GÉANT

FORESIGHT 2030

Navigating Change

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Executive Summary

The GN5-1 Foresight Study aims to identify key opportunities and challenges for the National Research and Education Network (NREN) community over the next decade.

The study is not about predicting the future, but rather using current knowledge and expert opinion to consider different future scenarios. The goal is for the NRENs to better prepare for these eventualities. The study explores technical and non-technical challenges as well as opportunities for NRENs, with the objective of raising awareness of these issues, scrutinising their likelihood, impact, and interactions to aid decision-making amid uncertainty. The study also recognises the diversity of NRENs – their different roles, activities, and funding models – and how these factors influence their strategic decisions.

The study's scope spans 5 to 10 years and aims to provide a practical framework applicable to all European NRENs. It addresses key questions about the evolution of the European NREN community, the factors influencing NRENs' roles, their response options to different futures (or scenarios), and the risks and opportunities arising from different strategic positions. The findings will also be useful for other stakeholders, as national and European authorities, e-Infrastructures, Research and Education (R&E) organisations, and global partners.

The report begins with a summary of the study methodology followed by an analysis of future challenges and opportunities identified by the NREN Focus Group and stakeholders across the wider R&E community. Six key challenge areas are identified and explored for future consideration, all of which interconnect in various ways:

- Interaction with Commercial Actors
- Climate Change and Sustainability
- Employment and Skills
- Technological Advances
- NREN Governance
- Delivering Research and Education at Scale

The study also presents a scenario development methodology for future use by the community to explore other potential futures by adjusting and adding to different factors that are at play within the identified challenge areas.

The study uses this methodology to generate three possible and plausible futures (or scenarios) in which NRENs may find themselves in 2030:

1. **Playing the Fair Game** – a scenario where NRENs will have much less distinction in terms of access to the funding, users, regulations, and skills from any other actors who are willing to operate within the area of same interests as NRENs.
2. **Rough Seas** – a scenario with the most challenging, while still plausible, set of parameters from the available directions of future evolution.
3. **The Beaten Track** – a scenario that represents a continuation of the NRENs' current situation. It considers the main contradictions of the current trends and aims to identify the main opportunities to act to retain the current situation.

Regardless of the different futures/scenarios explored in this study, three factors influence every aspect of potential evolution for NRENs and the GÉANT community:

- The changing emphasis on skills for future-proofing the NREN community.
- The interaction with commercial actors and the roles NRENs play here.
- Cybersecurity's relation to skills and technological influences, such as AI, and the involvement of NRENs.

These persistent factors are complemented by factors whose impact on the NRENs' activities depends on the specific national settings, such as national regulatory frameworks, the funding landscape, the R&E data management approach in each country, an NREN's approach to its internal evolution.

The study consistently highlights the value of NREN collaboration to maximise opportunities and tackle challenges both for themselves and their constituencies or customers (for example universities, research centres and R&E infrastructures). However, it does not delve into the specifics of such collaboration or how one might be implemented effectively; that is for future exploration.

The GÉANT Project study team wishes to express its sincere thanks and appreciation for the work undertaken by the members of the NREN Focus Group and other experts who have contributed to the work through various channels throughout the study.

1. Introduction and Background

There are many definitions used to describe 'foresight', but all tend to agree that it is using what is already known combined with expert knowledge and opinion to project forward into different future possibilities.

The GN5-1 Foresight Study aims to identify key opportunities and challenges for the European NREN community[1] in the next decade. Twelve years have passed since the last foresight study within the GN3-4 project [ASPIRE], during which time rapid technological advancements have driven the digitisation of R&E and the integration of digital technology into various aspects of operations, evolving the R&E community. This new study examines the challenges NRENs might face in the next 5 to 10 years and their potential impacts on the development of the R&E community. The timeframe has been chosen with the idea to look at medium to longer term; anything shorter than five years is, to some extent, taken into consideration in the existing NRENs'/GÉANT strategies.

Both technical and non-technical challenges as well as opportunities for NRENs have been explored. Understanding the interaction of these challenges within different scenario environments will enable better preparation for future changes, especially those with currently unknown impacts.

The purpose of the study is to raise awareness of these challenges and opportunities, and scrutinise their likelihood, impact, and interdependencies to aid decision-making amid uncertainties.

Diversity of NRENs

National Research and Education Networks (NRENs) operate in an evolving and multi-faceted environment, consisting of expanding service portfolios, diverse user groups, varied organisational models and financial autonomy, and differing levels of flexibility in response to changes. As shown in the GÉANT Compendium of NRENs, in Europe all NREN organisations operate differently, yet share the goal of supporting and enabling the R&E

[1] In this report, 'European NREN community' is used interchangeably with 'NREN community' to denote primarily European NRENs and GÉANT, while 'R&E community' denotes primarily NRENs and their constituencies.

community in the best possible way [COMPENDIUM]. All NRENs depend, to varying degrees, on public funding, both European and national.

NRENs have been persistent actors of the European and global research landscape, with the first R&E networks in Europe dating back to the 1980s. A community of NRENs in Europe as well as in other world regions has evolved through the years at different rates of development, depending on location.

While all NRENs within the GÉANT community share the common purpose of providing connectivity and connectivity-related services to their national R&E sector, i.e. universities and research institutions, beyond this, their role and activities differ considerably. This starts with obvious differences in the size of NRENs, ranging from those with fewer than ten employees and a budget of well below €1 million to NRENs with hundreds of employees and an annual budget of several hundred million Euro.

The differences in NREN size and funding levels partially reflects the different sizes of their countries of origin, but also the extent of their activities. While some NRENs limit themselves to their core purpose of delivering network infrastructure, others are active in areas beyond this core (although generally adjacent to it). This can include running data centres or supercomputing centres, or the provision of tools for education or educational content. If the range of activities of different NRENs varies, the same is true for their constituencies.

While all NRENs provide their services to universities and research institutes, a number have expanded either or both their service portfolio and user groups – for example to schools, government bodies, cultural institutions or (non-university) hospitals. Important differences also arise from the organisational backgrounds of NRENs, with some being membership organisations (founded and financed by their user institutions) and others being part of the government (run, and fully or partially funded, as or by government bodies such as part of a ministry). Between those two extremes hybrid forms exist. (A more detailed overview of the world of the European NRENs can be found in the GÉANT Compendium of NRENs [COMPENDIUM].)

How NRENs are funded and set up ultimately dictates what they can do – that is, how much autonomy they have in their strategic decisions depending on their governance models. This determines their ability to diversify both their offer and customer base, as well as the need for this diversification. NRENs that are government funded may hold a mandate for specific audiences or users by their government.

Changing Environment

The funding environment for GÉANT and the NRENs is evolving, as well as the NRENs' user environments (university campuses, research centres, schools and, increasingly, not directly R&E related public spaces such as museums, government departments and hospitals), including the use of infrastructure and services. At pan-European level, the current Multi-Annual Financial Framework (MFF) of the EU ends in 2027, concluding the GNx funding envelope. The GN5 Framework Partnership Agreement (GN5-FPA) is a 72-month agreement from 1 January 2022, supporting specific grant agreements such as the GN5-1 project. The funding instrument to be used by GÉANT in the next MFF is still uncertain. The influence of European Open Science Cloud (EOSC), European High Performance Computing (EuroHPC), and Quantum funding and policies on the NREN landscape, as well as a potential further diversification of accessible European Commission (EC) funding, will also become clearer by then. Additionally, geopolitical factors and national political changes, and the accompanying uncertainties, continue to play a major role for NRENs as public actors.

Whilst these upcoming changes will vastly influence the environment in which the NRENs will operate, they are largely out of the NRENs' direct influence. The team therefore chose to focus on the individual role of the NRENs, what they can do, and which opportunities they can and need to seize to be best placed in different possible futures.

Study Scope

The foresight horizon looks to the years after 2028, beyond the current project (GN5-1) and future Horizon Europe projects (GN5-2 and GN5-3). The study's scope was defined through discussions with project stakeholders, including the GÉANT General Assembly, the GÉANT Community Programme, the GÉANT EC Liaison Team, GN5-1 WP3, and the NREN Focus Group. Initially, the study took a broad approach, identifying numerous challenges relevant to NRENs. An in-depth analysis of all these challenges was not scalable within the timeframe and scope of this study; however, all the challenges identified are considered important to affect the ecosystem of NRENs in the upcoming years. Whilst the following topics are known and indirectly considered, they were considered to be beyond the remit of the study:

- Geopolitical factors (beyond NRENs' control)
- National developments of the R&E community or funding authorities
- International R&E landscape developments

- GÉANT organisation and future strategy
- GNx project
- Broader EC funding landscape

Aims and Objectives

The study aims to provide a toolkit applicable to all European NRENs, allowing stakeholders from other areas to benefit from the findings too.

This study therefore addresses the following questions:

- How might the European NREN community evolve in 5 to10 years?
- What are the key factors influencing NRENs' roles?
- What options do NRENs have to respond to different futures?
- What risks and opportunities arise from different strategic positions?

The study uses current knowledge and expert option to identify three future scenarios, including challenges and factors facing European NRENs and stakeholders from other areas. While the findings will be useful for other stakeholders, such as national and European authorities, e-Infrastructures, R&E organisations, and global partners, these are not the primary focus. However, the stakeholders were extensively consulted throughout and are encouraged to review the study results for their benefit.

1.1 Methodology and Study Development

The study commenced in the spring of 2023, comprising a three-phased approach. This is explained below and shown in Figure 1.1:

Phase 1: Design To shape and scope the methodology.

Phase 2: Challenges To explore potential challenges and disruptors that could significantly impact the NREN community in a 5-to-10-year timeframe.

Phase 3: Pathfinding To build potential future scenarios, identifying opportunities and responses for GÉANT and NRENs within those scenarios.

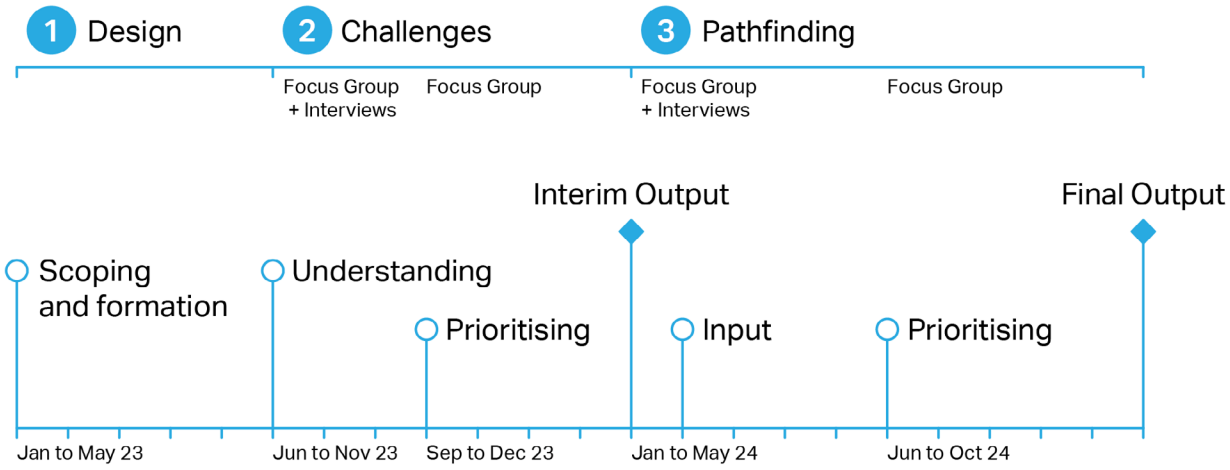


Figure 1.1: Study phases and timeline

Phases 2 and 3 involved a broad and open thought-process, followed by a phase of prioritisation based on certain criteria in order to focus and progress the study in a manageable way. Research was largely conducted online through a range of facilitated sessions using a virtual whiteboard (MIRO) and other collaborative tools such as Box and Wiki to structure, record, and organise input from the expert NREN Focus Group. An in-person workshop was held with the NREN Focus Group at the beginning of Phase 3 to start the scenario development process. Additionally, a series of interviews was conducted to provide a wider perspective on the challenges, impacts, and opportunities facing other stakeholders aligned with the activities of NRENs, along with an interactive session with the GÉANT General Assembly.

More details on the three phases of study and a full list of all involved are shown in Appendix A and B.

1.2 Community and Stakeholder Input

Throughout the study, additional community input was sought to validate the work at the respective stage and enhance the analysis. This was done through several channels and included the GÉANT General Assembly and other stakeholders from the GÉANT Community.

1.2.1 GÉANT General Assembly Interactive Session

The General Assembly is GÉANT's highest governing body, where representatives of its 43 member and associate NREN and REN organisations meet at least twice a year. Presentations were given at three General Assembly Meetings (June 2023, November 2023, June 2024) for the validation of scope and methodology, selected challenges, and scenarios, including an interactive session.

The interactive session was held during the GÉANT General Assembly meeting in November 2023. Here, the foresight study sought validation of the identified challenges and asked each NREN representative to assess the likelihood and impact of each challenge on their respective NREN, to guide future work. Feedback was also requested to determine if the selected challenges from the initial list were appropriate for further work or if any key aspects were missing.

The session results confirmed that all six identified challenges were suitable for further work. NREN representatives generally rated these challenges as having high certainty, high importance, or both. While some challenges elicited more varied responses than others, the overall list of challenges was successfully validated.

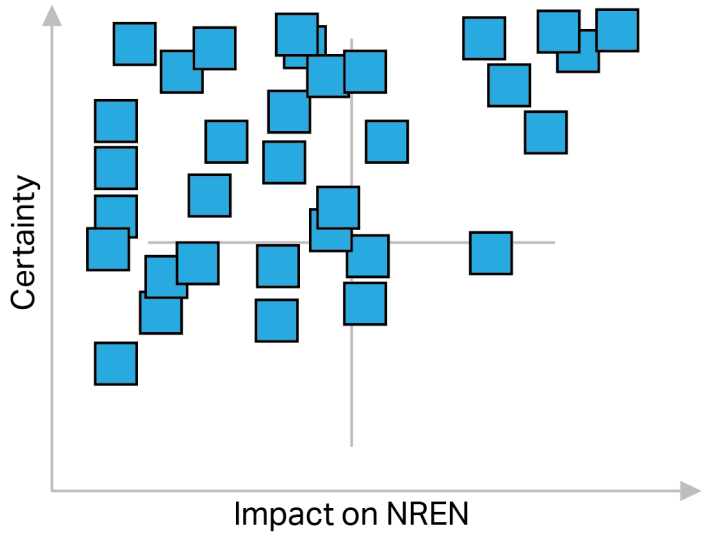


Figure 1.2: Example of the distribution of answers on the Climate Change and Sustainability challenge area

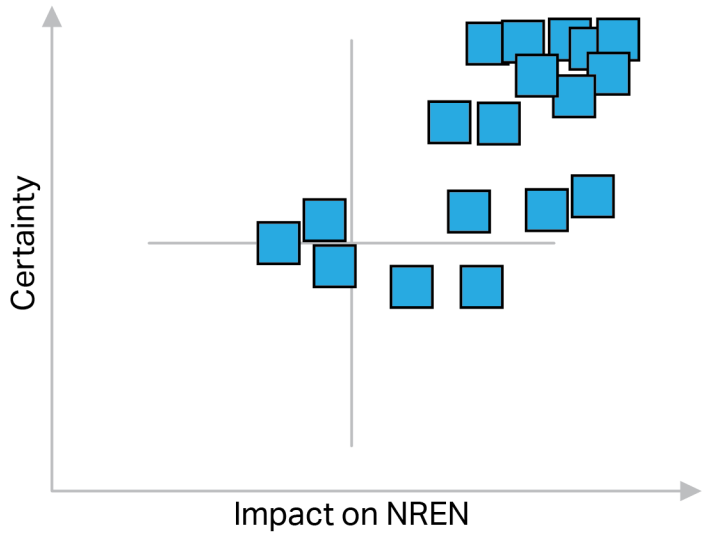


Figure 1.3: Example of the distribution of answers on the Employment and Skills challenge area

1.2.2 Stakeholder Interviews

In a series of structured interviews, the foresight study sought insight from outside the NREN Focus Group into the wider European R&E Community. Interviewees came from NRENs (PSNC, DeiC), international research organisations (CERN, ESA), pan-European infrastructures (EGI), stakeholder organisations (EUNIS) and a group of students that had participated in the GÉANT Future Talents Programme.

These interviews were carried out alongside the other study activities to gather additional input on the challenges the NREN Focus Group had identified, but also to learn about challenges the interviewees would see for their own organisations in the timeframe under consideration (5 to 10 years). As most interviewees' organisations have a relationship with GÉANT, they were also asked about expectations they would have in regards to the future of these relationships. This stakeholder-group expansion allowed for a more rounded picture of each challenge and its implications.

1.2.3 Other Inputs

- A focus group with participants of the GÉANT Future Talent programme was put together to understand their perception of the evolution of the R&E landscape.
- Several meetings with the EC liaison team were held to discuss the progress and possible relevant links or considerations regarding the evolution of the EC funding landscape.

2. Challenge Areas and Future Landscape

While this document does not intend to provide direct strategic advice, it aims to facilitate informed strategic decisions within the NREN community. For this purpose, the challenge areas and factors discussed in the following sections need, in the opinion of the Foresight Project Team and NREN Focus Group, to be considered in the projection of future landscapes and scenarios of the community.

The study group focused on the following list of challenges (more background on these can be found in Appendix A.2):

- Interaction with Commercial Actors
- Climate Change and Sustainability
- Employment and Skills
- Technological Advances
- NREN Governance
- Delivering Research and Education at Scale

The challenges are in different stages of their 'lifecycle', and the NREN Focus Group used the Gartner Uncertainty Spectrum of Trends [GARTNER] as a useful system to categorise each:

- **Reality today**: Strong evidence that the trend is embraced by organisations today
- **Predictable**: Develop in a predictable way over the time
- **Unpredictable**: Path of growth is heavily influenced by external accelerators or inhibitors that quickly alter the course
- **Transformative**: Impact can only be speculated and imagined

These categories are used to group the main trends identified in the following sections. Each challenge area was considered in the context of:

- **Environment**: partners, stakeholders, users (constituencies)
- **Value proposition**: value, delivery channels, service portfolio
- **Finances**: income, expenses, financial flows

These are included in the analysis of implications for each challenge.

