Characterising Demonstration Environments

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Characterising Demonstration Environments

This report explores and characterises demonstration environments, addressing the lack of shared definitions and inconsistent use of labels that can lead to misalignment in funding decisions, access arrangements, service provision, and organisational responsibility. Unclear requirements and performance criteria for demonstration environments can have significant implications for effective technology development and commercialisation. The report highlights that real-world demonstration environments are typically complex, addressing multiple forms of risk across different stages of technological, manufacturing, and system maturity within complex, layered contexts. Drawing on policy and academic literature, it proposes framing demonstration environments in terms of the specific risks they help to de-risk, enabling clearer language, sharper requirements, and greater value for both funders and users.

Contributors

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1. Introduction

Introduction

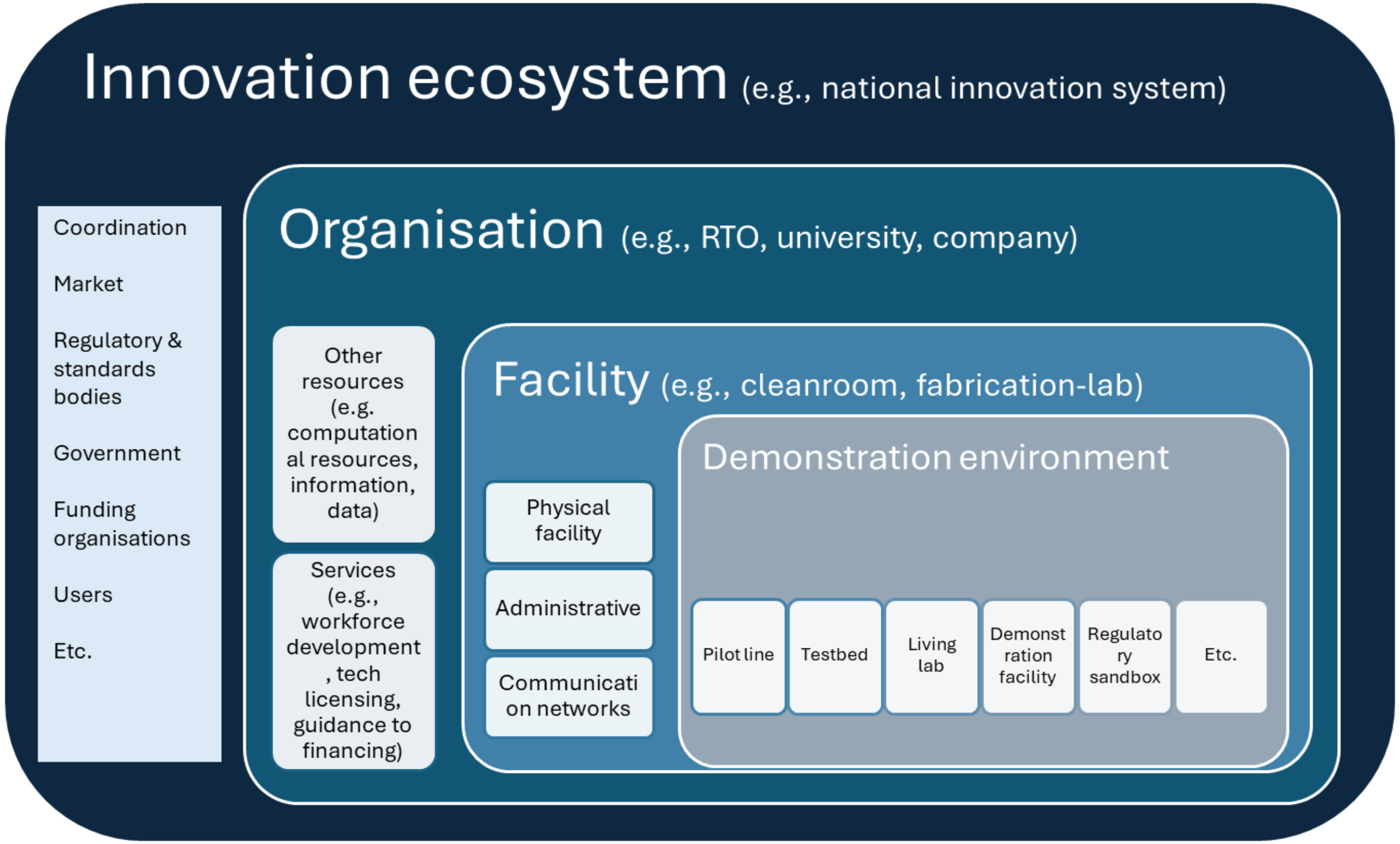
Why distinctions between demonstration environments matter and how they can be characterised

- There are many different definitions of demonstration environments, which can lead to talking at cross-purposes. This has implications for funding, access, services provided, organisational allocation, etc. essentially impacting technology development cycles and economic value capture.
- Unclear and uncertain requirements and performance criteria required for demonstration environments, which may differ in each particular case, can negatively impact technology development and commercialisation.
- Real world demonstration environments seldom serve a single purpose. They often help to address multiple risks at different levels of maturity (technological, manufacturing, system, etc.). They are also embedded within a multi-layered system which, if not defined properly, adds to the complexity around definitions and labels.
- Based on literature review of policy and academic work, we characterise the different types of risks that various demonstration environments may be addressing. We propose that by framing demonstration environments in terms of the risks that they help to 'de-risk', more concrete characterisation of demonstration environments may be possible – benefiting both funders and users in terms of sharpening language and requirements.

