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of National Research and Education Networks in Europe

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Abstract

The GÉANT Compendium provides an authoritative reference source for anyone with an interest in the development of research and education networking in Europe and beyond. Published since 2001, the Compendium provides information on key areas such as NREN budget and staffing; end users; involvement in EC-funded projects; network, traffic and capacity; and services. This report primarily covers the period January to December 2020. The GÉANT NREN Compendium may be found online at: **https://compendium.geant.org/**.

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

FOREWORD
ANDREAS DUDLER CHAIR OF GÉANT BOARD OF DIRECTORS


Andreas Dudler

It is my great pleasure to share here some personal thoughts on the 20th edition of the GÉANT Compendium of National Research and Education Networks. Each Compendium has been a source of reference for the work and activity of NRENs throughout Europe. In my former role as CEO of SWITCH, the Swiss NREN, I liked to use the Compendium to get an overview of the services and their developments in other countries. This was not just about individual figures; it was also possible to see where common developments took place or where new ideas were emerging.

But the now complete series of 20 years of Compendium reports allows more. Taken together, these editions are a unique record of the success story NRENs are in Europe. One can read how our entire community has evolved, how we have adapted methods and tools to meet the constant new challenges from research and education. The following examples will illustrate this:

Twenty years ago, the struggle for sufficient bandwidth was ubiquitous. The costs for corresponding upgrades were very high. As a result, NRENs lagged behind the actual demand. Today, things are very different. With the use of lambdas or even dark fibre, the NRENs can provide more than enough capacity for research and education. More importantly, they can also ensure that this bandwidth is truly available end-to-end. Thus, NRENs have become a real enabler in the digitalisation of research and education.

The digitalisation of research and education, coupled with increasing mobility, gives digital identity a very strong relevance. This is widely recognised today and with eduGAIN, eduroam and eduVPN the secure mobility of students and researchers is further supported. This topic first appeared in the Compendium with the term AAI in 2005. Its development to the all-encompassing services of today is fully documented in the subsequent editions.

Security also appears in the Compendium for the first time in 2005. At that time, however, only a small minority of NRENs had their own dedicated security staff member. In the meantime, the security of our infrastructures and services has become an integral part of our work. Our users in research and education must be able to rely on it. What is now a widely recognised requirement began with the pioneering efforts of a few NRENs 17 years ago.

These developments demonstrate that NRENs are and will remain relevant. The services are tailored to the exact needs of research and education. However, ongoing efforts are needed to keep it that way. That our community recognises this and will continue to actively address it in the future is evident in the variety of projects we lead or participate in.

I hope you will enjoy reading this latest edition of the Compendium.

FOREWORD
COMPENDIUM ADVISORY BOARD

When preparing the 20th (official) edition of the Compendium, we collectively took a deep dive into our personal history with it and (with the help of GÉANT veteran John Dyer) the history of the Compendium in general. The Compendium was born out of the wish of the NRENs to compare themselves against each other, which has – apart from satisfying curiosity – many uses. As an NREN, you might find untended patches in your garden when looking at your neighbours' efforts, providing both inspiration and motivation to improve your plot accordingly. This is very much reflected in our own experience:

János Mohácsi

"In 2003, when I initially met the TERENA Compendium at the TNC/CUC 2003, I instantly understood I had found a treasure chest. When it was first conceived, it seemed like an impossible effort to compare apples and oranges, but the extensive work of the Compendium Review Panel provided a comprehensive presentation of commonalities and key differences of the NRENs around the world. Since then I have used it many times to benchmark NIIIF and KIFÜ staffing and with various similar NRENs or to inform governmental funding representatives about funding needs and user numbers."

János Mohácsi, KIFÜ

János's experience is of course not an isolated one.
Nataša reported a very similar type of use:

Nataša Glavor

"CARNET uses the Compendium to compare ourselves with other NRENs both within the EU and specifically in our region. Budgets, number of employees, number of associates, services, and users are highly valuable information, as is information about which user groups are supported and which are not. We correlate data from the Compendium with our data and use them in negotiations with our stakeholders and authorities when negotiating or explaining CARNET projects."

Nataša Glavor, CARNET

Beyond illustrating immediate needs, the Compendium was, and still is, an invaluable source of information about the direction of travel of the NREN world, as it tracks service development and the connectivity needs of the research and educational sector, as well as the appearance of new fields of activity, as recently the emergence of the EOSC ecosystem.


Hank Nussbacher

"The Compendium is the only true way to know what European NRENs really need and what their future directions are. For close to 20 years, NRENs and their funding bodies monitor very closely, via the Compendium, what other countries are pursuing in order to determine what is a fad and what is a trend."

Hank Nussbacher, IUCC


Jennifer Ross


Daniel Wüstenberg

The Compendium also quickly found readership beyond the initial circle of users – aspiring NRENs outside of the relatively few members of what was then TERENA and would later become GÉANT were happy to use this "treasure chest" as a benchmarking tool for their own efforts.

Most of the European NRENs have matured beyond the "emerging NREN" state, but this out-of-community use has continued since, and emerging (and mature) NRENs around the world are still embracing the Compendium to make their case with funders and users alike.

In the 20 years of its existence, the Compendium has been a useful information source for many and we are looking forward to maintaining and shaping this "treasure trove" into the future.