Please note: the high number of footnotes in this section ensures that all the information needed for a thorough explanation is provided at the point at which it is needed.

INTERACTION WITH COMMERCIAL ACTORS

2.1 Interaction with Commercial Actors

Since the last foresight study, the worlds of R&E, ICT infrastructures, and services have become much more dynamic. They are no longer primarily based in universities and research centres. Commercial research has become a prominent component of the R&E landscape, contributing to the innovation and advancement of scientific knowledge. While the most advanced research initiatives still require tailored IT support, including data storage, processing, and network, many technologies and services that have started within and for the R&E community have matured over the years and are now available commercially at scale, making R&E a compelling market segment for commercial actors.

2.1.1 MAIN TRENDS

REALITY TODAY

NREN constituencies in some countries are increasingly relying on hyperscale solutions to their IT services. This in turn requires that NRENs accommodate commercial providers of IT services when providing connectivity.[2]

Funding regulations increasingly demand that research infrastructures are available to be used by commercial entities to capitalise on the investments.[3]

Despite the uniqueness of some services like cybersecurity and identify federation, it is increasingly harder to prove the relevance of the singled-out NREN connectivity services to constituencies who do not require specific connectivity-related functionality of the network due to the commoditisation of connectivity and services. This puts NRENs in competition with commercial actors. To date, NRENs typically have had limited experience of direct competition with commercial actors in delivering their portfolio of services (cloud services being a prominent example).

[2] IaaS services procured through the GÉANT procurement framework have increased from circa €4m in 2017 to almost €70m in 2022 [MEIJER] slide 12

[3] The EuroHPC JU has procured pre-exascale and petascale supercomputers (EuroHPC supercomputers), operated by centres in the EU. EuroHPC JU manages access time for EuroHPC supercomputers, ranging from 35% to 50% of total capacity. Academics, research institutes, public authorities, and industry can apply for computing time on these [EUROHPC].

2.1.2 ANALYSIS OF IMPLICATIONS

ENVIRONMENT

- The NREN Focus Group does not perceive that interactions with commercial actors will cause stakeholders and constituencies of an NREN community to undergo a substantial change in the timeframe of 2030. However, the partnership may introduce changes in the operations and governance of NRENs.
- The NREN community will be required to adjust its position towards commercial actors in the direction of partnership to jointly ensure the delivery of integrated IT services [HLRS]. There are good reasons for cooperation: commercial actors deliver quality products that are sought after by NREN constituencies, and NRENs have good knowledge and the trust of the community. A joint approach has the potential to produce value for all players, ensuring that Europe remains at the forefront of research worldwide and protects European sovereignty with appropriate data security standards. As a particular challenge, ensuring the NREN's visibility to partners and users in the delivery chain will become increasingly important to secure their value proposition. Current hyperscale commercial actors deliver the services directly to the end user and intermediate layers are not visible to the end users.[4]

VALUE PROPOSITION

- The current value proposition of a dedicated trusted environment will be challenged by the cooperation with commercial entities. This type of environment will likely impose additional challenges concerning security, sensitive data, and data sovereignty.
- Collaboration with commercial actors will present a challenge to the NREN service portfolio to adjust the value proposition to address the pain points of NREN constituencies.

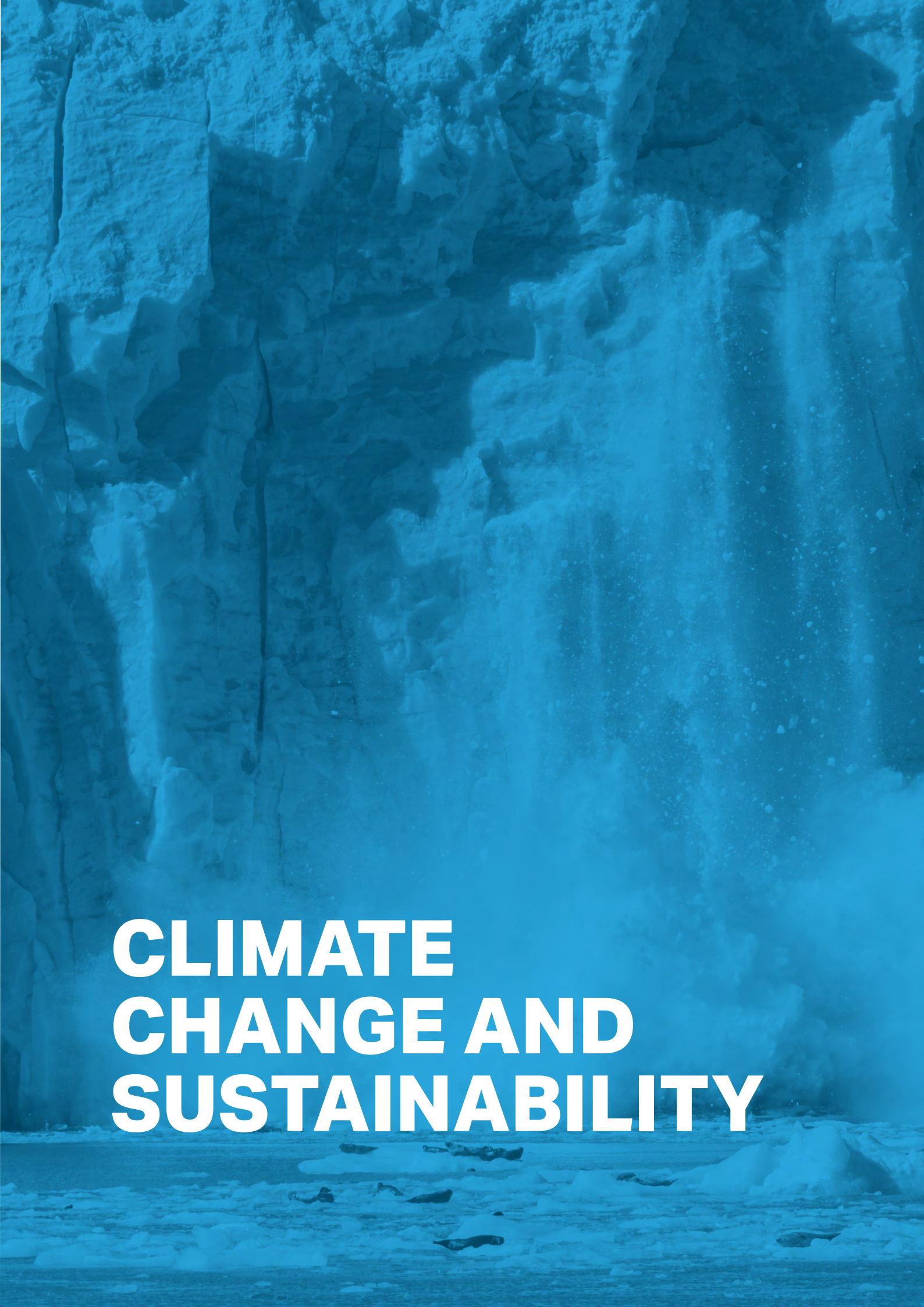
[4] Procuring hyperscale services via the OCRE/GÉANT framework as opposed to other vehicles based on market concessions. The NREN can then opt to support the framework activities in various ways, making visible the intermediaries, and driving NREN relevance through significant value add.

- The push to reduce IT costs strongly encourages the adoption of short-term solutions from commercial actors, despite the known risks, which include undermining the NREN's role in providing non-commercial long-term solutions (i.e. an NREN's unique selling points).
- Requirements for the delivery of the solutions aimed directly at the end user will imply that bespoke service solutions such as eduTEAMS and Federation as a Service, will gain momentum, and more services like this will be available in 2030.
- While commercial actors are capable of delivery of higher quality products at scale, a number of scientific applications will require high-level customisation, creating an opportunity for home-grown, tailored functionalities at earlier stages of product development, such as pilot implementations and proof-of-concepts.

FINANCES

- Expenses will likely become more operational expenditure dominated (OPEX-dominated) than they have been in the past, because more services will be procured from commercial actors 'as a service'.[5] This may in turn influence the charging mechanisms and funding streams (incomes) of NRENs.

[5] Monthly billing cycles associated with cloud consumption via GÉANT procurement frameworks. Suppliers mandated with periodic reporting via the GÉANT CMG (Contract management group) [MEIJER].



CLIMATE CHANGE AND SUSTAINABILITY

2.2 Climate Change and Sustainability

Climate change is a multi-layered global challenge that requires global actions. The R&E community is a key component to meet this challenge with fact-based decision making. NRENs are affected both by the actions undertaken as well as new requirements for support for scientific community to study the climate change.

2.2.1 MAIN TRENDS

REALITY TODAY

NRENs are also an enabler for climate research and climate change mitigation, by providing crucial infrastructure and services to researchers – a role that will likely increase in importance.

Currently, there's strong evidence that policy compliance regarding energy efficiency and carbon footprint will be required from all the entities sooner than 2030.[6] Regulations will affect the availability and reporting of information regarding the carbon footprint and mandatory measures to reduce said footprint. Regulations, however, will not be the only driver here, as society might start to perceive non-efficient processes more and more as wasteful and negligent.

PREDICTABLE

Effects of climate change will manifest in many forms across the globe including rising energy prices. It will require a global coordination of NREN efforts to help communities address these effects and implement the necessary solutions to meet the demands of the R&E community in this field.

Climate research is already a prominent discipline within the landscape of data-intensive R&E. The importance of climate science is likely only going to increase. Delivery of state-of-art solutions for climate science will represent a challenge for the NREN community.

[6] The *2023 Strategic Foresight Report* identifies areas where policy initiative is needed to ensure that the sustainability transition will remain focused on people's wellbeing and progress: Support shifts in production and consumption towards sustainability, targeting regulation, and fostering balanced lifestyles [EU STRATEGIC_FORESIGHT].
Establishing a framework of measures for strengthening Europe's net-zero technology products manufacturing ecosystem (Net Zero Industry Act) [EC PROPOSAL].
The EU and national governments have set clear objectives to guide European environment policy until 2020 and a vision beyond that, of where to be by 2050 [ENVIRONMENT_POLICY].

UNPREDICTABLE

Coupled with other factors in the political space, the effects of climate change might contribute to serious societal upheavals and crises, such as fuel and energy shortages and blackouts, which in turn will affect the fabric of the NREN community, as well as NREN services.

TRANSFORMATIVE

There will be consequences for the NRENs and the wider R&E communities they support,[7][8] with climate change affecting NRENs differently in accordance with their operational models and service portfolios.

The restrictions for carbon footprints will transform the global R&E community. They will impose global changes in scientific processes, reducing travel and increasing reliance on global, trusted, virtual research environments involving data storage, access and processing, as well as seamless communications.

2.2.2 ANALYSIS OF IMPLICATIONS

ENVIRONMENT[9]

- Compliance to climate-change-related regulations (for energy efficiency, for example) might force a change of business partners when procurement policies need to be updated. NRENs outsourcing most of their services will be more affected by this than NRENs that rely more on their own infrastructures and provide a 'full stack' of services. This contributes to the overall disparity of NRENs.
- The shift to trusted and secure virtual environments for international R&E, as opposed to requiring a physical presence, is altering NREN service delivery. NRENs can support this transition if their networks and above-the-net services

[7] Report explores what the impact of climate change will be on our educational institutions in the next decade: In 2020, CO2 emissions reached the highest-ever average annual concentration in the atmosphere – around 50% higher than when the industrial revolution began. Global warming, severe drought, rising sea levels, extreme weather events, increased wildfires, and food and water supply disruptions are only some of the consequences. If current trends continue, this frightening list is expected to get longer. Education is key to shifting course, with R&D systems developing technological solutions and classrooms working to empower students to take action in the global fight against climate change. [CHANGING_NATURE].
[8] By 2025, without sustainable AI practices, AI will consume more energy than the average European country [ELECTRICITY_2024]. Future scenarios for education [CHANGING_NATURE].
[9] Producing and providing eLearning courses consumes an average of 90% less energy and produces 85% fewer CO2 emissions per student than conventional face-to-face courses. [OPEN_UNIVERSITY].

remain competitive. Catering to the demands of such international research environments has a potential to change current organisational boundaries and structures.

- The global scope of the effects of climate change will put more emphasis on global partnerships and global NREN coordination.
- While the effects of climate change on the entire society will affect all organisations, partners, and end users, this is not likely to change constituencies or operational models.
- The case for NRENs as R&E solution providers will remain in 2030.

VALUE PROPOSITION

- The transformation of global R&E processes will rely more heavily on secure and trusted research environments, virtual presence, and communications networks rather than travel and physical presence. Fewer face-to-face events will have implications for the requirements for integrated end-to-end solutions for multiple R&E organisations distributed globally, and thus will have implications on the NREN service portfolio and on community-building activities.
- Compliance to the policies regulating the information about the carbon footprint as well as policies stipulating reduction of the carbon footprint will affect the value proposition of NRENs. Lack of action might be damaging to the brands of GÉANT and NRENs; in contrast, thoughtful action might present an opportunity not only in terms of the energy efficiency of the NRENs themselves but also by emphasising their role in facilitating scientific research in the domain to find responses to the challenge.
- Scientific research on climate change is essential to identify and address its impact. NRENs play a crucial role in global data sharing and research cooperation, which can increase efficiency and reduce the carbon footprint. For instance, rising temperatures may necessitate relocating data storage to northern regions, lowering energy needs but potentially challenging network capacity, topology, and policies on data transit and preservation.
- The technical capabilities and policies of NRENs will need to adjust to the changing operational environment because of this challenge. The unpredictability and imbalance of the ecological environment may require adoption of

special methodologies for business continuity. This will differ between NRENs as, for example, those NRENs that offer services like data repositories will be exposed to additional requirements.

- A special benefit can be potentially derived from international connectivity to support the needs of the Global South.

Beyond these core activities, NRENs can also contribute to ecological sustainability through their procurement activities, not only to reduce prices but also to enforce criteria supporting sustainability.

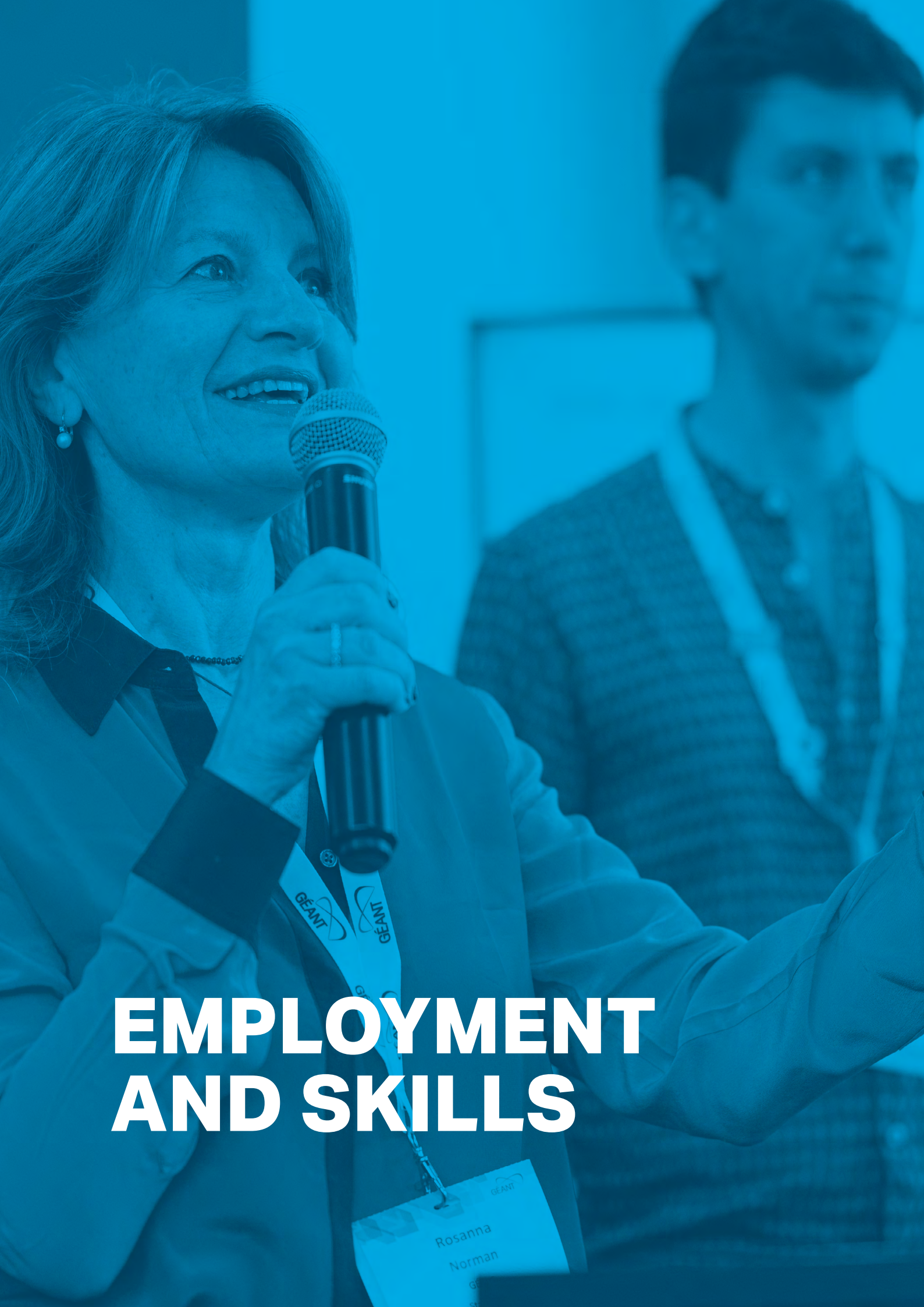
FINANCES

- Transitioning to providers of clean energy is a way to actively mitigate climate change issues on the part of the NRENs, with some (e.g. SURF, HEAnet) already having objectives in place. This is likely to incur higher operational costs, and might become mandatory through government regulation for publicly funded organisations. The opportunity to attract additional funding to address the carbon footprint and compliance will depend upon the timeliness of applying for it – earlier adoption of measures will be more likely to be funded.
- Energy prices in general will likely remain at an elevated level and potentially raise significantly as part of the costs of transitioning society to a carbon-neutral economy. This will impact on many areas and increase the cost of any (research) activity involving significant energy consumption.
- Backbone networks will still need energy to run, and their energy-saving potential is limited. To enable a more virtualised research process, networks will have to be operational and resilient all the time to ensure the reachability of research tools and data. This risk making the operation of networks more expensive and more energy consuming.
- NRENs will have to be prepared technically and financially for externally driven events like flooding, cooling problems, or fuel and energy shortages and blackouts, all of which might become more likely.