Multi-layered system

Consistency in definitions and labels depends on characterising the system

- Labels used to describe demonstration environments (e.g., demonstration facility, demonstrator, testbed, pilot line, etc.) are often used inconsistently, partly because these environments are inherently complex and difficult to describe in simple terms.
- In addition, labels used frequently conflate demonstration environment as the controlled environment for experimentation with where it is situated within a larger multi-layered system. For example, the label living lab could refer to a whole organisation or facility, meanwhile only a part of it might actually serve as a demonstration environment where conditions are controlled for enabling experimentation.
- See examples for inconsistency in definitions and labels on the next slides.



Source: Authors.

Same name, different meanings: “Testbeds”

Example of inconsistent definitions

Testbeds are “testing environments (or test beds), where new technology developments can be tested in controlled but near to real-world conditions.” (OECD, 2023)

“**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.” (European Commission, 2024)

"**Innovation testbeds** are programs that provide access to physical or virtual environments in which companies or public sector stakeholders can test, develop, and introduce new products, services, processes, organizational solutions, and business models, typically in collaboration with multiple stakeholders.“ (Technopolis, 2020)

Test and demonstration environments referred to as testbeds are “a physical or virtual environment in which companies, academia and other organisations can collaborate in the development, testing and introduction of new products, services, processes or organisational solutions in selected areas… important that the testbeds be open to users outside the individual organisation and be available for use for lengthy periods by a variety of different actors. Testbeds can involve almost any type of environment… generally are divided into three levels: laboratory environment, simulated environment and real environment. The first two environments are used primarily in academia and institutes and by industry, while the third largely involves the public sector.” (Vinnova, 2025)

Technology testbed vs. system testbed with the latter being for example: “In the context of manufacturing and digital innovation, however, industrial ‘testbeds’ are typically leveraged to explore how digitalised tools, components and subsystems (often from different suppliers and vendors) interoperate and perform and whether they function together as anticipated.” (CSTI, 2021)

Different names, similar meaning: “Organisational layer”

Examples of inconsistent labels

Technology infrastructures “are facilities, equipment, capabilities and resources required to develop, test, upscale and validate technology. They enable and accelerate technological innovations towards societal/market adoption, fostering industrial competitiveness. They provide a wide range of capacities and services from pre-competitive applied research services, through demonstration and validation of technology, up to small-scale production. They include, amongst others, test beds, demonstration and testing facilities, pilot lines or living labs, usually embedded within non-profit research and technology organisations, universities active in technology fields or technology centres, which are open to private and public users. They can be public, semi-public or privately owned, physical or digital.” (European Commission, 2025)

Innovation infrastructures are “facilities and assets that enable the development, demonstration and delivery of innovative (new to market) products, services or processes in business, public services, or non-profit sectors’. This includes infrastructure aimed primarily at industry and set up explicitly to foster and commercialise innovation, such as the Catapult Centres, Innovation and Knowledge Centres, Centres for Agricultural Innovation and Innovation Centres in Scotland. It also recognises the wider role of infrastructure where academic researchers and businesses collaborate and of innovation-focused activities based within universities, Public Sector Research Establishments (PSREs) or research and innovation campuses.” (UKRI, 2020)

Research and technology organisations (RTOs) are “non-profit organisations whose core mission is to produce, combine and bridge various types of knowledge, skills and infrastructures to deliver a range of research and development activities in collaboration with public and industrial partners of all sizes. These activities aim to result in technological and social innovations and system solutions that contribute to and mutually reinforce their economic, societal and policy impacts.” (EARTO, 2026)

