and efficient than having each country duplicate high-end infrastructure on its own. In summary, most expect EMPHASIS-ERIC to strengthen strategic coordination and avoid duplication across countries.

5.2 Impacts on Economy & Innovation

5.2.1 Increased innovation uptake and improved research-industry partnerships

Shared technical initiatives and EU projects linked to EMPHASIS have enabled co-development of tools (e.g., UAV thermography at ETH Zurich; drought-stress systems at NPEC; robotic sprayers at VIB) and supported start-ups such as Ecorobotix and RainBowCrops (Industry Engagement Survey, 2025). Yet, fully mature science-industry collaboration under the EMPHASIS umbrella remains limited. Technology providers often participate only in procurement phases, with little iterative feedback. Breeding companies stressed that public research sometimes provides outputs not aligned with commercial germplasm or IP requirements. Farmer involvement was also described as insufficient. Stakeholders expressed strong interest in more systematic co-design formats, exchange workshops, and visibility of user needs, while cautioning against centralised industry brokerage that replaces local trust networks (a lesson also evident from the underuse of EPPN2020's SME access model).

The commercial breeding company interviewed for this study confirmed the importance of public-private partnerships for innovation and speeding up development in general but also for them as a company. By capitalizing on public sector research and adapting it for their own needs, they can avoid reinventing the wheel. Partnerships are, for example, able to provide additional trial locations that improve precision of results and data quality. Particularly, early-stage joint design of projects and

deciding together on targets and traits, would create “win-win” situations for both public research and industry.

Participation in the wider EMPHASIS ecosystem has enabled research institutions to develop and align phenotyping technologies more effectively. Shared initiatives supported practical exchanges among researchers and engineers working on imaging systems, software tools, sensor integration or standardized protocols. While mostly not initiated by EMPHASIS directly, these projects were widely seen as connected to its environment.

With respect to technology provision to public research institutions, some of the technology companies that contributed to this study expressed the problem that current EU funding rules often favour personnel costs and internal developments over the purchase of external technological solutions. This was seen as problematic since it would result in researchers redeveloping tools already available on the market, leading to inefficiencies and missed opportunities for the adoption and scaling of innovative and already tested solutions.

Nevertheless, the majority of interviewees, both from academia and industry, expressed interest in closer cooperation between them. And while EMPHASIS itself has not yet established a structured pan-European pathway for industry-research cooperation, there was overall agreement that EMPHASIS could be important in supporting this and be playing a more active role in connecting research and industry in the future. Interviewees suggested concrete steps such as open calls for innovation partnerships, and regular dialogue between, for example, facility managers and technology providers as well as technology exchange workshops to gain a common overview of emerging technical needs. Such measures could help shift collaboration from occasional procurement to more strategic co-design.

5.2.2 Improved operational and economic efficiency in plant phenotyping research and development

A. Economic benefits of plant phenotyping services and technologies

Breeders and SMEs reported measurable efficiency gains: earlier genotype selection, reduced cycle time (from eight to five years, with potential for four), more precise stress testing, improved biostimulant validation, and reduced labour demands via automation. Image-based pipelines also halved data-processing time in some labs. Technology developers confirmed that phenotyping enables faster and more informed decision-making for their clients. However, most organisations do not yet track ROI systematically, and adoption by small companies remains constrained by cost.

Public and commercial breeders interviewed for this study reported that advanced phenotyping, such as high-throughput technology, has significantly improved the precision of selecting the best lines and has supported better decision-making. For small and medium-sized enterprises (SMEs) in plant breeding, phenotyping provides access to precision tools they could not otherwise afford. SMEs often lack the capacity for large-scale field trials or advanced sensor equipment. By outsourcing part of the evaluation to phenotyping platforms, they gain access to controlled experiments that would be difficult to set up independently. This lowers entry barriers and helps them test new materials more rigorously before investing in further development.

Phenotyping was also seen as an efficiency booster for internal research workflows. Some institutions emphasized how automation and structured data collection reduced time spent on manual measurements and post-processing. One laboratory that transitioned to a fully digital image analysis

pipeline reported cutting their data processing time by half. This freed up staff capacity for other tasks, including experiment design and supervision of students.

One technology builder noted that the high cost of phenotyping infrastructure makes it still challenging to offer services at a price point attractive to other commercial users. As a result, particularly small breeding companies often work with these platforms only during specific funded collaborations, rather than through continuous service agreements. This limits the long-term economic impact and makes it harder to build lasting commercial relationships. Also large, established public and private breeding institutions with their own infrastructures reported that they are still unable to quantify or monetize the benefits of high-throughput phenotyping. Nonetheless, they regard it as a strategic long-term investment expected to deliver substantial cost savings in the future.