OTHER

- NRENs will face a challenge to properly communicate and convey their energy effectiveness as a part of the overall value proposition to the R&E community and the general public, to avoid reputational damage.[10]

[10] A legacy of the global energy crisis may be to usher in the beginning of the end of the fossil fuel era: the momentum behind clean energy transitions is now sufficient for global demand for coal, oil and natural gas to all reach a high point before 2030 [WORLD_ENERGY_OUTLOOK].



EMPLOYMENT AND SKILLS

2.3 Employment and skills

NRENs operate in a broader environment of an ever-changing workforce, where ways of working and expectations around employment have step-changed irreversibly since the COVID-19 pandemic.[11] Coupled with this is the growing challenge for any organisation, including an NREN, being able to predict what employment and skills will be needed in 2030 to fulfil roles that don't currently exist. This challenge is already evident for most NRENs but will continue to grow by 2030, overlapping with the other challenge areas explored in this study.

2.3.1 MAIN TRENDS

REALITY TODAY

The new generation of specialists and overall workforce have different expectations of the working culture, forming part of their motivational package.[12] Expectations and motivations – the 'how, what and where' of working, across all levels of the workforce – are changing.

PREDICTABLE

Already, executive leadership personnel within some constituent organisations and NRENs themselves are being hired from outside the R&E community, for example from a more commercial background, bringing different perspectives and culture. This trend will increase, and in 2030 there will likely be a wide variety of backgrounds in the leadership of IT structures/services, including NRENs, influencing the consistency of common ground for the NREN community.[13]

[11] In 2016, surveyed companies predicted that 35% of workers' skills would be disrupted in the following five years. In 2023, that share has risen to 44%. This expected rate of disruption to skills nevertheless represents a stabilisation since the previous edition of the Future of Jobs Survey in 2020, when COVID-19-induced disruptions to working life caused respondents to forecast a skills instability of 57% in the following five years [FUTURE_OF_JOBS_REPORT].
Sustainability can also have a significant positive impact on non-environmental factors, such as brand, innovation, resilience and attracting talent [GARTNER].
Gartner anticipate through 2026, infrastructure and operations organisations that fail to meet the nonmonetary needs of employees will experience attrition rates 30% to 40% higher than in 2020–21. When it comes to attrition, compensation, manager quality and work-life balance were among the top factors that caused IT employees to be dissatisfied with their previous organisation [ATTRACT_RETAIN].
[12] The 2024 Prospects Luminate Early Careers survey by Jisc indicates that although young job seekers place greater importance on both work-life balance and salary in their choice of employment compared to 2021, work-life balance and training and development are now considered more important factors than salary. Career progression follows closely behind [EARLY_CAREERS].
Horizon Europe's guidance on gender equality plans also cites work-life balance as a key component of the transformation of an organisation's culture for advancing gender equality [HORIZON_EUROPE].
[13] Comparisons to previous surveys suggest that creative thinking is increasing in importance relative to analytical thinking as workplace tasks become increasingly automated. In 2018 and 2020, the number of surveyed companies that considered analytical thinking to be a core skill outnumbered those considering creative thinking to be a core skill by a margin of 35%

With the implications of climate change and evolution of the virtual environments, there will be a further globalisation of the labour market. The skills required could be attracted regardless of the country of origin. Higher levels of people migration within the community between different NRENs will continue.

Higher dynamics of labour market conditions will most likely result in higher churn rates for specialist positions for all the actors, including those of R&E community. New leadership methodologies will be required to attract and retain the talented workforce, including a more empathetic response and reliance on intrinsic values versus transactional relations. In addition, current practices of long onboarding process within NRENs will be challenged by the new dynamics.

UNPREDICTABLE

Increasing uncertainty in what skills will actually be needed to fulfil the jobs that don't yet exist is expected. Higher demands for different skillsets in NRENs are already evident due to the deployment of new technologies, requirements of compliance and new environment, especially interactions with the commercial actors. This trend will accelerate in the timeframe to 2030, with the need for higher adaptability to future-proof against this trend.[14]

and 38%, respectively. That gap has now decreased to 21% and may continue to close. Companies expect the automation of reasoning and decision-making to increase by 9% by 2027. Cognitive skills are reported to be growing in importance most quickly, reflecting the increasing importance of complex problem-solving in the workplace. Surveyed businesses report creative thinking to be growing in importance slightly more rapidly than analytical thinking. Technology literacy is the third-fastest growing core skill. In addition, 68% of companies' belief that consumers are becoming more vocal on social and environmental issues is likely or highly likely to drive transformation within their organisation in the next five years. Workers will require additional skills training if companies are to meet the increasing ethical demands placed on them as a result of adopting frontier technologies and adapting to the green transition [FUTURE_OF_JOBS].

[14] For many, the future of work is already here. And, although the total number of jobs lost in the technical revolution will be outnumbered by the 'jobs of tomorrow' it creates, the immediate impact could displace many workers and leave them without the skills needed to perform new and more technical roles [WORLD_ECON_FORUM].

2.3.2 ANALYSIS OF IMPLICATIONS

ENVIRONMENT

- A shortage of IT support and helpdesk skills is likely to create an increased requirement to outsource the IT support services for NRENs and their constituencies. This will imply changes to the landscape of the R&E environment – accepting new partners and new forms of collaboration, in particular with commercial actors, jointly developing new solutions and implementing innovative ways of providing high quality services to the R&E community.
- There is likely to be a greater need for leadership from academic/educational backgrounds in NRENs and GÉANT with 'the right industry mindset' to maintain the core purpose of supporting R&E.
- Retaining skills and enthusiasm will increasingly be a challenge to NREN community members, not only through competition (often via direct salary) from commercial actors, but the skilled workforce might also join other e-infrastructures or other NRENs. This in turn has a potential to increase the divergence among the NREN community, threatening the case for NRENs.[15]
- Increasing mobility of the workforce, virtualisation of offices, and disparity between countries may affect the coherence of the community when specialists are not bound to their 'home' NREN. At the same time, this poses an opportunity to access a broader set of skills and people to fill individual roles.
- With the development of new technologies, like AI, and changing skillsets, NRENs will not have as great a need for as many 'end-workers' or 'manual roles'. However, there will be a continuing need for quality assurance of these approaches, and 'soft skills' such as interpersonal (people), communication, and listening skills, as well as time management, problem-solving, and leadership.

[15] The movement of high-skilled workers has notably increased in Europe. In 2021, 32% of EU movers possessed high level of education, compared to 28% in 2016. The circulation of talent between countries can yield beneficial outcomes. But Europe has also witnessed the negative effects of brain drain [BRAIN_DRAIN].
Seventy percent of European businesses view the lack of digital skills as a major obstacle to investment, with 40% of adults lacking even basic digital skills. This challenge is not unique to the region. We found that learners in many regions are prioritising human skills over the digital skills that are in high demand. Enrolment growth in cybersecurity skills falls behind high-growth areas like cloud computing and data science. Worldwide, the gap between the number of needed and available skilled cybersecurity professionals rose by 12.6% year-on-year. In Europe, cybersecurity enrolments declined by 5% year-on-year, despite the region being heavily impacted by cyberattacks [COURSERA_REPORT].

VALUE PROPOSITION

- The service portfolio and value proposition of NRENs will heavily depend upon the capability to attract and retain highly qualified and motivated workforce. Unpredictability of technical challenges will create demand to understand applicability of new approaches to research processes, and to meet new requirements with new functionalities. That in turn will require new skills for positions that do not yet exist. To continue to be the enablers of R&E processes, by 2030 NRENs will need to make a significant move towards becoming 'people-centred' organisations, offering clearly defined career path options to counteract the financial pull of the private sector. Visibility, purpose, and the impact of work are all things that need to be shown more obviously to encourage motivation and recruitment: 'we are the product we offer'.
- The current model of NRENs requires extensive onboarding processes and the right mindset to comprehend the specific circumstances of the NREN community. Current onboarding practices will be increasingly challenged by the expectations and churn of a new generation who might be more driven by monetary factors as a part of the motivational package than by developing the mindset required.[16]
- Innovation in NRENs tends to happen on a more iterative basis than creating new, and therefore there is a challenge to engage potential candidates. Adopting faster cycles of innovation are likely to keep employees engaged.
- Currently, there is evidence that international work is considered as a short-term loss to an NREN because the same specialists cannot perform local tasks prioritised by the management. The successful co-construction environment that accompanies international/global collaboration presents an opportunity to extend the value proposition for future skills.
- A collaborative skillset becomes essential to strengthen the role of European R&E in the world. The community as a whole will have to be cohesive to achieve this.

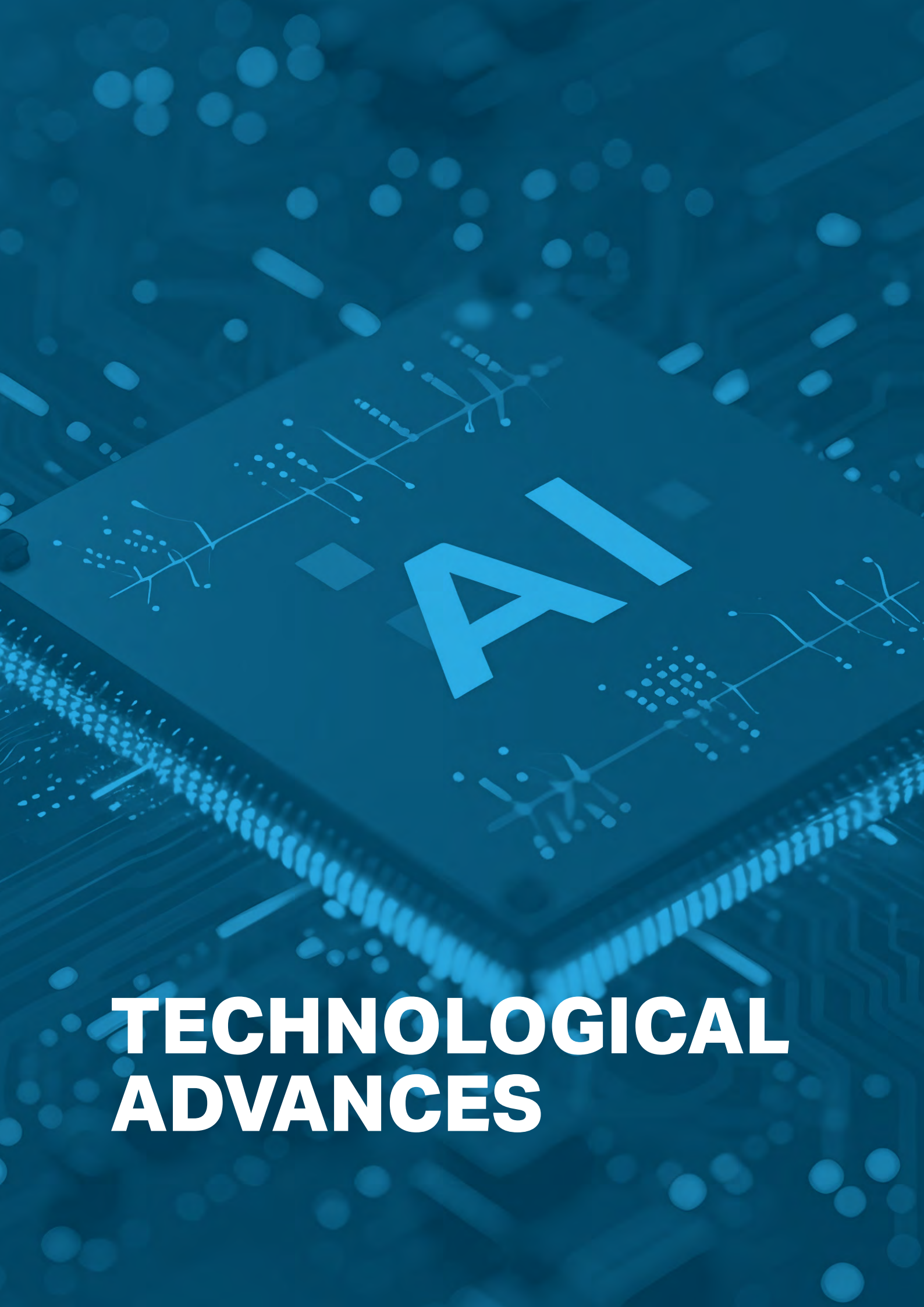
[16] Mid-life workers want menopause support, eldercare assistance, health screenings and more [BBC_WORKLIFE].

FINANCES

- NRENs will face a strategic challenge to change the recruitment strategies and invest significant amounts of effort to acquire and upskill a workforce with the right skills and mindset meeting the requirements of NRENs' value proposition.
- The emphasis on working culture, as well as approach toward people-centred organisations, will challenge the current budgets of NRENs and GÉANT. It's an opportunity to react timely and capitalise on one of the most important assets in the community – people.
- Spending or remuneration packages are very unequal across Europe, which may lead to a 'brain drain' for less affluent regions.

OTHER

- Creating career paths and developing the human network within the community that start early in people's careers would help to create a pool of employees familiar with the working culture of the community. NRENs generally have strong connections to the university sector, and many have leveraged this to recruit personnel. So, this existing strategy could serve as a template for the future.



TECHNOLOGICAL ADVANCES

2.4 Technological advances

New or developing technologies always require adaptations. While such changes can develop gradually or fast, speedy changes generally have more disruptive potential.

The Foresight Focus Group chose four areas as important technical challenges: artificial intelligence, cybersecurity, data lifecycle, and quantum technology. All of these have strictly technical aspects but, in most cases, the consequences of the applications that these new technologies enable will require more attention than the technology itself. This applies to the cybersecurity and data lifecycle challenges where the main problems do not result from groundbreaking new technologies, and is also true for quantum technology and AI, which present genuinely new technologies. This is reflected in the following considerations.

2.4.1 Technological advances: Artificial intelligence

Artificial Intelligence (AI) holds significant potential in continuing to transform R&E: accelerating data analysis, uncovering patterns, personalising learning experiences, making education more accessible and effective, introducing efficiencies and so on. However, it is not without its risks and challenges, such as GDPR (General Data Protection Regulation), research integrity and authenticity, which will need to be considered carefully as AI becomes increasingly pervasive in society. Amidst the hype, there remains uncertainty around how AI can be used most effectively and efficiently across the range of its potential applications.

2.4.1.1 MAIN TRENDS

REALITY TODAY

AI applications have proliferated quickly from the relatively closed domain of computer science to all disciplines ranging from agriculture to sensing of submarine fibres.[17] AI applications will significantly enhance research capabilities through automation of repetitive tasks, advanced data analysis, and predictive modelling. The AI domain will be a critical tool for innovation in R&E, offering numerous opportunities to enhance learning, streamline research, and address global challenges. However, it will also require careful consideration of ethical, regulatory, and workforce implications to ensure that AI developments benefit society as a whole. AI-driven personalised learning platforms will cater to individual learning styles and paces, enhancing educational outcomes. Ensuring AI systems are unbiased and fair will be

[17] For example, see GEO Group on Earth observations [EARTH_OBSERVATIONS].

critical, requiring continuous monitoring and updating of AI models, algorithms, and other components. Security is a specific field of applications where AI will develop as a threat, for example 'deep fake', but also as a toolset for detection and mitigation of attacks. NRENs and GÉANT are in a good position to proof and pilot new technologies, involving vast amounts of data with continuous processing, e.g. fibre sensing. AI offers an opportunity of application to the network management, security, and other areas of activity of NRENs. Some NRENs are already involved in developing the AI applications (using Machine Learning in particular) together with the scientific community, and will expand these activities as demand from the R&E community increases.

The popularity and pervasiveness of applications of Artificial Intelligence/Machine Learning (AI/ML) as well as Generative AI is already creating a demand in knowledge and training globally, including the R&E community. AI is no longer a remit of specialists, the knowledge and training in AI/ML is required in wide range of disciplines. AI will automate many tasks, changing the character of jobs which will need advanced AI skills and knowledge. Better understanding of how AI is working (such as source of the model, use of input and tools) in NRENs will allow them to offer better value to their constituencies.[18]

PREDICTABLE

AI will be a prominent part of R&E in the future. This technology is very dependent upon infrastructure, namely availability of infrastructure resources (such as GPU clusters) to produce better training for AI models, which, in turn, can increase the quality of AI applications. Infrastructure operated in a mature (Capability Maturity Model (CMM) manner can provide better input data, which will also support better AI models.

Market research predicts significant growth of infrastructure demand because of widespread adoption of AI.[19] Some NRENs are providing infrastructure to train AI models (GPU-based HPC) as a part of their scope of activities. This could be made available for community projects to attain effectiveness in deployment of applications.

Due to the vast demand for AI implementation in the R&E community, the need for infrastructure solutions is likely to grow. There may be a clear demand to access commercial

[18] The 2022 launch of ChatGPT ignited a global race toward AI literacy. GenAI course enrolments surged by 1,060% globally over the past year as learners sought foundational AI skills and enrolled in courses like 'Prompt Engineering for ChatGPT' by Vanderbilt University and 'Introduction to Generative AI' by Google Cloud... while regions are at different stages of AI adoption, there's a universal recognition of the need to develop AI proficiency [COURSERA_REPORT].
[19] Infrastructure is critical for AI advancement. Estimates for data centre chip usage suggest a potential 9x jump in the coming years, from 5.1 million in 2023 to 46 million in 2027 [AI_INFRASTRUCTURE].

resources to train the AI models from the R&E community. This will require NRENs to adapt, and in the case of those that provide HPC and data centre services, fundamentally rethink their networks to ensure the appropriate solution for their end-users.