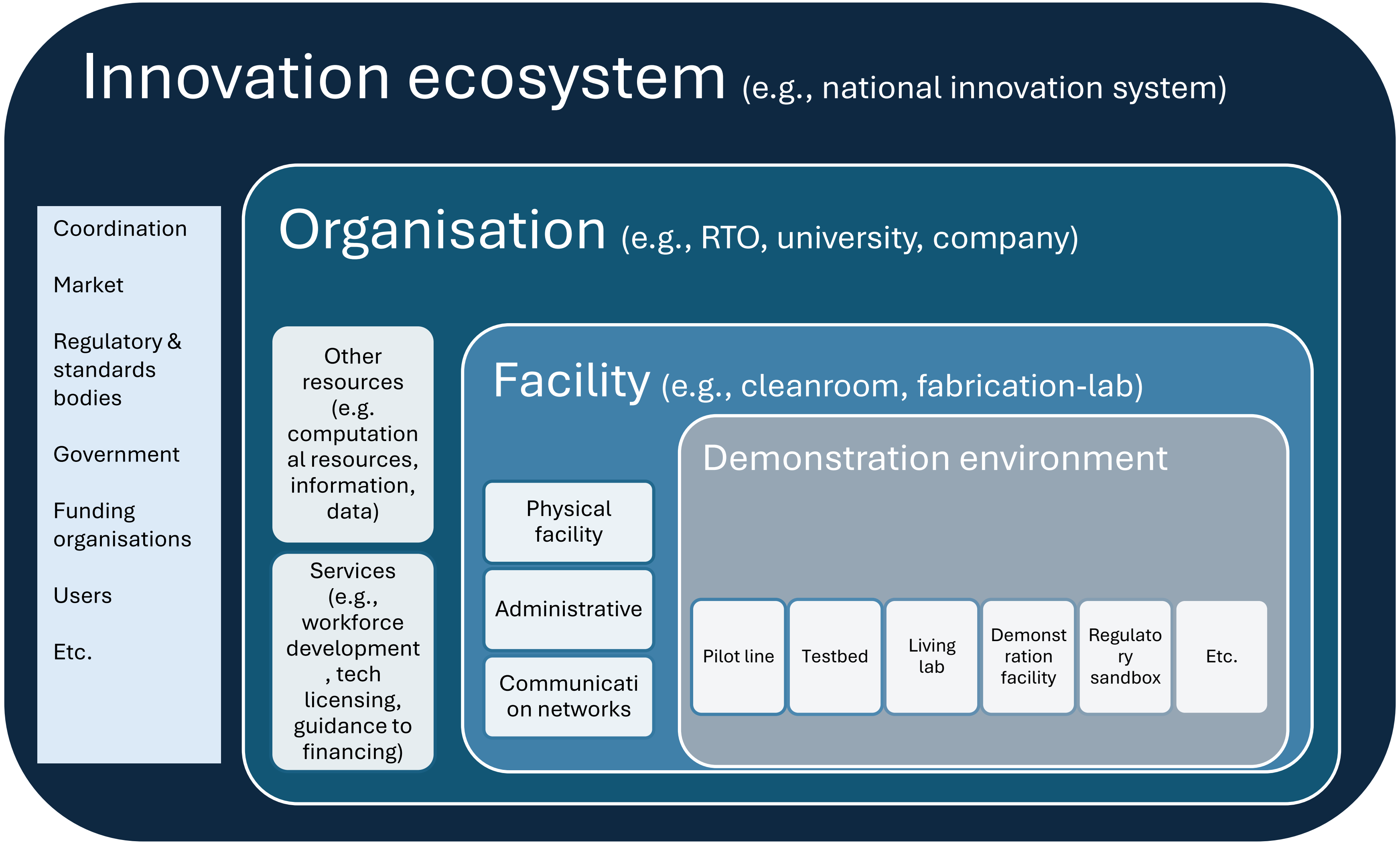
Technology and innovation centres (TICs) are “defined as organisations focused on the exploitation of new technologies, through an infrastructure which bridges the spectrum of activities between research and technology commercialisation.” (Hauser, 2010)

Multi-layered system: Scope of the project

Demonstration environments exist within multi-layered systems

Demonstration environments are part of a multi-layered system. They can be defined as **controlled (physical and virtual) environments for experimentation, enabling the de-risking of experiments by addressing one or more categories of risk.**

Demonstration environments are rarely standalone facilities; they are usually parts of facilities which sit within organisations and the wider ecosystem. They receive additional support for technology development in terms services, resources, infrastructure, capabilities, regulation, etc. from the wider system. The type and amount of additional support that can be provided makes certain facilities/ organisations/ ecosystems better positioned to host certain demonstration environments than others.



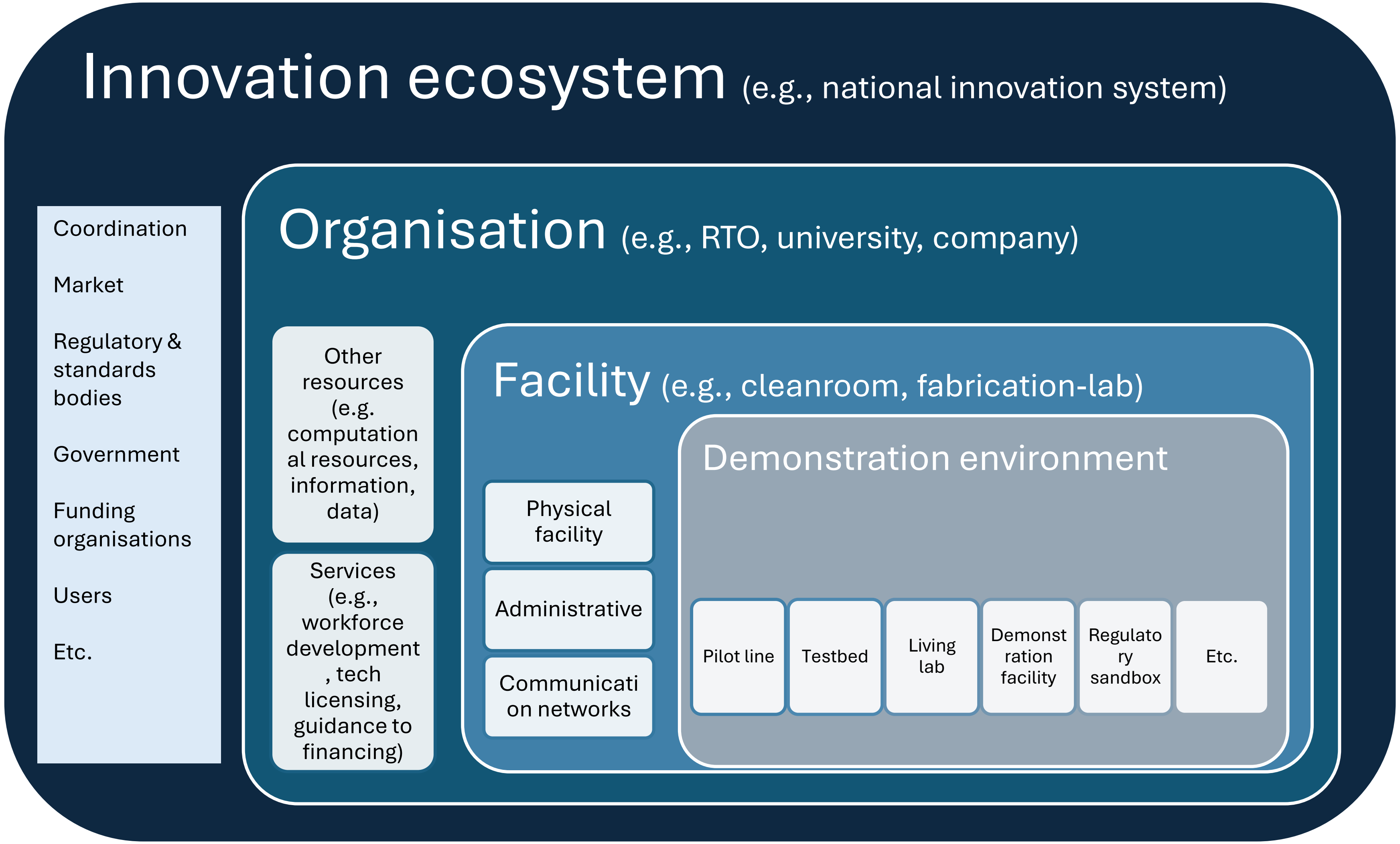
Source: Authors.