Despite these limitations, the interviews suggest that phenotyping offers real value in terms of time savings, risk reduction, and data-driven decision-making. Whether the user is a breeder selecting lines or a researcher optimizing workflows, highly technologized phenotyping can provide important insights much quicker and more precisely which reduces costs and improves outcomes – particularly in light of expected difficulties in hiring experienced field technicians in the future.

B. EMPHASIS as a support structure for operational efficiency

EMPHASIS has supported a framework that helps research facilities improve how they organize and carry out plant phenotyping. Preparatory projects (EPPN2020, EMPHASIS-PREP) improved decision-making around facility design, reducing risks of incompatible equipment or inefficient workflows.

The more recent EMPHASIS-GO activities, with their focus on creating the necessary governance architecture and operating model for the future fully-fledged legal entity may appear at this stage to have had less impact, although it seems highly likely these efforts will indeed yield positive benefits as EMPHASIS enters its next, fully operational phase.

Another important area is data management and documentation – for research in general and for breeders and pre-breeders in particular. EMPHASIS has driven uptake of FAIR-aligned practices (MIAPPE, BrAPI), improving data quality and interoperability (Tardieu et al., 2019). EMPHASIS activities have facilitated the integration of high-quality phenotyping datasets into commercial breeding pipelines, as seen in collaborations with organizations such as Hiphen and INRAE demonstrating how curated and standardized data can directly influence breeding processes and accelerate innovation (Industry Engagement Survey, 2025). Stakeholders suggested EMPHASIS could strengthen this role by providing shared templates, case studies, self-assessment tools, and staff training to promote operational efficiency.

5.2.3 Increased efficiency in breeding and resource use through plant phenotyping

Plant phenotyping technologies contribute significantly to agricultural innovation, not just by improving breeding outcomes but also by enabling more efficient and sustainable use of key resources such as water, nutrients, and land. Phenotyping accelerates selection under drought, nutrient limitation and heat, supports early-stage screening of vigour and root traits, and improves evidence for agronomic input trials. Several interviews also pointed to practical applications beyond breeding. Phenotyping is increasingly used in trials for biostimulants and foliar products, helping companies understand the physiological effects of their inputs and tailor recommendations for different crop conditions. One researcher mentioned how a partner company used phenotyping to back up

performance claims for a biostimulant under drought and nutrient stress, providing evidence for marketing and regulatory purposes. Interviewees described other cases where phenotyping avoided costly, poorly performing varieties or optimised trial space and resources. A case study at the ICORE greenhouse (<https://plantscience.agri.huji.ac.il/icore-center>, Hebrew University of Jerusalem) with ICL Specialty Fertilizers (<https://www.icl-group.com/our-business/agriculture/fertigation-fertilizers/>, Israel) demonstrated new drought-stress methods published in *Frontiers in Plant Science* (2019), directly improving pre-field screening (Industry Engagement Survey, 2025).

While the potential is clear, many tools remain at proof-of-concept stage; real-world validation and broader adoption depend on more sustained industry and farmer engagement. Some facilities mentioned that, although they have developed tools to measure traits, for example, related to resource efficiency, they rarely receive requests from private sector users to use these tools. This suggests a gap between what science is capable of offering and what the market currently values or that potential users do not see their direct benefit of what is offered. Costs remain a barrier, especially when phenotyping is not subsidized or when demand is too low to justify continuous operations, and several noted that internal incentives or legal frameworks do not always support ongoing collaboration (Industry Engagement Survey, 2025).

5.3 Societal and Environmental Impacts

5.3.1 Enhancing agricultural sustainability by increasing resource use efficiency and improving climate resilience of crops

Phenotyping enables selection of crops with improved drought tolerance, heat resilience, deeper or more efficient root systems, and better performance in low-input and agroecological systems. Interviewees linked these traits to long-term food security, especially in Mediterranean and Eastern European regions. According to a researcher, these traits are “*key to preparing agriculture for the next decades*”. Several researchers highlighted how they use imaging and sensor technologies to evaluate how different genotypes grow under conditions with limited nitrogen or without irrigation. This kind of testing is crucial for farming approaches like agroecology that aim to reduce chemical inputs and rely on more sustainable practices.

Scientific advances linked to EMPHASIS-associated networks include ultrasonic emissions from drought-stressed plants (*Cell*, Khait et al., 2023), early predictors of tomato yield (Gosa et al., 2022, *Plant Science*), and a barley mutation linked to reduced transpiration (Persello et al., 2024, *Plant Cell Reports*). These discoveries underpin future breeding for climate resilience and resource efficiency. HTP applications also support disease detection, post-harvest quality, precision and controlled-environment agriculture, insurance verification, and commodity forecasting. These findings complement other advances in quinoa, tomato, and barley that reveal novel drought resilience traits and genotype-specific coping strategies (Industry Engagement Strategy, 2025).