UNPREDICTABLE

As one of the applications of AI, Generative AI has both huge potential and significant risk. Currently it may evolve into the useful family of intelligent tools to optimise productivity, as well as become a substantial security threat.[20] It will also depend upon the regulatory frameworks being implemented across countries. The use of Generative AI in NRENs is still seen as an opportunity to increase effectiveness of the solution delivery for the R&E community. It might also present an opportunity to increase the value package towards NREN employees.

Currently, legislation is starting to be introduced to regulate AI both in the EU and in various countries around the world (e.g. China). The AI applications, including Generative AI, in R&E is a specific subset with particular requirements, especially when it comes to scientific research. NRENs have the opportunity to act as a united voice, representing interests of R&E community in this area [ETHICS_GUIDELINES]. Increased use of AI in R&E will raise concerns about data privacy and ownership, necessitating robust regulatory frameworks. At present, there is only partial or no control over the deployment of AI/ML toolsets on the data as more and more applications adopt 'in the cloud' business models ranging from business processes (e.g. Atlassian, Microsoft) to the network management. This may evolve into a situation where all the data will be processed and analysed by AI/ML. It is a risk as well as an opportunity to define the right balance and codes of conduct and expertise (legal, data analyst, US integrator, etc) to ensure a trusted AI environment for the R&E community [ETHICS_GUIDELINES].

[20] 32% of respondents are most concerned about attackers using Generative AI to optimise existing attacks, such as crafting more realistic phishing emails or refining malicious scripts. Less skilled, opportunistic hackers will exploit Generative AI to drive a significant uplift in social engineering attacks [STATEOFSECURITY].

2.4.1.2 ANALYSIS OF IMPLICATIONS

ENVIRONMENT

- The deployment and trends of control of AI/ML toolsets for IT applications will mean IT departments of NREN constituencies must reconsider in-house deployments, to ensure proper control over data and processes.

VALUE PROPOSITION

- The effective delivery and management of advanced end-to-end services will not be possible without AI-enabled automation to manage the relationship between numerous components and sub-services. Application of AI/ML in this context has the potential to offer better parameters of the service (e.g. SLAs). However, the cost-effectiveness may or may not materialise. The deployment of AI-enabled tools will require additional qualifications to sufficiently advance understanding and configure the new technologies. These skillsets will likely be in high demand in the marke..
- Wider deployment of AI tools within the R&E community will raise the demands for the verification, guidance, ethics, and security aspects of the AI.[21] This in turn presents opportunities for knowledge sharing between NRENs as well as providing solutions for NREN constituencies and expanding portfolios by helping constituencies understand and leverage the benefits of AI. For example, in an advisory capacity, this might help reduce risk, cost and complexity as well as accelerate the adoption of this enabling new technology [AI_TERTIARY].
- The advance of AI will most certainly introduce new cyber-security considerations and threats, requiring organisations to address it by certification and verification. NRENs will face the same requirements deploying the AI-enabled tools, and could, in principle, acts as hubs for knowledge sharing on the subject.
- The advancement of AI/ML tools has potential to further exacerbate the 'digital divide', where expensive and scarce resources for AI development will be available to the benefit of richer organisations and individuals. Although

[21] Research shows that efforts to regulate AI appear to be gathering pace. Stanford University's 2023 AI Index shows 37 AI-related bills were passed into law globally in 2022. The US led the push for regulation, passing nine laws, followed by Spain with five and the Philippines with four[AI_REGULATION].

requiring a complex environment, the value proposition and relevance of the NREN community could be strengthened by tackling this divide, for example, by setting up a federated pool of resources.

- The R&E demand for AI development and applications will impose challenges on the network infrastructure and interconnectivity fabric at both national and GÉANT level to accommodate the demand to access the necessary computational resources for AI development and model training, as well as ensuring the transfer of the data required to train the AI models.

FINANCES

- Productivity gains, if they materialise, will release funds for other purposes (for example network automation may lead to a decrease in the number of network engineers, and NRENs that offer services to the education sector could benefit from AI-enabled tools). On the other hand, there might be costs associated with, for example, increased energy consumption.[22]

[22] The use of technologies such as AI, cryptocurrency, the Internet of Things and cloud computing is driving concern about the related energy consumption and environmental impacts. This makes it more critical to ensure that the use of IT becomes more efficient, circular and sustainable. In fact, Gartner predicts that by 2027, 25% of CIOs will see their personal compensation linked to their sustainable technology impact [SUSTAINABLE_TECH].
Seventy-five percent of organisations will have implemented a data centre infrastructure sustainability program driven by cost optimisation and stakeholder pressures by 2027, up from less than 5% in 2022, according to Gartner
A continuation of the current trends in AI capacity and adoption are set to lead to NVIDIA shipping 1.5 million AI server units per year by 2027. These 1.5 million servers, running at full capacity, would consume at least 85.4 terawatt-hours of electricity annually – more than what many small countries use in a year [JOULE] [SCIENTIFIC AMERICAN].

2.4.2 Technological Advances: Cybersecurity

This challenge demands careful consideration and yet more careful implementation. Nobody would dispute the necessity of protecting key assets against intensifying attacks by various actors, including criminals and state-backed organisations. On the other hand, scientific research does require a certain openness and freedom of collaboration. The real challenge for the R&E community and NRENs is how to retain the latter while strengthening the former.

2.4.2.1 MAIN TRENDS

REALITY TODAY

The threats themselves will become increasingly smart, with the application of AI being one of the potential reasons. The mitigation tools need to improve accordingly. The prominent part of attacks is generated by the new kind of actors who have state resources and are targeting specific areas. The R&E community and NRENs are already targets of such attacks. The attacks, for example ransomware and other criminal attacks, have increased in sophistication and have been successful. Cyber threats will become more severe and varied, with advanced persistent threats (APTs), AI-driven attacks, and state-sponsored cyber espionage. Critical infrastructure such as power grids, water supply systems, and transportation networks will become prime targets for cyber-attacks.[23]

Exploiting human psychology will remain a major vulnerability in cybersecurity defences.

PREDICTABLE

The security framework is becoming increasingly regulated within the EU and world-wide. The implementation of the Network and Information Security Directive (NIS2) will present a challenge and an opportunity for NRENs to take a lead and become centres of competences helping the R&E community to achieve the necessary levels of compliance. Some NRENs may fall under the regulations for state critical infrastructures imposing additional regulatory obligations [CRITICAL_INFRAE]. A number of NRENs have already achieved or are in process

[23] "The Education/Research sector experienced a significant blow with an average of 2454 attacks per organisation weekly, leading the chart in targeted industries".
"Ransomware continues to surge: Europe saw a YoY 64% surge in ransomware attacks followed by Africa (18%), though North America emerged as the region most impacted by ransomware attacks with 59% out of close to 1000 published ransomware attacks from ransomware 'shame sites'."
According to the article "Shifting Attack Landscapes and Sectors" in Q1 2024 with a 28% increase in cyber attacks globally – (Check Point Blog) [SHIFTING_ATTACK].

of undergoing an ISO 27001 certification, especially concerning the services for sensitive data. Some EC procurements have required an ISO 27001 certification, but at this time the extent of this requirement is uncertain for future procurements and project calls.

The advent of quantum computing will pose significant threats to current cryptographic standards, potentially rendering them obsolete.

2.4.2.2 ANALYSIS OF IMPLICATIONS

ENVIRONMENT

- NREN constituencies seem unlikely to change because of cybersecurity challenges. However, there will probably be more stakeholders in the area as more players will get involved or will be required to engage with cybersecurity thorough national cyber-security centres, cyber defence e, as well as pan-European players, such as the European Cybersecurity Competence Centre and Network [CYBERSECURITY]. The landscape of partners will also potentially be affected, as the need for increasingly sophisticated security tools might make in-house solutions unfeasible.

VALUE PROPOSITION

- Security requirements might create a fragmented internet and/or restrict the freedom of the internet; a detrimental scenario for R&E networks that are intended to provide free access to data and services nationally and across borders. As cybersecurity teams are reluctant to share information by their very nature, the cooperative structure in the community will potentially become increasingly important to mediate the flow of information in the field.
- NRENs have yet to determine what role they want to take in the evolving landscape of cybersecurity trends. The position of NRENs and particularly wider national and international scope of some NRENs is a potential background for more involvement, improving their value proposition in this area.
- The dilemma of scientific openness and security will require that the voice of R&E community is taken into account on the policy level. NREN community is one of the perceived success stories at the policy level, which provides a good starting point to increase the value towards the R&E community and policy-makers.

FINANCES

- Increasing cybersecurity requirements will likely mean an increase in cost; compliance will need policies and procedures, and a workforce able to implement these.

2.4.3 Technological Advances: Data Lifecycle

Scientific research is fundamentally based on data. During the first decades of the 21st century, the world has made a huge step in the direction of becoming a single data-gathering entity, where the data for scientific research could be collected, stored, and processed at multitude of points. This, in turn, has made the description of data – its findability, accessibility, verifiability, and reusability – at least as important as the collection and storage of the data itself. Additionally, scientific instruments that were data-hungry at the turn of the century have increased amounts of data by an order of magnitude – and plan to go even further according to representatives of research infrastructure. Storage, transfer and access to large amounts of data is becoming a significant issue affecting more than one area of technical challenges within the data lifecycle.

2.4.3.1 MAIN TRENDS

REALITY TODAY

The ever-growing amount of data already raise a number of different challenges. The current trend is that data are produced at a rate that outpaces the capacities to store it properly[24] and the development of storage technology is lagging behind network technology when it comes to access time.[25] The exponential growth of data will require more efficient and scalable storage solutions, with a focus on data integrity, security, and accessibility.

The importance of data governance: stewardship, preservation, and curation (in particular) is growing, as are questions of compliance with relevant regulations (e.g. GDPR) and data sovereignty (and a subset of NRENs are data owners themselves) [JOBS_ON_THE_RISE]. Since data governance is becoming increasingly important in the commercial sector as well, it is likely to contribute to the highly competitive skills market situation in this area too.

FAIR principles (Findable, Accessible, Interoperable and Reusable) provide a framework for a unified dataspace, despite some evidence, it is not guaranteed that these principles will be heeded by all players, especially for data outside of the academic space [FAIR_DATA].

[24] Currently, we produce ~1021 digital bits of information annually on Earth. Assuming a 20% annual growth rate, we estimate that after ~350 years from now, the number of bits produced will exceed the number of all atoms on Earth, ~1050. After ~300 years, the power required to sustain this digital production will exceed 18.5 × 1015 W, i.e., the total planetary power consumption today, and after ~500 years from now, the digital content will account for more than half Earth's mass [INFO_CATASTROPHE].
[25] In a Big Data context, traditional data techniques and platforms are less efficient. They show a slow responsiveness and lack of scalability, performance and accuracy [BIG_DATA_TECH_SURVEY].

PREDICTABLE

This data deluge leads to an increasing fragmentation of the data space, as data are stored in different places, potentially using different standards.[26]

The demand for collaborative data sharing is pushed by current policies and direction of funding of the EC. It will increase, necessitating secure, transparent, and efficient data sharing mechanisms [OPEN_SCIENCE].

Managing the entire data lifecycle from creation to disposal, will require more sophisticated tools and strategies to handle the growing complexity and volume of data.

As data generation and utilisation increase, ensuring data privacy and robust governance frameworks and policies will become even more critical. This will likely be enforced by regulatory frameworks, emphasising data sovereignty, and the creation of trusted environments (e.g. for sensitive data). Ethical considerations around data use will become more prominent, with a focus on transparency, accountability, and the prevention of data misuse.

Integrating diverse data sources and ensuring interoperability between different systems will be crucial for comprehensive data analysis.

TRANSFORMATIVE

For all NRENs, access to scientific data is the primary aim of R&E networks, and the fragmentation of the dataspace is a serious challenge.[27] In particular, data will increasingly vary in type, from freely available datasets to those with more restrictive access criteria (e.g. medical or competitive data). By 2030, the data lifecycle domain will be a cornerstone of technological advancement and innovation [DATA_GOVERNANCE]. Addressing these implications with proactive strategies and leveraging the relevant opportunities will ensure that data continue to be a valuable asset, driving progress across multiple sectors.

[26] Modern scientific methods have created massive quantities of data. At the same time, the combination of increasingly diverse research teams and data aggregation in different portals has created a huge diversity of standards, which potentially makes accessing data difficult [SCI_RESEARCH_AND_BIG_DATA].

[27] Modern scientific methods have created massive quantities of data. At the same time, the combination of increasingly diverse research teams and data aggregation in different portals has created a huge diversity of standards, which potentially makes accessing data difficult [TEN_RULES].

2.4.3.2 ANALYSIS OF IMPLICATIONS

ENVIRONMENT

- Solutions enabling access to sensitive data as well as other data-driven demands have the potential to attract other sectors to NRENs, such as the medical sector (beyond the university hospitals) might become more common users of NREN services, while presenting own challenges, e.g. related to cybersecurity.
- Relevant data sets might be stored at commercial providers requiring peering agreements, which could allow commercial actors to access NREN networks.
- Data owners may follow a different distribution than the current organisational structure of R&E. To provide effective solutions for R&E, NRENs may be required to dedicate more effort to serving data owners, therefore changing the current stakeholders.
- Regulation of data privacy and security may contribute to the unification of the R&E community or to its fragmentation. Currently, there's no clear indication where this process may lead.
- In a heterogenous data space, it is in the interest of the R&E community to support efforts to establish common standards and access criteria among different data providers (e.g. by implementing FAIR principles).

VALUE PROPOSITION

- Access to data is the lifeblood of R&E networks, so adjusting to the requirements (access rights, peering agreements etc.) of the developing data landscape will be essential.
- Standardisation of data and data access will be crucial to enable NRENs to handle the growing diversity of data sources.
- While data storage is not offered by all NRENs, it is a common need for many NREN users – which would make this a suitable target for joint procurement efforts from NRENs (the current IaaS+ framework includes some solutions).

FINANCES

- Adjusting to the developing data landscape will require investments and research – funding for relevant projects will likely be available. The sustainability of the new infrastructure might be a challenge, though.
- Income streams are likely to increase under the conditions that new functionalities will be implemented and new segments of potential users will be attracted to NRENs.

2.4.4 Technological Advances: Quantum Technologies

During the last eight years, quantum technologies have made significant progress, from theoretical concepts into working prototypes [QKDTRIALS]. The current state of these technologies is placing them perfectly within the remits of the R&E community where they could mature further into production services. At present, quantum technology can include quantum sensing, quantum simulations, quantum computers, quantum key distribution, and potentially, quantum communications. There is more than one direction in which quantum technology currently evolves. Quantum technologies have acquired momentum in support from the funding organisations, who see these technologies as a potential geopolitical advantage. It creates a compelling case to participate in quantum initiatives, gaining valuable expertise and strategically positioning NRENs at the forefront of technology advancement.

2.4.4.1 MAIN TRENDS

REALITY TODAY

Quantum Key Distribution (QKD) is by far the most mature of Quantum Communication Infrastructure (QCI). The development of QKD infrastructures on a proof-of-concept level is advancing globally [QUANTUM_INITIATIVES]. The technology offers a compelling case to improve the security of encrypted data, and its development is funded by a number of funding authorities, including the EC. A number of NRENs are taking part in the deployment of national and international European Quantum Communications Infrastructure (EuroQCI) initiatives. The maturity level of the QKD technology for EuroQCI will create the opportunity for NRENs and GÉANT to participate in the development of technologies on national and pan-European levels. The deployment of international QKD infrastructure will require a conventional network infrastructure to be deployed for connectivity between the trusted Key Management Services (KMS) nodes.

The trend of EU/EC policy framework on quantum technologies is to protect and prefer EU vendors and research in the field, for example via funding policy (CEF) clauses for quantum technologies. This will present a challenge to the GÉANT community, which has a wider membership than just the EU member states. It will nevertheless create an opportunity for the dissemination of knowledge and expertise within GÉANT NREN community and globally.

PREDICTABLE

NRENs and GÉANT have accumulated unique expertise having been in the field of the QKD for a number of years. This creates an opportunity, together with further participation in the EuroQCI initiatives, to become centres of competence at least for the quantum communications as per an NREN's strategic priority. This, in turn, may contribute to the attractiveness of work in the NREN community.

UNPREDICTABLE

NREN constituencies, such as EuroHPC nodes, will deploy quantum in addition to HPC computers. The network and infrastructure requirements for quantum computers are not very well defined at the time of writing of this report. Some NRENs engage in the deployment of quantum computers directly as part of their wider remit, such as PSNC [QUANTUM].

Several commercial actors have made their quantum computers available, and have special offers designated for R&E communities, the most notable example being IBM Quantum Hub. It could be foreseen that such usage will proliferate through the R&E community. It is unclear at the time of writing of this report what would be the requirements for the network infrastructure and connectivity for these resources.

2.4.3.2 ANALYSIS OF IMPLICATIONS

ENVIRONMENT

- The developments in this area are closely related to the commercial research, with current solutions coming from the commercial actors. New industry partners will be required.[28] Such partnerships are already developing in joint research efforts [ORCA].

VALUE PROPOSITION[29]

- NRENs will have to update their network processes to adjust to the new (cryptographic) requirements.

[28] Microsoft, Google, and Honeywell, along with startups and nation states, are all racing to develop quantum machines (Source unobtainable).

[29] An NCSC whitepaper about mitigating the threat to cryptography from development in Quantum Computing: large companies and organisations "should factor the threat of quantum computer attacks into their long-term roadmaps" and start prioritising systems for a transition to quantum-safe platforms [QUANTUM-SAFE_CRYPT].
Quantum computing is an "existential threat" to classical data security. "Make no mistake," IBM warned. "The impact is coming – and it's not a question of if, but how soon and how disruptive [IBM].