Multi-layered system: Exemplified

Demonstration environments exist within multi-layered systems

For example, within a company (an organisation), a production cleanroom used for semiconductor fabrication (a facility) may also embed a specific space and process, such as a demonstration pilot line, for testing and demonstrating new processes (a demonstration environment). E.g., Intel or Bosch cleanrooms predominantly used for production may also embed demonstration pilot lines set up specifically for demonstration.

Likewise, a research and technology organisation (an organisation) may operate a dedicated demonstration cleanroom (a facility) containing one or more pilot lines (a demonstration environment). E.g., imec operates the NanoIC pilot line within its larger cleanroom facility to enable demonstration of manufacturability.



Source: Authors.

2. Characterising demonstration environments based on the risk(s) they are addressing

CSTI Science Technology Innovation Policy
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Department of Engineering

Identifying and characterising demonstration environments

What risks and uncertainties do different demonstration environments help to reduce

- Real world demonstration environments seldom serve a single purpose. They often help to address multiple risks and uncertainties at different levels of maturity (technological, manufacturing, system, etc.).

- We propose that by framing demonstration environments in terms of the risks and uncertainties that they help to reduce, more concrete characterisation of demonstration environments may be possible – benefiting both funders and users in terms of sharpening language and requirements.

- Based on literature review of policy and academic work, we characterise the different types of risks and uncertainties that various demonstration environments may be addressing. We provide examples of real-world demonstration environments using our characterization risks framework to exemplify its use.

2.1. Risks framework

Risks Framework: Risks being reduced in demonstration environments

Risk Category	Specific risk being reduced in DE
1. Technology	Scientific feasibility & technical possibility
	Functional performance & behaviour
	Reliability & endurance
2. Manufacturing	Process feasibility
	Process stability & repeatability
	Process scalability
	Cost efficiency at scale
3. System integration	Interface connectivity & interoperability
	Supply chain robustness
4. Enabling tools	Measurement & validation capability
	Design methods validity
	Equipment availability
	Equipment reliability
5. User involvement	Level of involvement
	Level of empowerment
	Adoption & acceptance uncertainty

Risk Category	Specific risk being reduced in DE
6. Regulation	Policy relevance & effectiveness
	Safety & compliance assurance
	Impact assessment uncertainty
	Standards compatibility
7. Market	Commercial viability
	Investment availability
	Market creation uncertainty
	Market relationship stability

Source: Authors' elaboration based on review. See appendix for references.

Risks Framework: Risks being reduced in demonstration environments

Risk categories in more detail

- Based on review of policy documents and academic literature, risk categories were identified so that each demonstration environment can be more carefully characterised.
- Seven risk categories that demonstration environments may help to address/ reduce during product and process development and commercialisation were identified.
- Categories 1-5 represent risks that roughly follow readiness level or lifecycle concepts with innovations progressing from low maturity to high maturity, from laboratory to real-world environment. Another way to look at this is that these are risks related directly to the physical controlled environment.
- Categories 6-7 represent more general or cross-cutting risks, which tend to be reduced simultaneously with categories 1-5, including the case of regulatory sandboxes. These are not the primary focus in this analysis but were found to be an important aspect of demonstration activities. Further categories could include workforce, supply chain readiness, etc.