In summary, conversations show that plant phenotyping is widely recognized as a strategic tool for promoting sustainable agriculture, helping to make crops more robust, productive and efficient under environmental conditions. While the practical implementation of these findings in breeding and agriculture still needs to be expanded, the scientific foundations and initial applications already show a potential contribution to resource efficiency and climate adaptation and thereby to long-term food security.

5.3.2 Improvements in food safety: reduction in contaminant residues

Direct links to food safety were not raised in interviews, but indirect impacts arise from breeding varieties requiring fewer chemical inputs through improved disease resilience. One facility described imaging-based pathogen assessments that could reduce reliance on plant protection products over time. Several researchers discussed how phenotyping allows for early and accurate detection of traits related to plant health and resilience. In particular, the ability to monitor how plants respond to pathogen pressure or environmental stress may contribute to selecting varieties that require fewer plant protection applications. Although this was not framed in terms of food safety, such varieties could in practice help reduce contaminant residues at harvest. The findings of this study suggest that the contribution of plant phenotyping to food safety is, maybe, not yet considered to be one of the most important ones. Most phenotyping activities remain centred on productivity, resilience, and efficiency.

5.4 Policy Impacts

5.4.1 Policy engagement and strategic influence

EMPHASIS achievements in pushing the strategic development of plant phenotyping at national level, including into national roadmaps, were confirmed by several interviewees who emphasized its important role in strengthening the credibility and strategic positioning of plant phenotyping in policy, particularly at national level. Across several countries, managers of national phenotyping infrastructures stated that EMPHASIS provided a structured platform through which they could present coordinated, coherent messages to their national ministries and funding agencies. Some facility managers described that EMPHASIS helped improve their relationship with their national ministry. They noted that the visibility and coordination created through EMPHASIS helped them to increase trust and connect more effectively with their national policymakers.

This aligns with the broader pattern in the interviews that EMPHASIS gave plant phenotyping advocates a stronger voice or legitimacy in their national context, which has helped recognize phenotyping on the national agendas; something that might not have happened without the EMPHASIS framework. As one interviewee put it, EMPHASIS allowed them to *“approach the ministry not just as individual institutions, but with a shared strategy”*. Facilitating dialogue with ministries and stimulating strategic planning processes for plant phenotyping at national level are early but important forms of influence that will certainly shape future policy directions. Such dialogue is not without its challenges, however:

“In some countries, the perception was that they already had functioning national infrastructures or coordination initiatives. So, the reaction was: why do we need to pay again for something we already have? That complicated the discussions with ministries.” (ESFRI delegate)

Countries can also question added value relative to existing national initiatives; terminology (e.g., “node”) has caused confusion; and EMPHASIS’s messaging has been seen as too technical for non-expert policymakers. Interviewees stressed the need for clearer narratives linked to major EU priorities such as the Green Deal, Farm to Fork, and the bioeconomy. It was considered that such narratives could demonstrate how EMPHASIS helps with these goals, by supporting the development of crops that use resources more efficiently, for example, varieties with better nitrogen uptake or improved root systems, which can lower agriculture’s environmental impact, improve food security, and also provide biomass for non-food uses.

EMPHASIS has contributed to strategic documents such as the **European Life Science RIs FP10 Position Paper (2024)**, and global RI-VIS white papers, which have collectively been viewed >4,225 times and downloaded 2,842 times. However, it was also mentioned that EMPHASIS should “*develop clearer narratives and stronger linkages to political objectives*” to have more influence in policy discussions. Some also said that plant phenotyping in general does not yet have a strong public message. While its importance for climate adaptation and food security is well understood by scientists, it is not always explained clearly to policymakers or the public. EMPHASIS should identify its own “flagship stories” that show real-world impact, rather than just describing itself in technical or organizational terms.

The steady recent progress of EMPHASIS, with successful Step 1 ERIC submission, ESFRI Landmark status application underway, and anticipated Step 2 ERIC establishment in the near future, all involving a dozen or more diverse countries, does suggest that this long preparation phase has resulted in a shared understanding of how EMPHASIS should operate in the future, and a strong sense of co-design and ownership in that future. Stakeholders expect the transition to EMPHASIS-ERIC to strengthen its policy presence by providing a clearer governance structure and a single, recognisable point of engagement for ministries, and that central coordination will deliver some of the desired impact in this area, differentiated from the technological and scientific impacts which are perhaps more readily identifiable at the national/local level of EMPHASIS.

6. Conclusions

6.1 Community feedback

On 24 July 2025, a feedback session was held with key stakeholders who are actively involved in the implementation of EMPHASIS to discuss the results of the above evaluation and how these findings can be used to further improve EMPHASIS.