- NRENs will also be crucial in helping users keep up with compliance requirements, again mostly in the security/cryptography area.
- By being involved in research and development (R&D), the NRENs will give the R&E world a voice at the table in this developing field.
- NRENs have the opportunity to improve their value proposition towards the R&E community as well as towards potential employees by involvement in the proof-of-concept and pilot implementations of state-of-the-art technologies like QKD or quantum computing.
- NRENs will have the opportunity to increase their value to the R&E community by establishing the infrastructure necessary for the pilot QCI implementations as well as by ensuring access to the quantum computing resources.

FINANCES

- Due to the current slow progress, for the foreseeable future incurred costs will be mostly research costs.
- The demand to access commercial resources may introduce additional costs.
- Participation in QCI and quantum computing projects is an opportunity to increase income streams and overall turnover within the timeframe of the study.

OTHER

- Availability of quantum computers for certain players with the resources to become early adopters in or before 2030 is a potential security issue. NRENs have the opportunity to act in this area shifting focus to the R&E community for proof-of-concept and pilot implementations of applications. It may require an unorthodox approach towards partnerships with commercial actors.

NREN GOVERNANCE

2.5 NREN Governance

The long-standing ability of NRENs to deliver working infrastructure solutions to the R&E community over the years has matured and expanded their remit beyond network operations. The federated network operated by the NRENs and GÉANT has become an asset, and it is a key infrastructure to support R&E. Having such a solid foundation has allowed NRENs to deploy additional infrastructures to address new requirements, for example to support international roaming and to enable global federated authentication. The NRENs' governance has evolved during the years. It is expected that, due to the evolving landscape, more changes and opportunities will arise that NRENs can embrace to continue to fulfil their pivotal role.

2.5.1 MAIN TRENDS

REALITY TODAY

The trend so far shows that an NREN's governance is very much influenced by national strategies driven by the national government and/or the NREN's members. Several countries have seen their NRENs transforming or integrating into an organisation with a wider remit where the traditional NREN function is only a part of what the new organisation does.

UNPREDICTABLE

Many NRENs already serve a larger constituency than only research institutions and universities. They also connect primary and secondary schools, libraries, museums, hospitals etc [COMPENDIUM]. It is not unthinkable that more NRENs will follow this path of providing services to a larger constituency. The widening of constituencies and services places network and network service-related activities in the subset of overall NREN engagements. This in turn challenges the direction and community collaborative spirit of GÉANT with the current NRENs core activity loosening its central, unifying role.

Compliance with regulations will push new requirements on the NRENs and their governance, such as changes resulting the NIS-2 directive (starting in 2025) or NRENs becoming national critical infrastructures.

UNPREDICTABLE/TRANSFORMATIVE

National services are being replaced by European/regional services, requiring coordination of NRENs and GÉANT to provide services across the federated environment.[30] This will require supranational governance structures to respond effectively if the NRENs want to remain competitive.

TRANSFORMATIVE

Universities and education are changing, with the EC as a driving force and pushing for a strong digitalisation, different ways to build curricula, a broader set of skills and information sharing. National governments will define policies and laws to support the required changes. The NRENs have an opportunity here to follow these trends and help universities into this transition endeavour. Universities are increasing their cross-border alliances and working, which has a significant impact on the NRENs' governance [ACTION_PLAN].

Taking on a more strategic role, especially participation in Public Private Partnerships as well as procurements, will require changes in governance to allow for agility of NRENs.[31] This, however, should be carefully balanced with maintaining control against drifting away from NRENs' core values and scope.

Harmonisation of policies across NRENs to support international initiatives, i.e. the Copernicus programme and the long-standing operational models, will impose another challenge on the governance of the NREN community [COPERNICUS].

2.5.2 ANALYSIS OF IMPLICATIONS

ENVIRONMENT

- Stakeholders and NREN constituencies may expand to allow for a wider interaction with government and industry (including small and medium sized enterprises, or SMEs). This may also require changes in the Acceptable Usage Policy of individual NRENs, and even a revision on pan-European level.

[30] EuroHPC JU is a good example with its distribution of the HPC centres across Europe. Copernicus or EUMETSAT as well [EUROHPC_JU], [COPERNICUS], [EUMETSAT].

[31] The European Investment Bank signed the €40 million investment grant provided by the European Commission with GÉANT, coordinator of the European National Research and Education Network and AFR-IX, who will be executing the infrastructure project to bolster digital connectivity between North Africa and the European Union through the €342 MEDUSA Submarine Cable Project [MEDUSA], applying experience from the previous Bella project. Becoming part of the cable consortium or an anchor tenant brings a new set of obligations, responsibilities and risks that the community governance needs to factor in and navigate through. Ability to be agile in its decision making and operational setup allows for a successful collaboration with major market players.

- NRENs will be presented with an increasing number of opportunities to provide solutions to the R&E community that will involve a subset of GÉANT members, for example EuroHPC and EuroQCI. NRENs and GÉANT will have the chance to prove their capability to innovate and provide working solutions with a swift reaction to these challenges. Governance mechanisms should allow for such coalitions to act.

VALUE PROPOSITION

- Some NRENs are already assessing how they can be more active in the education sector and what type of infrastructure will be needed to support university initiatives (i.e. university alliances, etc). It is expected that in the next five years more NRENs will be required to engage in these types of activities. The NREN governance will need to adjust to ensure these initiatives are well resourced, funded, and executed.[32]
- The core constituency and the main core business for some NRENs may change quite substantially. The value proposition will be impacted by these external factors. In this case, the NREN community will have to update their service offering, particularly an adequate infrastructure to support education and data skills to support delivery of education at scale and the scientific data lifecycle.

FINANCES

- A broadening of the portfolio of solutions delivered by the NREN community as well as adaptation to the different requirements will potentially introduce larger turnovers, this will challenge the ability of NRENs to manage and govern the financial streams, especially with the need for flexibility and fast adaptation to new requirements.[33]

[32] The number of NRENs offering education-related services has increased from 23 in 2019 to 28 in 2023 [COMPENDIUM].
[33] "We need to be ready as the GÉANT Association, as well as the NRENs and our community, to be able to accept funding in different ways than just grants. This could mean the negotiation of a contribution agreement and a common understanding of what that means for the GÉANT and NREN dynamics. Equally, we may need to transform and in the future be able to compete with our services in public procurements by the EC or its operational entities." (Cathrin Stöver, GÉANT Association) [CONNECT].

- The demand for new roles and the fact that NRENs may be required to engage in new areas will increase the number of specialised staff and therefore increase the expenditure, but might also present opportunities to generate additional streams of income. NREN governance will need to allow for this.

OTHER

- An NREN's governance needs to enable it to respond timely to changing user needs and changes in the R&E landscape. Whilst compliance with regulations will impose more procedures, NRENs must remain agile and responsive to continue supporting an excellent national and European R&E environment.
- With NRENs' remit growing, their 'other sector' engagement may expand to health, SMEs, government etc. How this will change is not easy to predict, but it will certainly require more legal support in each NREN.

DELIVERING RESEARCH AND EDUCATION AT SCALE

2.6 Delivering Research and Education at Scale

The education environment is evolving. Delivering R&E at scale in this environment presents several key challenges, such as facilitating access to increasingly vast amounts of scientific data and diversification in how education is delivered. Balancing these factors while fostering innovation and collaboration is a complex but vital task. It's a challenge facing all R&E organisations, not just NRENs.

2.6.1 MAIN TRENDS

REALITY TODAY

- The increasingly vast amounts of data produced by big experiments like the ones performed at CERN and SKA can no longer be moved easily. It has to be stored and processed close to the point of collection. This requires that scientists who want to process these amounts of data do that remotely without the movement of data. The resource therefore has to be managed so that sufficient and secure access to consolidated research data can be granted based on whatever criteria the owner defines.

TRANSFORMATIVE

- Education is moving in the direction of self-service and becoming increasingly internationally distributed as a result, i.e. students can combine modules from different sources to create their own learning portfolio. This will require a system to make different modules compatible, alongside micro-credentials and the willingness of providers to work together to make it happen.[34]
- Education is no longer limited to university classrooms. It requires ubiquitous access to material from anywhere. This trend has accelerated under the conditions of the COVID-19 pandemic, when most of work and study was performed remotely with substantial use of video-conferencing and tools for

[34] Micro-credentials are often seen as facilitating lifelong and life-wide learning. At the same time, no single definition exists of what micro-credentials are or of their essential characteristics. This lack of a shared understanding can create confusion to users and has negative implications with regards to the transparency, quality, portability and cross-border recognition of micro-credentials[MICRO-CREDENTIALS].
The University of Texas System, which spans nine academic campuses serving roughly 240,000 students, offers an example of how institutions are using micro-credentials to complement traditional offerings with in-demand digital skills from leading industry brands [TEXAS].
The recent attraction of micro-credentials can directly be linked to declining student enrolment, especially after the COVID-19 pandemic, has made universities expand its reach to non-traditional student markets and international, geographically distant learners (McGreal & Olcott, 2022) [SPRINGER].

remote collaboration. This development has led to an increase in demand for online learning delivery and the appearance of online/virtual universities providing most, if not all, of their courses online and with minimal physical presence.[35] [36] In view of the above trends, much traffic from the R&E sector may be re-routed, changing the requirements and potentially importance of NREN networks.

2.6.2 ANALYSIS OF IMPLICATIONS

ENVIRONMENT

- There is a shifting emphasis on learners making informed choices regarding their education decisions. Some NRENs are in a good position to provide solutions to enable this evolution.
- More providers of education are entering the market (not necessarily new universities but certainly providers of training, skills, further education or existing universities increasing online provision to meet demand) – this may have implications on NREN membership/constituent bases and might impact NREN's service delivery (including infrastructure), income streams, and governance.
- Stakeholders and NREN constituencies of the NREN community may shift their connectivity to other providers and rely less on NRENs. NRENs will come closer to the single end users where before an NREN's main user was the user's institution. It will create the opportunity to adapt the user support, deploy more automation, service software scaling, and a different agreement between the NRENs and the institutions.

VALUE PROPOSITION

- More demand on getting the learning how, where, and when users want it

[35] In 2016, 21 million students registered for Coursera's online courses, a number that increased annually by around 7 million over the next two years. But the switch to remote working as the pandemic hit triggered a three-fold increase in new registrations, bringing the figure to 71 million in 2020, and 92 million in 2021 [ONLINE_LEARNING].
Global E-Learning market to Reach $325 billion by 2025 (Research and Markets) from $107 billion in 2015 [FORBES].
From 2011 to 2021, the number of learners reached by massive open online courses (MOOCs) increased from 300,000 to 220 million. Between 2012 and 2019, the number of hybrid and distance-only students at traditional universities increased by 36%, while the circumstances of the COVID-19 pandemic in 2020 rapidly accelerated that growth by an additional 92% [ONLINE_ED_DEMAND].
[36] Online learning is the fastest-growing market in the education industry with a 900% growth rate globally since the year 2000 [ONLINE_STATS].
For example, a private university based in Rome, founded in 2005. It is a consortium of 43 universities, companies and public bodies that provide distance e-learning courses [UNINETTUNO].

will have implications concerning connectivity/accessibility – for example extending to remote or rural areas, and also cybersecurity. Commercial and alternative providers will spot this gap in the market and will seek to fill it aided in delivery by AI. To meet the requirements, NRENs will have to focus even more on service offerings not available through commercial providers.

- R&E institutions and individuals are the driving forces in this area. NRENs have a good position of trusted partner thanks to the working identity federation, but they will have to make strategic choices to venture further into this area to respond to and accommodate changing requirements so as not to lose out.
- The trend towards the self-service education is an opportunity to capitalise on the collaborative environment of NRENs to cater to the need of having the neutral and widely acknowledged system of micro-credentials.
- The network infrastructures and services of R&E institutions will also be affected by this trend. NRENs have the opportunity to provide guidance and coordinate implementation of some measures, such as coordination of the evolution of the 'peering fabric' nationally addressing specific needs for constituencies.

FINANCES

- The topology and service change may imply additional costs for modification.
- Offering end user support for NREN services would require substantial changes in the way NRENs operate. Such changes to the network and the services may mean an increase in costs.

OTHER

- The NRENs' infrastructures have to be engineered to cope with potential changes in their traffic flows topology, and a significant part of R&E traffic might happen outside the NRENs' infrastructures. Direct peering with mobile and residential providers may become increasingly important. This will also entail additional security requirements, as the service backend and user support might need to be scaled up.

- Data and related services provided by NREN users may be hosted outside existing research networks. The content providers may offer direct connectivity to end user sites to guarantee better connectivity service and presence. Consistent services provided by the NRENs and other e-infrastructures present the opportunity to consolidate the R&E community.

3. Developing Foresight

To help identify how the various challenges might impact NRENs up to and beyond 2030, the Focus Group, using a scenario-based approach, condensed and prioritised the challenges into seven key inter-related themes or factors, which they felt would have the most likely impact on NRENs over this time period, as listed below in Figure 3.1:

Factor Area	Challenge Area
Commercial	Interaction with commercial actors
Skills	Employment and skills
Cybersecurity	Technological advances: cybersecurity
Data	Technological advances: data lifecycle
Behaviours	NREN governance
Regulations	Present across all areas
Funding	Present across all areas

Figure 3.1: Factors and challenges mapping, as used in the scenario build

Within each factor, a number of different conditions was considered. For instance, within cybersecurity, involvement could range from NRENs and GÉANT playing a crucial role to having a limited role, with R&E institutions primarily responsible for their own protection. By combining different factors, it is possible to construct specific future scenarios under particular conditions (see Appendix A for full methodology).

This provides a framework to facilitate the creation of different potential future scenarios. By selecting the settings of each factor, various combinations can be used to construct specific future scenarios under particular conditions (see Appendix A for full methodology).

3.1 Commercial

This factor area represents potential futures for interaction with commercial actors. It represents possible developments of the Interaction with Commercial Actors challenge area as projected within the timeframe of the study.

- **Collaboration.** NRENs collaborate with the commercial actors to achieve the best result and deliver the highest-quality solutions for the R&E community.
- **Unique selling point**. Ring-fenced offers for specific niche demands, such as tailored or even co-developed service solutions, for individual research groups covering digital services needs over the entire research process.
- **Highly competitive environment**. NRENs compete against commercial actors for the same services to the same market segment.

3.2 Skills

This area delineates a number of factors related to employment and skills. It is wider than the challenge area, taking into account the possible evolution of the new technologies, such as AI and potential developments of trends identified in the Employment and Skills challenge area.

- **Highly competitive, employee driven**. This potential future presents the situation (already indicated in the trend analysis) where the competition is high in the area of skills required for NRENs. Therefore, employees are free to choose based on the full motivational packages offered by different players.
- **Ring-fenced, employer driven**. This direction is towards a future where NRENs have a ring-fenced source of employees via their close connection to universities and higher education institutions, and are therefore less dependent on the fully competitive labour market. It does not intend to reverse the trends indicated in the challenge area, depicting the possibility of stronger action on NREN community part.
- **Right jobs; wrong skills**. This potential future presents the situation where the skillset of NRENs does not correspond to the requirements of the new developments on either the managerial or the technology level.

3.3 Cybersecurity

This area is specifically dedicated to the cybersecurity climate in the future. While cybersecurity is one of the Technological Advances challenges, its effects proliferate through other factor areas. In combination with the development directions of other factor areas, cybersecurity evolution is one of the key factors defining the narrative of the particular future. The

settings of this factor area belong to two groups: the motivation of attacks and the cybersecurity situation in the R&E space.

- **Dominating criminal attacks**. This direction is towards a future where criminal attacks dominate the landscape of cybersecurity threats. Attacks aimed at individuals as well as organisations (e.g. ransomware) are designed to yield profits to the attackers.
- **Dominating 'state' attacks**. This future presents the situation where cybersecurity attacks are targeted towards the disruption of the key elements of society (R&E being one), rather than monetary benefits of the attackers.
- **R&E space is more secure and trusted**. Researchers have access to the scientific data and instruments in a safe and trusted environment as compared to the general internet. This allows for unrestricted data reusability facilitating the advancement of science.
- **R&E space is less secure and trusted**. The R&E space does not differ from the general internet in terms of cybersecurity. There is little, if any, specific measures to make sure that research is conducted within the separate cyber-space.

3.4 Data

This factor area loosely corresponds to the Data Lifecycle Technological Advances challenge. However, it focuses less on the technical challenges associated with data lifecycle, and more on the potential developments of the landscape.

- **Common framework (data commonwealth), safe and trusted environment, FAIR**. Represents a future where the current efforts for data sharing and interoperability lead to a harmonious environment in which data is findable and interoperable enabling seamless multidisciplinary workflows.
- **Data fiefdoms**. A possible future where the effort for interoperable and trusted data environments is limited to the specific national or thematic areas with trusted environments fragmented over a few larger players in the field.
- **Disorganised or partially organised**. This direction is towards a future where the effort for data interoperability and FAIRness does not lead to any substantial changes to the current situation.

3.5 Behaviours

This factor area is different from all the others because it represents potential futures for the internal evolution of the community. It loosely corresponds to the NREN Governance challenge area. Potential futures for this factor area:

- **Full consensus driven**. Essentially represents the current situation projected to the future environment. This means that all of the decisions of the community will have to be endorsed by all the members. This approach has long-standing merits based on the success story of GÉANT and the NRENs, it allows to steer the community while making sure that everybody is on board.
- **Greenhouse / accelerators of initiatives. Embracing diversity**. Is different from 'full consensus driven' in that coalitions of able and willing NRENs are endorsed by the community, enabling a much faster, but partial, reaction to opportunities or new developments, when the real value to the community cannot be fully determined before the development.
- **Reactive 'Passenger'**. The NREN community's behaviours follows or reacts to external trends. In this particular case, more effort is allocated to the adaptation to the environment than to actively change the said environment.
- **Proactive, in a driving seat**. Is a future where NRENs dedicate major efforts to lead the way in technical developments, policies, and innovative approaches, setting an example for the R&E community.