Risk Category	Specific risk being reduced in DE
1. Technology	Scientific feasibility & technical possibility
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Risks Framework: Risks being reduced in demonstration environments

Risks Framework exemplified using hypothetical examples

- Hypothetical examples of common demonstration environment types are provided to showcase how the risk categories can be used to characterise demonstration environments.
- The below examples are hypothetical and describe pure demonstration environments with a focus on reducing a single main risk. This however does not mean that they are not simultaneously also dealing with the other risks. In fact, in the real world, demonstration environments tend to be complex addressing several risks and maturity levels. For example, a pilot line set up to integrate a new process tool is helping to primarily reduce risks related to manufacturing and system integration, yet if it is primarily testing the involvement of technicians with the pilot line (or the new process tool itself), it might be closer to the definition of a living lab in the traditional sense of the word.
- **Pure pilot line:** primarily helps to reduce manufacturing risks and uncertainties such as process feasibility, stability, repeatability, scalability, and cost efficiency.
- **Pure system testbed:** primarily helps to reduce system integration risks and uncertainties such as interface connectivity, interoperability, and supply chain robustness.
- **Pure living lab:** primarily helps to reduce risks and uncertainty around user involvement, empowerment, adoption and acceptance.
- **Pure prototyping:** primarily helps to reduce risks and uncertainty related to technology such as scientific feasibility, technical possibility, functional performance, behaviour, reliability and endurance.
- **Demonstration plant:** primarily helps to reduce risks and uncertainty related to market such as commercial viability, but also system integration, production, enabling tools, and technology often specifically aiming to showcase (e.g., demonstrator) that the innovation (product or process) can work at near real-world conditions and/or continuously. Different demonstration plants are likely to focus on reducing different risks depending on the innovation/project.
- **Regulatory sandbox (most likely combined with another type of demonstration environment):** primarily helps to reduce risks and uncertainty around regulation. This is a great example of complexity, where regulatory sandboxes are usually combined with other types of demonstration environment, providing regulatory leeway.

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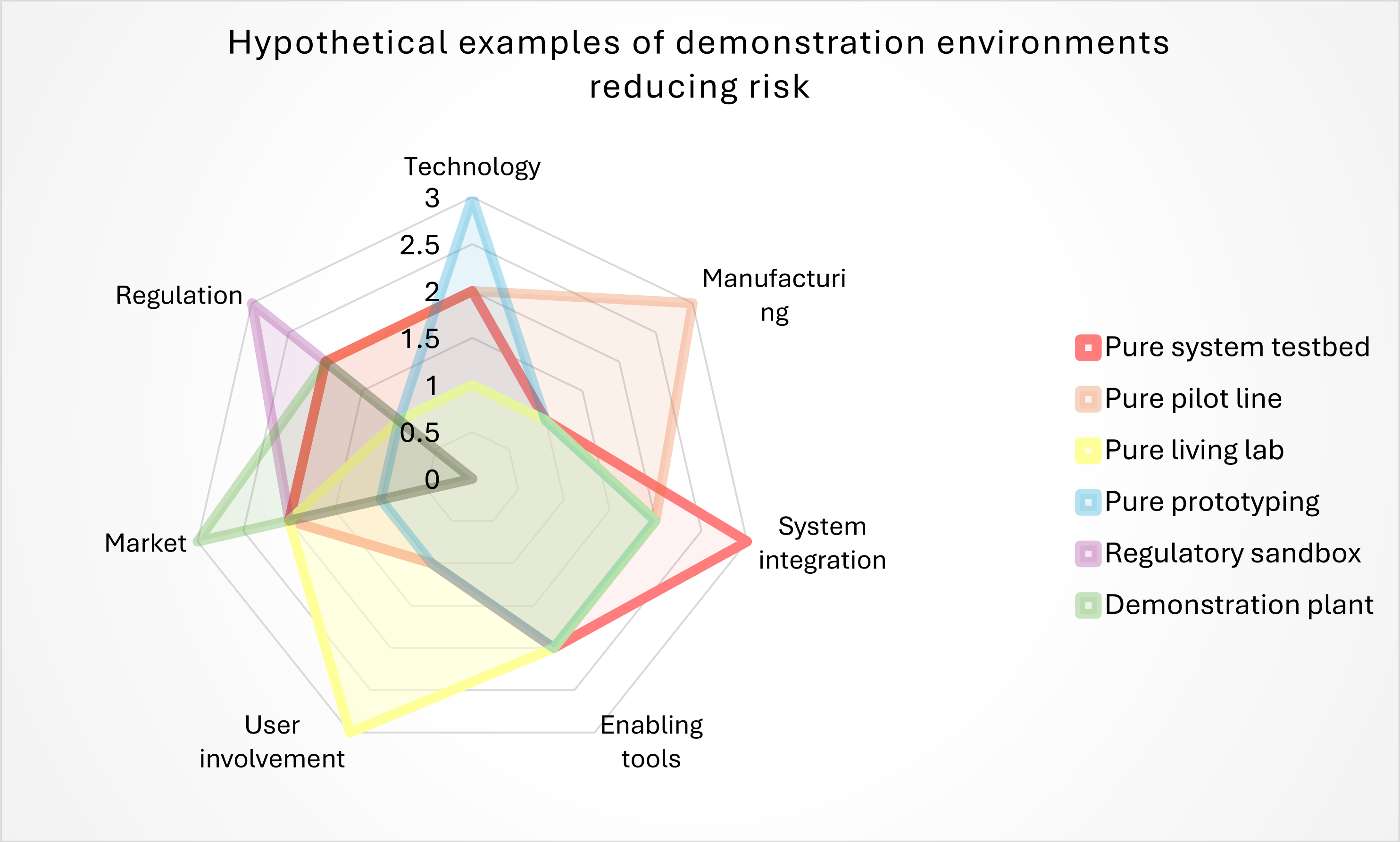
Risks Framework: Scoring to help characterise demonstration environments