Participants expressed strong support for EMPHASIS as a critical European infrastructure. EMPHASIS was recognised as enabling national phenotyping development, training new scientific talent, and supporting early-stage (low-TRL) research essential for downstream innovation. Several stakeholders noted that without EMPHASIS, some national initiatives (e.g., PHENOME in France) would not have secured long-term viability.

However, participants emphasised the need for stronger visibility, clearer communication of EMPHASIS’s added value, and more compelling narratives linking phenotyping to climate resilience, sustainable agriculture and food security. The group highlighted the need to better demonstrate value for breeders by connecting trait-focused phenotyping to practical breeding outcomes. Industry concerns were taken seriously: research infrastructures should avoid competing with SMEs and instead foster complementary innovation. Some participants pointed out that the EMPHASIS community has, over 15 years, trained and nurtured much of the workforce now active across industry and public research.

Finally, stakeholders stressed that plant phenotyping requires pan-European coordination at scale; only an infrastructure like EMPHASIS can deliver systematic, multi-environment, multi-year research that individual countries cannot achieve alone.

6.2 Conclusion

EMPHASIS and its predecessor projects (EPPN, EPPN2020, EMPHASIS-PREP) have transformed a previously fragmented European landscape. Before 2012, nascent plant phenotyping capability operated largely in isolation. Over the last decade, these initiatives have created a coherent community, strengthened national capabilities, improved data standards, and enabled shared learning that EMPHASIS now extends.

A key strength has been support for national infrastructures as they have emerged and matured: aligning strategies, enhancing political visibility, and helping countries develop or upgrade facilities. Scientifically, EMPHASIS has promoted quality, interoperability and technological uptake—particularly through FAIR data principles, MIAPPE, BrAPI, and harmonised measurement standards. The most tangible impacts so far come from hands-on collaboration: staff exchanges, working groups, and shared experiments that have enhanced technical capacity and improved operational decisions across countries.

Plant phenotyping research enabled by EMPHASIS is also beginning to deliver real-world benefits—accelerated breeding cycles, improved stress-tolerance screening, and more efficient data pipelines. Although economic impacts are still emerging and often difficult to quantify, stakeholders acknowledge phenotyping as a long-term strategic investment essential for European agriculture.

Challenges remain. Structured research–industry collaboration is still underdeveloped; cooperation often relies on individual networks rather than systematic EMPHASIS mechanisms. EMPHASIS also needs stronger visibility among scientists, industry, and policymakers, especially in Southern and Eastern Europe. Clearer messaging and more direct links to policy priorities (Green Deal, Farm to Fork, bioeconomy) will be crucial.

EMPHASIS is now at a pivotal moment. It has earned community trust and established strong foundations. The next step—full ERIC establishment—will allow EMPHASIS to offer consistent, long-term services and become a recognisable European hub. Given that phenotyping impacts materialise over long timeframes, a practical, lightweight system for monitoring impact is needed to track progress, support future evaluations, and demonstrate value. Establishing such a framework now will help ensure that EMPHASIS’s contributions to European science, innovation and sustainability are visible and evidence-based in the years ahead.

7. Recommendations

1. Clear definition of roles and services

Stakeholders need a clearer understanding of EMPHASIS’s core functions. EMPHASIS should define its essential services, highlight where it adds value beyond existing national and project-based initiatives, and focus its industry engagement on strategic support (e.g., roadmapping low-to-high TRL pathways for plant phenotyping, mapping needs, sharing best practices, and showcasing successful collaborations) rather than acting as a direct broker.

2. European community hub and stronger visibility

EMPHASIS should strengthen its presence as *the* central European meeting point for plant phenotyping by organising regular cross-European events, thematic workshops, and stronger links with national

initiatives. Communication efforts should also help raise the public and policy visibility of plant phenotyping.

3. Expansion of a central access point

A simple, transparent access point for research infrastructures and services is essential. EMPHASIS, in its transition to full ERIC operations, should finalise and expand its planned platform to describe available services, access conditions, and opportunities—supporting both established infrastructures and new users.

4. Demand-driven industry engagement

Industry collaboration should be guided by the concrete needs of breeders, researchers, SMEs, and technology developers. EMPHASIS can support this by collecting and sharing needs systematically, addressing concerns of small technology providers, and promoting co-design and joint testing formats. Through transparent processes, co-design formats, and joint testing, EMPHASIS can help build trust and create mutual benefits.

5. Strengthening the role as a neutral broker

EMPHASIS can play an important role as a trusted, neutral platform connecting public and private actors. Clear collaboration principles, transparent processes, and focus on mutual benefits can support more effective innovation and help align supply and demand across the plant phenotyping landscape. The goal should be for both sides to benefit from each other's strengths and to jointly drive innovations that are relevant in practice.

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