3.6 Regulation

This includes all the regulatory framework development indicated in the NREN Governance challenge area, including the regulations of technological developments like AI and quantum, as well as more formal requirements such as an organisation's carbon footprint. Potential future developments for this factor area:

- **Increasing harmony of regulations in Europe and worldwide (effective)**. In this future, regulatory frameworks have been developed in close consultation with the affected communities, including the R&E community. This results in a regulatory environment where compliance is based on general consensus by the players themselves rather than on a formal requirement by policy makers.
- **Disharmony of regulations in Europe and worldwide**. In this future, top-down

regulatory frameworks impose requirements that are in certain cases contradictory, making compliance complicated while providing limited value to the complying organisations themselves. As a consequence, compliance tends to suffer, adding to the regulatory uncertainty prevalent in such a scenario.

- **Highly regulated, high requirements for compliance, top-down**. Strict and ubiquitous regulations on both, European and national levels are the norm and need to be adhered to, adding substantial overhead to the general operation of an NREN.

3.7 Funding

This area considers different developments of NREN and GÉANT funding. It does not correspond to any of the challenge areas. However, potential funding futures, combined with settings in other factor areas, can produce scenarios that create important opportunities for further development of the NRENs and GÉANT.

- **Community driven funding, more autonomy from funding agencies and therefore political influences**. This potential future presents the situation where NREN constituencies cover the majority of the costs of GÉANT and NREN operations. On the other hand, this might risk limiting the development of new technologies, because funding will likely be more limited.
- **Push towards doing more with the same or less**. This direction is towards a future where service portfolio and delivery by NRENs and GÉANT will need to adapt to the new developments, requirements and technologies, while remaining essentially within the same (or even smaller) budget envelope.
- **Big funding with an agenda, autonomy from commercial and an opportunity to do more**. Implementation of strategic priorities as set out by the EC and other funding bodies (e.g. digital gateways, quantum), with specifically allocated funding may provide higher levels of autonomy by allowing higher investment levels into improving existing and developing new services in the areas, where GÉANT and NRENs are considered experts.

4. Exploring Possible Future Scenarios

Scenarios describe potential futures, enabling the analysis of opportunities and decisions needed to guide the NREN community in a desired direction. They serve as thought exercises, facilitating future thinking and forecasting opportunities. The scenarios presented in this chapter do not attempt to cover all possible conditions and future directions.

The scenario methodology, developed during this study, helps build these potential futures. By combining different conditions from each factor, it is possible to generate potential future scenarios with specific sets of conditions.

The NREN Focus Group used this approach to build three plausible scenarios for 2030:

1. **Playing the Fair Game** – a potential future where NRENs will have much less distinction in terms of access to the funding, users, regulations, and skills from any other actors who are willing to operate within the area of same interests as NRENs.
2. **Rough Seas** – a scenario with the most challenging, while still plausible, set of parameters from the available directions of future evolution.
3. **The Beaten Track** – a potential future that represents a continuation of the NRENs' current situation. It considers the main contradictions of the current trends and aims to identify the main opportunities to act to retain the current situation.

Three persistent global conditions were identified by the experts during the NREN Focus Group workshop as remaining in place regardless of the future directions and narratives outlined by the different scenarios. Consequently, these invariant conditions are considered to apply similarly in each of the three scenarios.

1. **High energy prices**. Currently, experts of the GN5-1 Foresight Study team as well as NREN Focus Group do not see any indication that the energy prices will start to fall within the timeframe of the study. This implies that optimisation of the operational costs of GÉANT and the NRENs and deployment of energy-saving solutions will become paramount to keep the level of costs reasonable.

It's an opportunity for NRENs to innovate and implement hybrid solutions, when usually a service uses energy-efficient strategies or technologies. This will require expenses on new hardware, development of such hybrid solutions and their implementation, as well as will need qualified specialists to calculate, compare and justify the costs.

2. **Global insecurity**. Global security trends are expected to be shaped by a combination of technological advancements, geopolitical shifts, and evolving threats outside of an NREN's control. The collaborative effort of the NREN community presents an opportunity for the creation of global distributed data centres/services (offering cross-backup solutions) improving the resiliency of data solutions provided by NRENs to the R&E community in the extreme events threatening the very existence of nations. Of course, an enhanced interaction between NRENs is required for such developments.
3. **Fast development of technologies**. There is no evidence to suggest that the speed and rate of technological change will abate any time soon; if anything, it's likely to increase. The challenge lies not only in keeping up with these advancements but also in harnessing them to create a more sustainable and equitable future for the whole of society. Emerging technologies require NREN staff to invest additional time, skills, and effort to explore and adopt them, in collaboration with R&E community representatives and innovation groups. This effort is essential to maintain the trust of NREN constituencies and governing authorities, while also supporting current services and developing new, more sophisticated ones.

Table 4.1, below, provides an overview of factors within scenarios.

<table>
<tr><th>Factor</th><th>Playing the Fair Game</th><th>Rough Seas</th><th>The Beaten Track</th></tr>
<tr><td>COMMERCIAL</td><td>Collaboration. New business models and comm Collaboration. New business models and commercial research</td><td>Highly competitive environment for NRENs competitive environment for NRENs</td><td>Unique selling point. Ring-fenced Unique selling point. Ring-fenced offer for specific niche demands for specific niche demands</td></tr>
<tr><td>SKILLS</td><td colspan="2">Highly competitive, employee driven</td><td>Ring-fenced, employer driven</td></tr>
<tr><td>CYBERSECURITY</td><td colspan="3">Dominating ‘state’ attacks
R&E space is more secure and trusted</td></tr>
<tr><td>DATA</td><td colspan="2">Common framework (data commonwealth), safe and trusted environment, FAIR</td><td>Data fiefdoms</td></tr>
<tr><td>BEHAVIOURS</td><td colspan="2">Greenhouse / accelerators of initiatives.
Embracing diversity
Proactive, in a driving seat</td><td>Full consensus driven
Reactive ‘Passenger’</td></tr>
<tr><td rowspan="2">REGULATIONS</td><td rowspan="2">Increasing harmony of regulations in Europe and worldwide (effective)</td><td colspan="2">Disharmony of regulations in Europe and world-wide</td></tr>
<tr><td></td><td>Highly regulated, high requirements for compliance, top-down</td></tr>
<tr><td>FUNDING</td><td>Community-driven funding, more autonomy from funding agencies and therefore political influences</td><td>Push towards doing more with the same or less</td><td>Big funding with an agenda. Autonomy from commercial. Opportunity to do more</td></tr>
<tr><td colspan="4">GLOBAL CONDITIONS:
High energy prices
Global insecurity
Fast development of technologies</td></tr>
</table>

Table 4.1: Mapping of factors to scenarios

Scenario 1 - Playing the Fair Game: Summary

In this future, ideal regulatory frameworks and conditions enable NRENs and GÉANT to embrace change and evolve both externally by seeking new opportunities and internally by refining processes and values. NRENs will increasingly focus on delivering solutions for research and education, necessitating proactive change management and integration with commercial entities to meet the evolving needs of the R&E community.

HIGHLIGHTS

REGULATIONS

Need for faster, agile development and evaluation cycles and decision making

Leveraging our federated advantage is a key asset

SKILLS

Challenge in competing for talent/bridging skills gap

Expertise and trust are key values

FUNDING

Shift from network focus to delivering R&E solutions

COMMERCIAL

Necessity of collaboration with commercial suppliers and solution providers

BEHAVIOURS

Innovative business models required to own and develop services/products

Adaptation to new technologies ensures sustainability

SECURITY

Increased regulatory compliance

Re-balancing funding towards community-driven approaches

Figure 4.1: Scenario 1 highlights

OPPORTUNITIES

- Collaborate with range of stakeholders to deliver high value and quality solutions, adopting new and different approaches to delivering products and solutions
- Implement thorough business-case analysis for proposed solutions, streamline decision-making, shorten development cycles, and allow constant re-evaluation of solutions, ensuring timely adjustments in portfolios
- Advance global reach and technologies of R&E networking through innovative collaborations
- Increase delivery of end-to-end solutions for R&E community, capitalising on NRENs and GÉANT collaborative advantage
- Implement innovative approaches to attract skilled workforce. Emphasise value-driven strategies to attract and retain talent
- Represent R&E community to regulators and policy makers
- Increase positive publicity of NRENs and GÉANT

4.1 Scenario 1: Playing the Fair Game

COMMERCIAL	SKILLS	CYBERSECURITY	DATA	BEHAVIOURS	REGULATIONS	FUNDING
Collaboration. New business models and commercial research	Highly competitive, employee driven	Dominating 'state' attacks R&E space is more secure and trusted	Common framework (data common-wealth), safe and trusted environment, FAIR	Greenhouse / accelerators of initiatives. Embracing diversity Proactive, in a driving seat	Increasing harmony of regulations in Europe and worldwide (effective) Highly regulated, high requirements for compliance, top-down.	Community driven funding, more autonomy from funding agencies and therefore political influences
GLOBAL CONDITIONS: High energy prices Global insecurity Fast development of technologies						

Table 4.2: Overview of factors for Scenario 1 including global conditions

4.1.1 Scenario 1: Synopsis

In this future, the regulatory frameworks and conditions within the NREN environment are ideal for stepping out of comfort zones and embracing change for NRENs and GÉANT. This evolution encompasses both external opportunities sought by the community and internal advancements in processes and values. This scenario offers a unique chance for NRENs to evolve and seize opportunities on a more level playing field, operating under independent conditions within the R&E community.

4.1.2 Highlights

The relevance of NRENs will gradually shift the emphasis from the network to the delivery of the solutions enabling R&E – this will become a challenge to NRENs pushing towards implementing the change management and looking into the opportunities of integration with commercial actors. The main 'product' of the NREN community will be solutions that enable R&E. This objective will require a significant effort in learning about the actual requirements of the R&E community, and even more effort in engaging with them.

- NRENs won't be capable of salary-only competition for the talented workforce in this future. On the other hand, NRENs and GÉANT must cater to the requirements and expectations of highly competitive conditions of the labour market.

- The demand for specialists in new and advanced fields like AI and cybersecurity will outpace the supply, leaving a gap for the whole industry. All entities requiring a skilled workforce will be implementing unorthodox approaches for attracting good specialists.
- This scenario is characterised by the need for collaboration and joint approaches with a variety of players, including commercial suppliers and solution providers. This is not limited to a single challenge area – it will influence most of the areas associated with the functionalities and services of GÉANT and the NRENs. Most notably, this will touch upon the area of cybersecurity where such requirements are already present.
- NRENs will retain ownership of the majority of services and products towards the NREN community. Maintaining and further developing these products will require innovative business models, including multiple-partner development, and procurement of innovation to deliver the best solutions to R&E.
- There's a clear indication that all entities located in the countries of the GÉANT community as well as globally will face increased requirements of regulatory compliance. In this scenario, compliance may not be possible without deployment of solutions based on or integrated with commercially available products. While cybersecurity is likely to be the most prominent challenge area, other challenge areas will be affected as well. Data, AI, and climate change constitute other possible areas of stricter regulation.
- This scenario envisages to re-balance funding towards a more community-driven funding approach, i.e. less funding being made available from large projects, adapting to the new approaches by funding bodies, moving from EU grants to tenders, and so on. Combined with the other settings, this implies that NRENs will have to adopt a much stricter business-case evaluation for all functionalities, including both operational and the development of new services.
- Notably, the scenario, and probably all scenarios due to the accelerated pace of advancement, will require development and evaluation cycles that will allow for quicker adjustment of the portfolio of solutions than is currently common in the NREN and GÉANT community. This factor will have an impact on the current ways of working for GÉANT community, which will need to adopt faster and more agile approaches which will, in turn, benefit the whole community.

- The capability to adapt to the new technologies quickly and provide the highest quality solutions to the R&E community will ensure the sustainability of NRENs and GÉANT in this scenario. Countries and institutions that lead in AI research and application will gain significant competitive advantages in the global landscape.
- Expertise and trust are important added values of NRENs in this and all scenarios.
- NRENs' capability to collaborate and federate on a pan-European and global scale is a distinct advantage over the commercial providers who do not see the business case for federation.

4.1.3 Scenario 1: Opportunities

The Playing the Fair Game scenario presents a number of opportunities for GÉANT and the NRENs. It outlines the main potential directions that NRENs could follow to navigate the circumstances of this scenario while delivering the value and quality solutions necessary for R&E community.

- **Collaboration with other players to deliver the value and quality**. This scenario includes collaboration with commercial actors, integrating commercial products in the solutions provided by NRENs. To address challenges in the domains of AI, cybersecurity, and Data, NRENs will have to establish wider partnerships, including governmental institutions, and NREN constituencies. Collaboration and unorthodox approaches towards the implementation of new functionalities and solutions will be extremely important in light of the gap in skills of the workforce, especially in areas of potential high technical advance. This could include procuring the innovation from and co-development with commercial actors, joint development with users of tailored products/solutions, as well as central procurement of solutions for the whole R&E community.
- **Business-case analysis and evaluation of value and quality of solutions**. This scenario features a valuable opportunity to enable a more thorough analysis of cases for proposed solutions, expediting the decision-making process making it faster and more straightforward. It will enable much shorter development cycles with intermediate go/no-go decisions, allowing constant re-evaluation of case for solutions in an NREN portfolio, enabling timely decisions when the case for a particular solution is no longer relevant.

- NRENs and GÉANT could capitalise on the collaborative environment between themselves to increase delivery of end-to-end solutions to meet the demands of the European and global R&E community. This is the opportunity to deliver quality solutions based on the competitive edge over any commercial actors. This is particularly relevant to challenges associated with technologies, like data lifecycles or quantum technologies, however, it is also relevant in the areas where such collaboration would provide additional value, for example supporting requirements of climate research.
- **Emphasis on value-driven strategies to attract (and keep) a skilled workforce**. In this scenario the full Employee Motivation Package will be a decisive factor influencing choices of employees. This in turn presents a unique opportunity for NRENs to advance in other-than-salary aspects of their motivation package, including: continuous learning/training opportunities, providing a global, collaborative environment, non-profit organisation, advancing R&E, and the possibility of scientific and specialist individual growth. Implementing a motivational package like this has strong potential to attract a talented and motivated workforce.
- **Increase positive publicity of NRENs and GÉANT in the general public**. This is a specific case of previous opportunity, combined with other opportunities concerning engagement with innovations like AI, quantum technologies, and cybersecurity. High-publicity use cases of advanced NREN solutions will, in turn, help to reconfirm R&E networking as a frontier position as well as contribute to the attractiveness of NRENs and GÉANT as a place for new talent.
- **NRENs as a voice of the R&E community** towards regulators and policy-makers. The future depicted in this scenario presents an opportunity for NRENs to become a voice, representing the R&E community in cases of compliance requirements that are not necessarily in line with practices of the scientific process. As successful research infrastructures, NRENs are in a good position to explore this opportunity to increase their value proposition towards the R&E community as well as policymakers.
- Settings in this scenario create a realistic opportunity for NRENs **to get into the driving seat** advancing the global reach and technologies of R&E networking. This, however, is associated with a significant effort on the part of NRENs and GÉANT to establish innovative ways to collaborate within the R&E community and with actors outside. Examples of such innovative ways include:

- Collaborate with commercial partners to produce an **NREN quantum cookbook** including quantum communications, quantum computing, and services required to establish these technologies as actual usable services for the R&E community.
- **Prepare an overview of available AI tools** and enhancements for network management based upon experience by NRENs and in collaboration with network equipment and network management solutions, including the solutions that are in fact used by NRENs.
- Establish the protocol to exchange the **information on the carbon footprint** of resources available for R&E, define data formats, exchange formats, security, etc. Ensure that the protocol is sufficient to match the compliance requirements.

- This scenario implies that the scientific data will remain rather distributed with metadata accumulated throughout a number of places, including commercial entities. With the advance of commercial players in the data field, the position of EOSC is not clear in this scenario. This allows the reconsideration of opportunity to **lead the Data Federation/Commonwealth effort**. However, this requires a more thorough evaluation, since GÉANT and NRENs some time ago decided not to lead these efforts as community.

Scenario 2 - Rough Seas: Summary

NRENs must swiftly adapt to a highly competitive landscape, regulatory inconsistencies, and funding pressures, while leveraging opportunities to navigate challenges effectively. NRENs remain trusted partners in delivering solutions for the R&E community, driving innovation and diversifying their portfolios through proactive adaptability in governance, procurement, and recruitment.

HIGHLIGHTS

REGULATIONS

NRENs must adapt quickly to external changes without compromising quality

NREN governance and operating models will need to adapt

SKILLS

A diverse range of technical and non-technical skills is needed, with pressure to attract the right talent

DATA

Understanding the carbon footprint of NRENs and their solutions will become complex, especially with mixed delivery models

COMMERCIAL

Effective partnerships with commercial actors are crucial, ensuring solutions are fit for purpose

Defining NRENs' market niche and deciding when to compete, collaborate, or avoid engagements with commercials is increasingly important

BEHAVIOURS

Disharmonious regulations challenge data management, data stewardship, privacy, compliance, and ethics

Ethics and policies surrounding AI use are crucial, requiring time to understand and influence its development

Figure 4.2: Scenario 2 highlights

OPPORTUNITIES

- Articulate clearly NRENs' position, purpose, and unique selling points (USPs)
- Develop niches that establish NRENs as sustainable, go-to providers through creativity, flexibility, and openness
- Form partnerships at local, national, and international levels to combine or share skills and resources
- Secure trusted relationships with national funding authorities to be seen as trusted and reliable partners
- Build effective relationships with commercial actors, using NRENs' trust and knowledge to influence co-solutions
- Maintain visibility of NRENs' value when partnering with commercials for integrated IT services
- Promote NRENs as great workplaces with positive societal impacts. Invest in highly qualified employees to secure market position and retain talent
- Commit to societal values (green, FAIR, employee-driven) and adapt organisational structures to navigate geopolitical uncertainties and reduce energy expenditure

4.2 Scenario 2: Rough Seas

COMMERCIAL	SKILLS	CYBERSECURITY	DATA	BEHAVIOURS	REGULATIONS	FUNDING
Highly competitive environment for NRENs	Highly competitive, employee driven	Dominating 'state' attacks R&E space is more secure and trusted	Common framework (data commonwealth), safe and trusted environment, FAIR	Greenhouse / accelerators of initiatives. Embracing diversity Proactive, in a driving seat	Disharmony of regulations in Europe and world-wide	Push towards doing more with the same or less
GLOBAL CONDITIONS: High energy prices Global insecurity Fast development of technologies						

Table 4.3: Overview of factors for Scenario 2 including global conditions

4.2.1 Synopsis

This scenario could be considered the opposite of the previous one, Playing the Fair Game. The scenario assumes that NRENs face a highly competitive landscape, contending with commercial providers to deliver infrastructure and services for R&E. Although a common and trusted data framework exists, national regulations may prevent NRENs from undertaking new initiatives nationally and internationally. With high demand for skilled professionals and pressure to achieve more with limited funding, NRENs must adapt more swiftly than ever before. This accelerated pace necessitates quicker decision-making and prompt action, which may be challenging for many NRENs given their governance. For instance, many NRENs, in addition to the board, may have to get the support of additional stakeholders. Despite the growing challenges, NRENs have the opportunity to skilfully navigate these turbulent waters and steer clear of potential storms.