Risks Framework scoring exemplified using hypothetical examples

- Scoring risk reduction from 1-3 was used to help characterise demonstration environments.
- **Higher score = greater risk reduction (i.e. lower remaining risk) by the given demonstration environment.**
- This essentially tells us which risk each demonstration environment reduces and therefore what the environment can offer.
- A spider diagram visualisation enables showing that several risks can be reduced simultaneously and that demonstration environments are usually hybrid, complex and project/innovation requirement dependent. See score table on next slide.



Risks Framework: Scoring to help characterise demonstration environments

Risks Framework scoring exemplified using hypothetical examples

	Dimensions						
Environment type	Technology	Manufacturing	System integration	Enabling tools	User involvement	Market	Regulation
Pure system testbed	2	1	3	2	1	2	2
Pure pilot line	2	3	2	2	1	2	2
Pure living lab	1	1	2	2	3	2	1
Pure prototyping	3	1	2	2	1	1	1
Regulatory sandbox						2	3
Demonstration facility						3	2

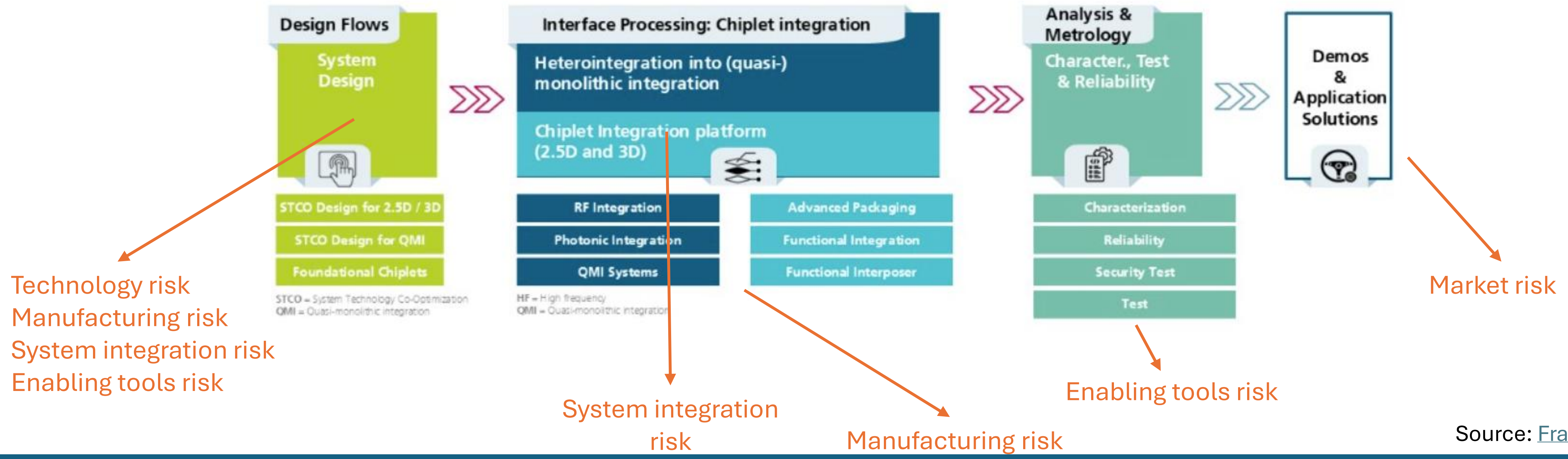
Note: The scoring does not reflect one true demonstration environment, instead it tries to highlight that different demonstration environments are likely to focus on reducing different risks depending on the innovation/project and industry, and that they are likely reducing several risks at once.

2.2. Real-world cases of demonstration environments

Advanced Packaging and Heterogeneous Integration for Electronic Components and Systems (APECS) Pilot Line, Germany

Example of a pilot line facility which can help to reduce several risks

- As part of the EU Chips Act, APECS was established as a novel pan-European *pilot line* for heterogeneous integration and advanced packaging in 2024. APECS covers end-to-end design and pilot production capabilities, to accelerate progress from cutting-edge research to practical, scalable manufacturing solutions. Coordinated by the Fraunhofer-Gesellschaft and implemented by the Research Fab Microelectronics Germany (FMD), it integrates novel testing, reliability methodologies and a system technology co-optimisation (STCO) framework. The APECS consortium brings together the technological competences, infrastructure, and know-how of ten partners from eight European countries.
- **Based on its label 'pilot line', APECS's primary focus suggests to be manufacturing risk reduction. However, it is actually closer to a facility with additional support that can help to reduce other risks as well. It can be used for different purposes, i.e., it has different parts, lines, areas, etc. that can serve different demonstration requirements and address different risks, depending on innovation/project needs.**



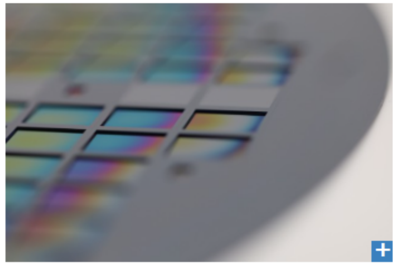
Source: Fraunhofer IPMS

Advanced Packaging and Heterogeneous Integration for Electronic Components and Systems (APECS) Pilot Line, Germany

Example of a pilot line facility which can help to reduce several risks

Heterointegration towards quasi-monolithic integration

Advanced Packaging and Heterogeneous Integration for Electronic Components and Systems



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Pocket wafer with placed chiplets

A key part of our contribution to APECS is the development of quasi-monolithic integration (QMI), which will set new standards in chiplet integration technology. The key strength of QMI lies in its ability to combine different materials and technologies in a highly integrated way to create an extremely high performance and reliable end product. In contrast to fully monolithic systems, QMI allows for greater flexibility and customization.

Demonstrator for high-performance computing (HPC) and hybrid packaging solutions

The demonstrator shows how modern HPC system modules can be implemented in real applications. It provides a platform for the demonstration and further development of hybrid packaging solutions in electronics. The demonstrator is based on a silicon interposer equipped with several computing and acceleration units as well as high bandwidth memory (HBM). The use of hybrid bonding and high-density interposers enables the integration of more than 5 chiplets. It thus represents an important step in the integration of high-performance computing (HPC) and artificial intelligence (AI) in modern electronic systems. Fraunhofer IIS is responsible for the holistic development of the demonstrator.

Chiplet integration (2.5D and 3D)

Advanced Packaging and Heterogeneous Integration for Electronic Components and Systems

An important part of APECS is 2.5 and 3D integration technologies, which are crucial for creating powerful, compact and energy-efficient systems. 2.5D integration combines the advantages of 2D and 3D technologies by placing multiple chips in a single plane connected by an interposer layer. This technique enables optimal connection and communication between the chips, improves signal quality and reduces latency. As a result, different technologies and materials can be combined efficiently, which increases the flexibility and performance of the systems. 3D integration goes one step further and stacks chips vertically, resulting in even shorter wiring connections. This arrangement allows for a significant improvement in data transfer rates and overall performance while minimizing space requirements. The reduction in signal paths also contributes to energy efficiency, which is of great importance in high-performance applications.

Fraunhofer IPMS in the APECS pilot line: analytics and metrology

Our characterization, test and reliability work includes the development of test technologies, qualification and adaptation of system technologies and CTR (Characterization, Test and Reliability) kits for:

- **2.5D/3D/quasi-monolithic integration**: novel and adapted localization techniques for electrical and functional defects in complex 2.5D/3D and QMI components. Development, adaptation and introduction of innovative defect diagnostics and associated analyzers for more complex 2.5/3D and QMI devices
- Wafer-scale tests
- Functional testing of modules

Source: Fraunhofer IPMS

Levenmouth Demonstration Turbine (LDT), UK

Example of a demonstration facility which can help to reduce several risks

- The Offshore Renewable Energy (ORE) Catapult has a 7MW *demonstration* offshore wind turbine that can be used for technology development and demonstrations. LDT is connected to the shore by a short ramp enabling testing and validation. It allows developers to demonstrate new systems and methods – helping to reduce time and costs of conducting tests at a working offshore wind farm. It is also vital that the turbine also plays a role in locally developing and supporting the next generation of Scottish engineers.
- Key services:
    - Platform for data collection supporting innovative research projects and product development (e.g., real time blade analysis)
    - Testbed for integrating robots and automated systems into its operations for example to cut inspection costs
    - Testbed for experimentation with a variety of new digital applications. More than 120 packages of instrumentation including lidar installations, novel lightning strike detection systems and sensors that monitor the conditions within its nuts and bolts
- **Risks being controlled by demonstration environment, to different extent depending on innovation/project needs:** market, technology, system integration, enabling tools risks

Source: ORE Catapult

GreenLab Designated Regulatory Test Zone, Denmark

Example of a green industrial cluster as a regulatory sandbox

- The Danish Energy Agency granted GreenLab the status of an official *regulatory test zone*, where the authorities allow activities to operate outside the existing electricity regulations. The test zone enables GreenLab's companies to share each other's surplus energy through a SymbiosisNet™ to explore new and integrated energy solutions. It therefore enables testing new innovative business models and new technologies that have so far encountered barriers under current electricity regulations. The idea is that new industrial parks can set up joint energy production and consumption without negatively affecting the existing collective energy network.
- The GreenLab works primarily at the higher levels of the TRL scale, with active research projects in the technology demonstration or system development phase. It provides a strong focus on the commercialisation of solutions, continuously searching for new revenue streams and market opportunities to promote circular economy and integrated energy systems.
- Key services:
  - Plug-and-play facility for green production with cost-effective setup and prebuilt capacity, a diversified energy mix, and a direct connection to renewable energy, ideal conditions for a get-to-market fast-track
  - Access to the most relevant and beneficial green certificates that are crucial for marketing products as sustainable and circular and ensuring market competitiveness
  - Large-scale test facility for new technologies open to new ideas and collaborations
  - Test ideas in a large-scale living lab and collaborate with industry partners
  - Facilitating collaborations between businesses and academia
  - Exploring sector coupling and industrial symbiosis through real-world cases
  - Contribute to the development of global models for sustainable industrial clusters
- **Key risks reduced include regulation, market, technology, system integration, user involvement, depending on innovation/project needs**