4.2.2 Scenario 2: Highlights

The Rough Seas scenario aims to explore the opportunities available to NRENs even in the most challenging situations identified by the foresight study.

In this scenario, NRENs retain the trust and knowledge of the R&E community, which still makes them preferred partners for delivery of solutions. It will likely lead to a more diverse range of NREN portfolios, encompassing both the products and services they directly offer and those they collaborate on with partners for the benefit of the R&E communities they

support. Even in Rough Seas, the need for quick adaptability in this uncertain and more chaotic environment will require changes in many of the NRENs' processes, such as governance, procurement, and recruitment, which may, in turn, drive even greater innovation within the community.

Many of the implications concern how quickly NRENs must make decisions and take action to adapt to external changes without compromising the quality of support they provide to their NREN constituencies, whether driven by cost, scalability, convenience, lack of alternatives, pressure from commercial actors or otherwise.

- A key implication involves the pace of change in partnering effectively with commercial actors to ensure solutions are fit for purpose, including aspects like **cybersecurity** and **data lifecycle**, and where commercial actors offer full suite of integrated services. It's crucial these solutions are not rushed at the expense of more affordable alternatives, particularly when relying on hyperscalers and ensuring connectivity and integration. There is a risk that cheaper solutions may compromise quality and introduce associated risks.
- Defining the niche for NRENs in the market versus identifying where it is in their best interest to compete, collaborate, partner, or avoid certain engagements with **commercial actors** will become increasingly important. This is especially so if commercial actors become less willing to collaborate and rather opt to compete.
- Understanding the **carbon footprint** of NRENs, their constituencies, and the commercial solutions they provide is becoming increasingly complex, especially as the model of mixed delivery and integration grows.
- A diverse range of **technical and non-technical skills** is needed in this scenario, with a possible increase in the latter. This will put pressure on ensuring the right balance between these skills, understand which ones are necessary, and know how to attract the right talent.
- Although there is a common framework for **data lifecycle**, disharmonious regulations make it challenging to manage increasing data volumes and the growing fragmentation of the data space, such as the use of cloud services. This also has implications for data stewardship, privacy, compliance, and ethics.
- Given the increasing use of **AI** in many contexts, ethics and policies surrounding its use in a highly dynamic environment are crucial. While technological develop-

ment will continue unabated, it's important to understand how AI can be used most effectively and swiftly react to influence its development accordingly.

- As mentioned, **NREN governance** and operating models are likely to need to adapt.

4.2.3 Scenario 2: Opportunities

- Clearer articulation of the NRENs' position, purpose and unique selling point(s).
- Develop niches which complement the specific circumstances in a way that allows the NRENs to establish themselves sustainably as go-to provider for the respective area of expertise and services offered. Creativity, flexibility and openness to new areas/ways of working will be crucial to succeed.
- Partnerships on local, national and international levels allow to achieve more with less in a fast-changing environment as skills and resources can be combined or shared. Weak ties may be sufficient to manage effort invested and allow to strengthen as/when needed.
- Secure a trusted relationship with national funding authorities to ensure being considered as a trusted and reliable partner in face of insecurity.
- Developing effective relationships with commercial actors is vital, allowing use of NRENs' trust and sector knowledge to influence commercial actors when developing co-solutions.
- Retaining visibility of NREN's added value and contribution to constituencies when providing full suite/partnering for integrated IT services with commercial actors.
- Promote NRENs as a great place to work emphasising the positive societal impact they have.
- Full commitment and meaningful investment in highly qualified employees allow to secure market position and stand out and retain talent in a highly competitive employee market.
- Clear commitment to societal values (green, FAIR, employee-driven) and shaping an organisation's structure and procedures to accommodate. This allows them to navigate an increasingly insecure geopolitical environment and reduce energy expenditure.

Scenario 3 - The Beaten Track: Summary

NRENs find themselves operating within similar boundaries to now, serving as key and trusted providers of network and related services for the R&E community. Little has changed in operational and funding models. NRENs focus effort on retaining current market position and maintaining the status quo, which affects growth and evolution, but through trust and shared values will allow for continuous cooperation/collaboration amidst global challenges.

HIGHLIGHTS

REGULATIONS

Strategic positioning, political recognition and strong brand are vital to succeed

NRENs strengthen position in European research environment

Cooperation to address geopolitical tensions and ideological differences

Regulatory inconsistencies across borders put pressure on the consensus-driven governance model

COMMERCIAL

GÉANT and NRENs act as mediators with commercial actors, highlighting their unique strengths where commercial interest orcapability is lacking

BEHAVIOURS

NRENs collaborate to re-define cybersecurity role

Funding drives NREN network and service development, but proactive innovation can boost their unique value

SKILLS

Trust with users is vital for future-proof solutions, aligning community initiatives with broader funding agendas

NRENs can attract graduates through university connections but must appeal

Figure 4.3: Scenario 3 highlights

OPPORTUNITIES

- Maintain a stable community in a changing environment by leveraging NREN reputation in digital infrastructure and services, though it requires significant effort
- Secure relatively stable funding by being part of the European e-Infrastructure landscape
- Enable more exploratory R&D through reliable funding, to meet R&E community needs
- Attract talent by increasing R&D activities and collaborating more with universities and research institutions
- Leverage NRENs' leading position in the European research environment to interact with commercial players, making them attractive for procurement frameworks, service distribution, and R&D partnerships
- Create and deliver unique end-to-end solutions by utilising NREN reach and trust within the R&E community, and be agile in taking on strategically important initiatives when approached in digital infrastructure and services, though it requires significant effort

4.3 Scenario 3: The Beaten Track

COMMERCIAL	SKILLS	CYBER SECURITY	DATA	BEHAVIOURS	REGULATIONS	FUNDING
Unique selling point Ring-fenced offer for specific niche demands	Ring-fenced, employer driven	Dominating 'state' attacks R&E space is more secure and trusted	Data fiefdoms	Full consensus driven Reactive 'Passenger'	Disharmony of regulations in Europe and world-wide Highly regulated, high requirements for compliance, top-down	Big funding with an agenda Autonomy from commercial Opportunity to do more
GLOBAL CONDITIONS: High energy prices Global insecurity Fast development of technologies						

Table 4.4: Overview of factors for Scenario 3 including global conditions

4.3.1 Scenario 3: Synopsis

In 2030, NRENs find themselves operating within similar boundaries and serving as key providers of network infrastructure and related services for the R&E community. Little has changed in their operational model: the funding model builds predominantly on public funding and adheres to regulatory frameworks. While NRENs excel in catering to the specialised needs of educational institutions, their growth potential requires continual justification of their value. Despite facing challenges such as regulatory disparities and competition from commercial solutions, NRENs maintain a dedicated workforce and governance structure focused on community-driven initiatives. While they serve the needs of the R&E sector, as trusted partners of the funding authorities, the strategic direction of the NRENs is closely coupled to the priorities of the latter. This positioning ensures sustainable operations through substantial budgets allocated for specific initiatives and maintenance of the basic infrastructure. To secure their position as trusted partners, NRENs proactively harness the community's strengths and positioning as a source of unique expertise.

4.3.2 Highlights

In the Beaten Track scenario, NRENs continue their existing value proposition by investing significant efforts in retaining their current constituencies in a changing and demanding environment around them. Essentially, this scenario explores what NRENs need to do to stay the same. This means that while the NREN community leaves strategic decisions to funding bodies, it needs to be very proactive in being able to implement such strategies.

Keeping the status quo both on the operational and governance levels will take up a significant amount of effort and resources, which will impact the ability to grow and evolve beyond the current service portfolio and user base. Trust and shared values, such as European and national autonomy and security, both with user communities as well as funding bodies, is needed, and will allow for continuous cooperation and collaboration in the face of challenging global threats, such as ever-increasing global climate and energy crises and proliferating cybersecurity state attacks.

- Community-wide initiatives will need a strong alignment with the agendas of the funding bodies, both on the national and pan-European levels, because NRENs need to be seen as trusted partners.
- Significant efforts will have to be dedicated into ensuring the strategic positioning of NRENs and GÉANT as well as a clear recognition of their activities on the highest political levels. The NREN community is expected to enhance its role as a digital enabler for research, education, and innovation on a pan-European scale. Some of the work is already undergoing in GÉANT as Fit for 2028, EU liaison, and research engagement activities, while NRENs provide the expertise necessary for the implementation of projects like SUBMERSE.
- This scenario presents a unique opportunity for NRENs to lead the European research environment and as such benefit from having a strong reputation of being an indispensable element for the advancement of the research landscape, also participating in the co-creation of future directions of development.
- GÉANT and NRENs would act as mediators to the commercial world for their user base. Strong positioning and recognition within the funding bodies give an ability to deal with changes in regulation in a constructive and controlled manner.
- This will require dedicated efforts to retain and evolve the common trust between NRENs and users to create a partnership that jointly works towards future-proof solutions and ensures a common framework.

- NRENs will need to work to ensure that their unique selling point lies in their functionalities (services and products) and to not place themselves in direct competition with commercial actors. On the other hand, NRENs will have to allocate significant efforts to find and develop services in areas where commercial market actors have no interest or are incapable of providing suitable services for the R&E community. This will happen in an environment where commercial market actors are increasingly aware of NREN constituencies as a potential customer segment. A strong and well-recognised brand is important to make use of many of the opportunities inherent to this scenario.
- Geopolitical tensions within and outside of Europe may influence decisions and actions within the GÉANT community and will require efforts to address ideological differences collectively. Science diplomacy will be key. A consensus on the general values that guide the community would allow an appropriate level of autonomy to undertake some activities that engage only a subset of the community which helps increase the agility and competitiveness.
- Regulatory constraints on NRENs exist at both the EU and national levels, often leading to inconsistencies across borders and with non-EU countries. This misalignment creates friction within the GÉANT membership. Additionally, as the consensus-driven governance model requires time and effort to overcome the differences, it risks alienating both members and external stakeholders.
- Introduction of new technologies and evolution of NREN and GÉANT networks are strongly bound to opportunities for funding, and therefore it is dependent upon the decisions of funding agencies. Taking into account other factors, this scenario allows some flexibility and proactiveness via the co-creation phase of funding programmes. Proofing and piloting advanced concepts and technologies will strengthen the unique value of NRENs and GÉANT, especially leveraging the 'penetration' into the global R&E community.
- GÉANT and NRENs should strengthen their position towards national and European stakeholders as a go-to partner for proof-of-concept and pilot implementation of technologies concerning communications, for example quantum communications, but also addressing the requirements related to the data transfer as well as access and possibly data management.
- Cybersecurity is foreseen as one of the key areas where funding will be allocated to develop and pilot new technologies. It is also one of the key challenges for

the R&E community. NRENs and GÉANT in this scenario are well positioned to collaborate with the policy makers to re-define their role in this area.

- The conditions for attracting staff are in the NRENs' favour, as they can leverage their connection to the universities to have a privileged access to graduates in addition to the wider labour market. However, they must actively work to ensure their environment is relevant, dynamic, innovative and value-aligned to attract young talent.

4.3.3 Scenario 3: Opportunities

- The Beaten Track scenario presents the opportunity to retain a stable community of GÉANT and NRENs in a changing environment. It is quite clear that this stability won't be possible to achieve without significant effort. However, it will enable the community to capitalise on its long-standing reputation as a provider of digital infrastructure and services.
- As the go-to partner for implementation, the NRENs' position as integral part of the European e-Infrastructure landscape will mean a relatively secure funding stream.
- Reliable funding will provide the opportunity for more explorative R&D as less production ready 'proof-of-concept' functionalities are developed to fulfil requirements of the R&E community effectively and timely.
- Significant R&D activities will contribute to make the NREN community an attractive workplace. Another source of attractiveness for prospective employees could hail from being part of the European e-Infrastructure if there was a public awareness for of this. The close cooperation of NRENs with their constituencies will also provide the opportunity to access talented people early in their career. This, however, cannot be achieved by continuing the current practices. Instead, NRENs will have to significantly increase the collaboration with universities and research institutions to be able to properly ringfence a workforce capable of participating in the implementation of various projects/initiatives.
- The NRENs' position as the leading provider of solutions and functionalities, primarily related to the network and Trust & Identity Internet Service Provider (T&I ISP) within the European research environment and having a strong reputation of being an indispensable element of the research landscape, provides

a gatekeeper position that can be leveraged in interactions with commercial players. It will make the NREN community attractive as a partner for procurement frameworks, as a re-seller/distribution channel of services and as an R&D partner.

- The NRENs' reach within the R&E community as well as the mutual trust with their constituencies also provides the opportunity to create and deliver end-to-end solutions based on federation and collaboration as a unique advantage over solutions offered by commercial actors. However, not all growth opportunities will be the NRENs' choice. As a consequence of being the go-to organisation for initiatives that are considered strategically important by funding organisations, the community needs to be willing and agile enough to take on such tasks when approached.

5. Conclusions and Recommendations

This report summarises the work and thought process of project team members, NREN experts, and members of the wider community of R&E stakeholders. It outlines factors that, according to experts, will exert a significant influence on the community of NRENs and GÉANT in the coming 5 to 10 years, and provides and analyses a set of example factors and challenges. NREN experts working on the study have proposed several potential paths for future developments, grouping them under the consistent narratives of different scenarios for further consideration. The study throughout highlights the value of NREN collaboration to maximise opportunities and tackle challenges both for themselves and their constituencies. However, it does not delve into the specifics of such collaboration for differing circumstances or how it might be implemented effectively: this will be explored in the next phase of the foresight activity. Strategic and executive decisions are beyond the remit of this study, although it does provide a mechanism to conceptualise potential futures to enable the creation of strategies, outlining goals, priorities, and actions.

The NREN community conducted a foresight study in 2013 called the ASPIRE report. At the time, ASPIRE identified the development of the network and T&I infrastructures as the most important challenges for the NREN community. Eleven years on, these infrastructures remain the bedrock of the NRENs' service offering, which is testament to the effort of the community and collaboration with the EC through a number of projects, notably under the GÉANT FPA, wider framework programmes and other instruments.

While the improvement and maintenance of these technologies by the NREN community remains an ongoing effort, this is now perceived by the NREN community as less challenging compared with the technological and non-technological factors identified by this study, some of which depend on and others enhance the underlying infrastructures.

The challenges outlined in this study have different degrees of importance and may require actions at different levels, from executive decisions regarding technical developments to the strategic choices about the direction of the NREN community. It is also evident that this study puts more emphasis on organisational than technical challenges on the basis that the consequences of the application of new technologies require more attention than the technology itself. Meeting these challenges will need strategic decisions by the NREN community at a high level as well as a careful balance and coordination between different

stakeholders and partners at the national, European, and global levels. Notably, decisions, actions and strategies may vary widely from NREN to NREN reflecting their diversity, and between different regional levels to respond to different environments in an appropriate way to work towards the same objective.

Regardless of the different futures explored in the presented scenarios, several factors seem to influence every aspect of potential evolution for NRENs and the GÉANT community. Most certainly, none of these factors is new, as the work has been going on in these areas.

In summary, the report emphasises the increasing importance and complexity of these challenges as the NREN community approaches 2030:

- **Skills become essential to future-proofing the NREN community**. The readiness to explore and develop new solutions for the R&E community will need a different balance of factors; the emphasis on digital infrastructure will remain while the demand for skills will significantly increase. This requirement reiterates through all the challenges. Examples of potential actions to attract a skilled workforce include increasing the visibility and value of NREN and GÉANT work, and the implementation of joint measures with universities. There are other opportunities to have an early access to talented candidates, as well as outsourcing the expertise to commercial actors.
- **Interaction with commercial actors will clearly affect the strategies of NRENs**. The study outlines several possible and quite distinct paths of action for further considerations: increased integration of commercial products, opening for wider partnerships with commercial actors (such as outsourcing the expertise), increased emphasis on the unique selling point towards the R&E community, and non-competition. The actual situation will most likely depend on the delivery of new solutions for R&E, to meet requirements on a case-by-case basis. Regardless of the approach, conscious decisions will have to be made, with the NREN community remaining crucial in helping exchange experience and knowledge in this often-new environment, where partnerships with commercial actors are likely to become increasingly complex.
- **Cybersecurity is also interweaved throughout the range of challenges, from AI to skills, and relationships with commercial actors**. The regulatory framework will impose requirements on NRENs as well as other members of the R&E community, and in turn will create demands and opportunities. The

decision on the role NRENs play in the cybersecurity will have to be taken by NRENs in the timeframe of this foresight study.

The scenario section (Section 4), with its possible futures, illustrates possible consequences and opportunities that are likely attached to different possible futures. Some opportunities might sound intriguing enough on their own to make tempting strategic objectives – but they usually come as a package with other conditions.

As a final point, while the study has explored three plausible and relevant future scenarios for NRENs in 2030, it acknowledges that other possibilities exist. Therefore, the report introduces a methodology which allows NRENs to create future scenarios by combining different factors and conditions or by adding new parameters that may be more relevant to their specific circumstances or interests.

5.1 Recommendations

Several specific actions were identified both during the scenario development and throughout the study, which address at least some of the challenges highlighted in this report. Some identified actions are already solidly in place or on their way, in this case the recommendations should be understood as positive reinforcement and encouragement that the community is already well set up in many places to tackle future challenges and it is more about conscious evaluation, readjustment, and evolution to best utilise what is in place.