Source: GreenLab

GreenLab Designated Regulatory Test Zone, Denmark

Example of a green industrial cluster as a regulatory sandbox

Source: GreenLab

New Operating Room (OR) test room at the Living Lab of the Swiss Center for Design and Health (SCDH), Switzerland

Example of an operating test room as a living lab

- An OR testing environment was established as part of the living lab facility of SCDH, a centre of excellence for design research in the health sector. The OR meets the standards of a modern hospital and makes it possible to simulate operating theatres and their workflows on a 1:1 scale.
- At its core is the generation of knowledge to enhance safety, efficiency, and working conditions. By using cutting-edge methods such as immersive sound simulation as well as motion and eye-tracking, processes can be analyzed and optimized in detail.
- The OR test room gives architects, medical planners, and users the opportunity to review layouts, workflows, and spatial scenarios at an early stage of projects. Medical technology companies, in turn, can test their systems and devices in collaboration with experts for ergonomics, usability, and interaction.
- **The test room within a living lab facility is a prime example of a living lab as a demonstration environment. It enables reducing risk around user involvement, system integration, enabling tools (design), technology, regulation and market.**

WHAT DO WE SIMULATE?	EQUIPMENT AND TECHNOLOGIES	METHODS
Operating theatres	Products, medical devices	Usability testing
	Lighting systems	Simulation workshop
	Sound systems	Co-prototyping
	VR/AR technology	Experimental study
	Motion capture	
	Eye tracking	

Source: SCDH

3. Conclusion & future plans

Conclusion

The Risks Framework developed enables clarifying terminology around demonstration environments (e.g., demonstration plant vs. demonstrator – both reducing different risks to different extent)

Most importantly, it also enables thinking about how to design and fund demonstration environments. It can be used to characterise the different types of risks that various demonstration environments may address helping to clarify and sharpen language around requirements and performance criteria.

It shows that the public good may fall within an institution's remit because it enables the characterisation of several interconnected risks. For example, while a technology at TRL 9 may initially appear to lie beyond the funding remit of a research and technology organisation, an interconnected risks framework can reveal substantial remaining manufacturing risk at MRL 3–4, strengthening the case for institutional support. Likewise, a TRL 8 technology facing significant systems integration risk at SRL 2–3 may justify continued demonstration support. Framing support decisions around interconnected risks rather than TRL alone helps clarify where public intervention can still add value.

Our examples generally highlight that while demonstration environments might focus on reducing a key risk, there are many other risks that are being reduced simultaneously. The risk focus of demonstration environments is furthermore project, innovation and industry specific. Demonstration environments are complex and hybrid, and they evolve throughout the lifecycle of the innovation.

This suggests the need for agile and adaptive approaches to supporting demonstration environments and related capabilities.

Next steps & future plans

- Expand understanding of different types of demonstration environments, including technology testbeds, system testbeds and regulatory sandboxes
- Develop and validate more real-world cases, including
  - Complex hybrid demonstration environments reducing several risks
  - Pure demonstration environments primarily focusing on one risk (if existing)
  - Technologies at the intersection of cyber-physical spaces (e.g., drones)

4. References

Risks to be reduced in DE with references

Type of risks and uncertainties being reduced in the demonstration environments	References	Dimension
Scientific feasibility and technical possibility	(IRC, 2025), (EU Commission, 2025)	1. Technology
Functional performance and behavior	(EU Commission, 2024)	
Reliability and endurance	(F Engels et. al, 2019)	
Process feasibility	(EU Commission, 2024)	2. Manufacturing
Processs stability and repeatability	(IEA bioenergy, 2020)	
Process scalability	(IEA bioenergy, 2020)	
Cost efficiency at scale	(EU Commission, 2015)	
Interface connectivity and interoperability	(EU Commission, 2024)	3. System
Supply chain robustness	(EU Commission, 2015)	
Measurement and validation capability	(DoD, 2025)	4. Enabling tools
Design methods validity	(A Moussa, 2022)	
Equipment availability	(EU Commission, 2015), (DoD, 2025)	
Equipment reliability	(A Moussa, 2022)	
Commercial viability	(IADB, 2020), (Nesta, 2019)	5. Market
Investment availability	(IADB, 2020), (Nesta, 2019), (IEA bioenergy, 2020)	
Market creation uncertainty	(J Frishammar et. al, 2014)	
Market relationship stability	(EU Commission, 2015)	
Level of involvement	(EU Commission, 2024)	6. User involvement
Level of empowerment	(Eriksson, M., Niitamo, V. P., & Kulkki, S, 2005)	
Adoption and acceptance uncertainty	(Ballon, P. et. al, 2005)	
Policy relevance and effectiveness	(EU Commission, 2025)	7. Regulation
Safety and compliance assurance	(EU Commission, 2022)	
Impact assessment uncertainty	(IEA bioenergy, 2020)	
Standards compatibility	(EU Commission, 2025), (OECD, 2023)	