This list is by no means exhaustive. The authors of this report hope that it will help to inspire and support the community to navigate the changing environment with its guidance and concrete ideas that actively explore potential futures and opportunities for evolution.

5.1.1 Future-Proofing Skills

- Enhance employer branding to attract new talent: position NRENs and GÉANT as desirable places to work for specialists with future-ready skills, including initiating awareness campaigns and promoting high-visibility use cases to emphasise positive societal impact.
- On NREN level, build strategic partnerships with universities and other related entities: Partner to create internships, support bachelor or master thesis or other forms of participation with a focus on, but not limited to evolving areas such as cybersecurity, AI, or cloud services.

- Increase retainment rates in early career stages through continued development efforts across the community through dedicated development programmes providing clear career paths and opportunities for future potential employees.
- Leverage mutual expertise in areas of innovation: Develop and capitalise on NREN expertise, complemented with cookbooks and knowledge bases for emerging technologies, like AI or Quantum, or understanding carbon footprints, to help NRENs and the R&E community maximise opportunities.

5.1.2 Working Effectively with Commercial Actors

- Develop a joint GÉANT and NREN strategy towards commercials actors: develop a joint strategy and undertake open and transparent discussions to define a set of common principles for interacting with commercial actors. This will help balance the advantages of these partnerships while preserving the unique roles and positions of GÉANT and NRENs.
- Systematically build on the expertise and negotiating power developed in joint procurements to further leverage on economies of scale within the pan-EU environment to secure an attractive national service offering which is favourable for the NRENs constituencies.
- Joint innovation initiatives: Engage in joint research and development projects with commercial actors to co-create innovative solutions tailored to the unique needs of the R&E community. This can enhance the value proposition of NRENs by combining the strengths of both sectors.
- Highlight unique selling points: Clearly communicate the unique benefits of NREN services, such as specialised cybersecurity, identity federation, and bespoke connectivity solutions, to differentiate from commercial offerings. Emphasise the long-term, non-commercial support that NRENs provide.
- Increase visibility in the delivery chain: Ensure that NREN contributions are visible to end-users by branding and promoting their role in the delivery of integrated IT services. This can help maintain the trust and recognition of NREN services among stakeholders.

5.1.3 Making R&E a More Trusted and Secure Environment

- Develop a joint pan-European cybersecurity strategy by implementing robust cybersecurity frameworks on pan-European level that can equally be tailored to the requirements of particular NRENs. This will help NRENs meet the evolving regulatory demands as well as strengthen resilience of network and services. Regularly assess both frameworks and activities against the commercial sector to stay current.
- Continue and enhance cybersecurity training programs across the community to secure and further develop the common security skill standards across the NRENs. Extending training beyond the technical teams to management could help achieve a higher level of awareness and stronger implementation in organisation strategy and activities.

5.1.4 Enabling NRENs to Adapt to Change

In addition to the recommendations concerning specific challenges and scenarios analysed in this report, the community experts identified essential components of the current modus operandi, that may not be perceived as challenging at current moment. The foresight team chooses to emphasise these actions as enablers of our community to address specific challenges highlighted in this report:

- **Facilitate an engaged, confident, and diverse GÉANT membership and governance**: GÉANT membership is a tried and tested formal vehicle for NREN collaboration. A consistent effort will be required to ensure the sustainability of such membership through dedicated resources for representation, succession planning, and continuous engagement of NREN representatives on behalf of the entire community.
- **Maximise the GÉANT Community Programme as a low barrier platform for exchange**: The GÉANT Community Programme is a proven informal platform where NRENs come to discuss topics of interest affecting a broader audience. Strengthening the connection between this programme and the strategic process could be beneficial, particularly in pinpointing the necessary actions to tackle specific challenges and advancing them through the most suitable channels. To secure diverse input and collaboration, conscious efforts need to be made to engage NRENs on both, European and international level.

- **Implement foresight as a continuous activity**: Foster an environment among NRENs where foresight is an ongoing, proactive process of anticipating and preparing for future developments, opportunities, and challenges. Perform activities to systematically scan the external environment, analyse trends, and use strategic insights to steer decisions. Build on the existing community activities and bring them together in a systematic manner to support active discussion and exploration in national and regional contexts with common learning shared to help the community as a whole.

6. Future Work

6.1 Dissemination of Results

The foresight study will be made available publicly on the GÉANT website, and the key findings/recommendations will be shared with the GÉANT General Assembly. The future work in GN5-2 and beyond will continue focusing on the dissemination of challenges and trends analysis, as well as potential future scenarios for the NREN community and each NREN in particular. The GÉANT Network (GN) Project, Partner Relations, EC liaison, and wider stakeholder relations teams will have the means to facilitate discussions with a wide variety of stakeholders, including but not limited to the European NRENs.

Most importantly, the dissemination and discussions surrounding the identified challenges and scenarios would allow these outcomes to be adapted to the situation of each NREN, changing the relative importance of particular challenges, outcomes and implications, highlighting important decisions for each case.

6.2 Application of Results

The most immediate application of the foresight study results will be to provide contextual input to the GÉANT strategic process. The current GÉANT strategy has been adopted for the timeframe of 2021–2026 [STRATEGY]. The strategy update process will likely take place in 2025. The challenges, trends, factors and scenarios will be presented to the GÉANT board together with the methodology to facilitate the strategic planning processes.

The situation of each NREN may require adjustment to the parameters of the forward-looking methodology. Outlined factors may take directions that were not foreseen in the scope of this report, reflecting the situation in each particular country. It may require a specific set of scenarios that were not included in this report. The project team will work to make the scenario development methodology available to NRENs potentially as a flexible and adjustable tool for internal planning processes.

The challenges will be presented to and explored together with the GÉANT Community Programme, which currently contains several task forces and special interest groups (SIGs) corresponding to the particular challenge area [COMMUNITY_PROGRAMME]. These groups

serve as fora for primarily NREN experts to discuss the specific topic, such as Information Security Management (SIG-ISM), where the challenge, trends and implications on security may be discussed in more detail, suggesting the key decision points, priorities, and actions to strategies of GÉANT and NRENs [SIG-ISM].

6.3 Taking Foresight Forward

The scenarios presented in this report are example projections of the future. The landscape will change, but the ongoing review and mapping of challenges will help NRENs build a strategy that is ready for the future. This foresight study was intended to stimulate discussion and broaden awareness of the changes facing NRENs. The community of European NRENs will keep the foresight activity as a permanent sub-task of GN projects. Some effort has been allocated for it under the GN5-2 project and subsequent projects, pending the evaluation of the results and update of the NREN Foresight Study.

Exploration of the different options of the collaboration between NRENs to maximise effects for each particular situation would be among the first considerations for the evolution of the foresight. The report indicates that the collaborative environment of NRENs is the ultimate enabler for end-to-end solutions that are required for today's science. The federative approach, complementarity of resources, and exchange of resources would be the options to explore in the evolution of this report. It will increase understanding of the various options and their suitability to various scenarios.

One of the outcomes of the work in the foresight study has been a series of contacts with the representatives of NRENs who are engaged in 'futuring' and foresight activities. Futuring is also a prominent field of activity with established methodologies and procedures to consider different options of development. There's also a wide range of subjects for such activities, from the analysis of technical trends to the development of organisations. The project team together with the whole stakeholder activity in GÉANT will undertake to explore the appetite for the permanent part of community programme in the form of a SIG dedicated to exchange of the experience, methodology, and results of futuring activities.

APPENDIX A
Methodology and Background

A.1 Phase 1: Design - Study Scoping and Formation

All NREN organisations in the GÉANT community were invited to nominate a representative to form an expert NREN Focus Group, with individuals from eight NRENs proposed by members of the NREN General Assembly participating, along with the GÉANT Community Programme chair, to provide a vital link with the GÉANT Community Programme. The purpose of the NREN Focus Group was to provide input and insight from the perspectives of different NRENs, as well as analysis of size, service portfolio, funding source, and reporting. The process was supported by a project team and programme of interviews with key stakeholders outside the NREN Focus Group, outlined below:

	Project Team	NREN Focus Group	Other Stakeholders
Purpose	Project oversight and management, facilitation, analysis and reporting	To explore evolution of NREN service portfolio within different future scenarios. Discussed in the context of both technical and non-technical challenges to include inter alia the evolution of stakeholder environment, people and skills, NREN value propositions, network and above network services, security and impact of new technologies.	
Who	Project team	Strategic, policy and technical experts from NRENs within GÉANT membership	Key stakeholders from outside NREN community (and NRENs unable to commit to joining the Focus Group)
How	Project management Research and synthesis	Facilitated discussion groups	Interviews and other flows of insight from wider GN5-1 WP3

Table A.1: Study teams and interactions

The study adopted a challenge-based scenario approach, as detailed in A.2

A.2 Phase 2: Challenges - Understanding Areas and Future Landscape

The purpose of this step was to brainstorm the possible challenges and disruptors to the ecosystem of NRENs and GÉANT, and to select the challenges that should have the highest priority for the NREN Focus Group to concentrate their work on.

An initial meeting of the NREN Focus Group identified over 50 individual challenges. These challenges were then prioritised and consolidated into six challenge areas to focus the study on, described more fully in Section 2, on the basis of having most likely and significant impact on NRENs within this timescale using the following five criteria: evidence, likelihood, magnitude, relevance and timescale.

Challenge Areas
Interaction with Commercial Actors
Climate Change and Sustainability
Employment and Skills
Technological Advances: Artificial Intelligence (AI), Cybersecurity, Data Lifecycle and Quantum Technologies
NREN Governance
Delivering Research and Education at Scale

Table A.2: Challenge areas

The next step was to look at each challenge and identify the implications and opportunities for the ecosystem of NRENs and GÉANT, observing that none is mutually exclusive and all interconnect in various ways. To structure the analysis, three main areas for consideration were identified, inspired by the Business Model Canvas [CANVAS]:

- **Environment**: partners, stakeholders, users (constituencies).
- **Value proposition**: value, delivery channels, service portfolio.
- **Finances**: income, expenses, financial flows.

The different challenges are in different stages of their 'lifecycle' and the NREN Focus Group used the Gartner Uncertainty Spectrum of Trends as a useful system to categorise each:

- **Reality today**: Strong evidence that the trend is embraced by organisations today.
- **Predictable**: Develop in a predictable way over the time.
- **Unpredictable**: Path of growth is heavily influenced by external accelerators or inhibitors that quickly alter the course.
- **Transformative**: Impact can only be speculated and imagined.

An interim progress report summarising the challenge areas was shared with the GÉANT General Assembly on 21–22 November 2023, and feedback was obtained through an interactive session providing further insight into the prioritisation of the challenges from an NREN governance perspective.

The stakeholder interviews, recruited with the support of GÉANT GN5-1 WP3, sought perspectives on the challenges, impacts and opportunities facing other stakeholders within the R&E ecosystem. Also included was a group interview with four students from the 2023 GÉANT Future Talents Programme.

A.3 Phase 3: Pathfinding - Developing Foresight

Phase 3 commenced with an in-person workshop with the NREN Focus Group in Cambridge on 6–7 March 2024 to start developing possible future scenarios. This built on established scenario development approaches but was adjusted to enable creation of a multi- rather than two-dimensional view, incorporating factors and settings influencing all challenge areas [FUTURES TOOLKIT] [SCENARIO_METHOD].

Step	How	Example
1. Identify key factors within each challenge area	Brainstorm all possible factors within each of the 6 challenge areas; resulted in 90 factors	Cybersecurity factors might be: NREN and GÉANT involvement and responsibility, success rate, frequency, motivation of attacks
2. Generate factor axes	For each of the 90 factors identified generate the polar opposite or extreme/ alternative condition	An axis for the cybersecurity involvement and responsibility factor might be: NRENs and GÉANT play a crucial role in providing cybersecurity for R&E, taking on the responsibility of deploying essential services to safeguard R&E institutions vs NRENs and GÉANT have a limited role in cybersecurity efforts; mainly facilitating knowledge sharing and community coordination, with R&E institutions primarily responsible for their own protection.
3. Consolidate and prioritise factors	Combining 90 factors would generate too many permutations, so a qualitative Principal Component Analysis approach was used to describe the factors in as few as possible terms where change is most likely/impactful on NRENs, acknowledging the inter-relationships between challenge areas. This resulted in a more manageable set of 8 themes, each containing 3 to 4 factors (later to form the 'dials' within the scenario machine, see Chapter 5)	E.g. for the funding factor, three settings were identified: 1. Community driven funding. Autonomy from political influences 2. Push towards doing more with the same or less 3. Big funding with an agenda. Autonomy from commercial. Opportunity to do more

Step	How	Example
4. Build the scenarios	Combining factors to build different scenario conditions for GÉANT/NRENs, based on different settings of the 'dials' Scenarios must have: Plausibility (must fall within the limits of what might conceivably happen) Differentiation (should not be so close to one another that they become simply variations of a base case) Consistency (must not have any built-in inconsistency that would undermine the credibility of the scenario) Decision-making utility (contribute specific insights into the future that will deliver value) Challenge (conventional wisdom about the future)	• Most interesting • Most likely to happen – least effort • Keeping as is – status quo – requires effort • Innovative – challenging, out of comfort zones • Most 'desired'
5.Develop the scenarios	Choose the scenarios (3) to progress and add narrative, based on which ones the NREN Focus Group felt had most utility	Rough Seas: "a future where NRENs must swiftly adapt to a highly competitive landscape, challenging regulatory frameworks and funding pressures, while leveraging opportunities to navigate challenges effectively"

Table A.3: Approach to scenario building

Appendix B
Acknowledgements

B.1 NREN Focus Group

Name	Job title	NREN	Country
Mauro Campanella	International research and development officer	GARR	Italy
Veronika Di Luna	Senior Project Manager	GÉANT	Netherlands
Licia Florio	Strategy and Policy Manager	NORDUnet	Nordic countries
Simona Holstein	Product Manager	IUCC	Israel
George Konnis	Managing Director, GEANT Board Member	CYNET	Cyprus
Victoria Moody	Director HE and Research	Jisc	United Kingdom
Olga Popcova	Marketing Communications Officer	RENAM	Moldova
Karen Thornton	Director of Strategy & Business Planning	HEAnet	Ireland
Alexander van den Hil	International Policy and Strategy Manager	SURF	Netherlands

Table B.1: NREN Focus Group members

B.2 Consulted Stakeholders

Members of the GÉANT General Assembly, the highest Governance Body of the GÉANT Association and GN5-1 Project, consisting of a primary and deputy representative of each of its 43 NREN and REN Member and Associates.[37]

Claudio Allocchio,
GÉANT Community Committee Chair, GARR

Edit Herzog,
Senior EU Liaison Officer, GÉANT

Cathrin Stöver,
Chief Collaboration Officer, GÉANT

Members of the GN5-1 Work Package 3 "Stakeholder Engagement"

B.3 Interviewees

Sergio Andreozzi,
Head of Strategy, Innovation and Communications, EGI

Martin Bech,
Head of NREN Operations, DeiC

Tony Cass,
Leader, Communication Systems Group, CERN

Gill Ferrell,
Relationship Manager, EUNIS

Luca Girardo,
Ground Segment Manager, ESA

[37] https://about.geant.org/membership/members-associates-general-assembly-representatives/

Krzysztof Kurowski,
Deputy Director of PSNC, Head of PSNC Future Labs

Jolyon Martin,
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Antonio Rodriguez Vazquez,
Head of Earth Observation and Third Party Missions, ESA

Michael Webb,
Director of AI, Jisc

Participants of GÉANT Future Talent Programme 2023:
João Daniel Correia Brandão (Portugal), Thalita Nazaré (Portugal), Martina Palmucci (Italy), and Vladislav Válek (CZ/GER).

B.4 Project Team

Charles Hutchings,
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Raimundas Tuminauskas,
Head of the PSNC Network and Service Infrastructure Department, PSNC

Beatrix Weber,
Head of Partner Relations, GÉANT

Daniel Wustenberg,
Community Research Officer, GÉANT

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Glossary

AI	Artificial Intelligence
APT	Advanced Persistent Threats
CERN	European Organisation for Nuclear Research
DeiC	Danish e-Infrastructure Consortium
EC	European Commission
EGI	European Grid Infrastructure
EOSC	European Open Science Cloud
ESA	European Space Agency
EUNIS	European University Information Systems
EuroHPC	European High Performance Computing
EuroQCI	European Quantum Communications Infrastructure
FAIR	Findable, Accessible, Interoperable and Reusable
FPA	Framework Partnership Agreement
GDPR	General Data Protection Regulation
GN	GÉANT Network
GN5-1	GÉANT Network 5 Phase 1 project, part-funded from the EU's Horizon Europe research and innovation programme under Grant Agreement No. 101100680
GN5-2	GÉANT Network 5 Phase 2 project, part-funded from the EU's Horizon Europe research and innovation programme under Grant Agreement No. 101194278
GN5-FPA	GN5 Framework Partnership Agreement
GPU	Graphical Processing Unit
GNx	Any GÉANT Network Project
HPC	High-Performance Computing
IaaS+	Infrastructure as a Service Plus Framework
ICT	Information and Communications Technology
ISO	International Organisation for Standardisation

ISP	Internet Service Provider
IT	Information Technology
K-12	Education from Kindergarten through to Year 12
KMS	Key Management Service
ML	Machine Learning
MFF	Multi-Annual Financial Framework
NIS2	Network and Information Security Directive
NREN	National Research and Education Network
OPEX	Operating Expenditure
PSNC	Poznan Supercomputing and Networking Center
QCI	Quantum Communication Infrastructure
QKD	Quantum Key Distribution
R&D	Research and Development
R&E	Research and Education
REN	Research and Education Network
SIG	Special Interest Group
SKA	The Square Kilometre Array intergovernmental international radio telescope project
SME	Small- and Medium-sized Enterprises
SUBMERSE	SUBMarine cablEs for ReSearch and Exploration
T&I	Trust and Identity
WP3	Work Package 3: User and Stakeholder Engagement