Nataša Glavor, CARNET (Compendium Advisory Board)
János Mohácsi KIFÜ (Compendium Advisory Board)
Hank Nussbacher, IUCC (Compendium Advisory Board)
Jennifer Ross, GÉANT
Daniel Wüstenberg, GÉANT

A GUIDE TO THE GÉANT COMPENDIUM OF NRENS

National Research and Education Network (NREN) organisations run special communication networks dedicated to supporting the needs of the scientific and academic community within a country. The 43 European NRENs are interconnected by the pan-European GÉANT network, the largest and most advanced research and education (R&E) network in the world.

The GÉANT Compendium of National Research and Education Networks in Europe (the Compendium) is a comprehensive portrayal of the networks supporting the research and education community in Europe, giving a full picture of what the NRENs do to meet their users' requirements, the resources they have at their disposal, and the way they are organised.

The Compendium is the result of a broad, collective effort based on data from the annual NREN Compendium survey, which invites Europe's NRENs to provide detailed information about their network, equipment and users. The survey conducted in 2021 focused primarily on the period from January to December 2020, though some NRENs may have added more recent data if they were available. The survey questions requested information grouped around the NRENs' respective organisations, their service portfolio, their users, and their network, and were drafted under the guidance of subject specialists from within the GN4-3 project. The same group of specialists also supported the analysis of the respondents' data.

The results, based on responses submitted by 39 of the 43 NRENs, are summarised in this document. Publicly available data, data from within GÉANT and data from other surveys were added to supplement the survey data and to cover additional areas such as trust and identity (T&I) and education. Where such supplementary data were used, and where the data allowed and it seemed useful to do so, the report extends beyond 2021. However, unless otherwise stated, readers can assume that the data in this document originated from the Compendium survey results. The data from this and past NREN Compendium surveys may also be accessed from the online version of the Compendium [COMPENDIUM].

The diversity and complexity of the NREN community can make comparisons challenging. Also, due to the voluntary nature of the survey, the data record has gaps, i.e. not all data are present for all years for all NRENs. For time series spanning several years, this means the period over which a meaningful trend analysis is possible will differ, depending on the availability of sufficient comparable data[1].

It is the Compendium's ambition to provide an overview of and insights into this multi-faceted community. It is simultaneously a depiction of the diversity of the NRENs and a reminder that, despite their variations and particularities, the European NRENs are built around delivery of the same interlinked core services.

[1] This is especially true when percentage increases across NRENs are shown (e.g. Figure 2.1: Development of total NREN budgets since 2017; Figure 2.6: Total staff numbers of the NREN sector; Figure 5.1: Increase of traffic into the NRENs from NREN end users (upper panel) and external networks (lower panel) 2019 to 2021; and Figure 5.5: Development of the NRENs' IRU networks 2018–2021). Such a trend analysis requires the same NRENs to be present over all the years in the series and any NREN that has not responded in one year needs to be excluded from the whole dataset. The period over which trends are shown therefore reflects the time over which the data available are still representative for the whole, i.e. the majority of NRENs are present in the numbers and the subset of NRENs in question is not biased geographically or with regard to size.

This Compendium is a community-led document, created by the NREN community, for the NREN community, as a means to understand the status of the collective as a whole, as well as of each individual NREN. It is a dataset with which NRENs can inform and shape their strategic decisions.

The Compendium has been compiled from information provided by the people who carry out this work, from the executive directors, to technical officers, to service portfolio strategists and many more professionals. Subject matter experts reviewed all of the responses within a given area and summarised the main data points in this document.

A big thank you to the NRENs that took the time to complete the survey and provide their views.

EXECUTIVE SUMMARY

Published annually, the GÉANT Compendium presents a comprehensive picture of the National Research and Education Networks (NRENs) in Europe. This Compendium Report brings together some of the findings of the annual Compendium survey conducted in 2021 and focuses on the time period from January to December 2020; 39 out of the 43 GÉANT NRENs took part in the survey. The report covers organisational aspects such as budget and staffing; end users; involvement in EC-funded projects; network and traffic; and services, including security, trust and identity, cloud and education services. In certain areas, the report draws on supplementary data; for example, the sections on trust and identity, and education services, are based on other surveys. In some of these areas, more recent data have been used. The full Compendium is available online at [COMPENDIUM].

Like past Compendium surveys, the 2021 results reveal changes and continuing trends in the NREN landscape, although the changes are mostly gradual. Nonetheless, the impact of the ongoing COVID-19 pandemic is evident in some of the more recent data.

The environment in which NRENs operate still varies considerably. Nevertheless, most European countries have a broadly liberalised telecommunications market, where access to bandwidth and technology is unconstrained by regulation or monopoly. NRENs therefore need to respond to the specific demands of the research and education community if they are to justify their existence to their funding bodies, many of which are not their primary users. The data from the Compendium survey should help to trace how NRENs meet this challenge.

Budget & staff numbers

Reflecting the continuing increase in the importance of data networks in research and education, budgets and staff numbers as a whole have expanded between 2020 and 2021 (by 2% and 7%, respectively). This growth has enabled NRENs to upgrade their networks and further develop their service portfolios.

Pan-European activities

A clear trend over the last few years has been an increase in NRENs' involvement at the European level: the number of EC-funded projects (in addition to GN4-3/GN4-3N) which had at least one NREN as a participant has almost doubled from 56 in 2018 to 100 in 2021. The project with the most NREN participants is EaPConnect, which aims to decrease the digital divide within Europe by establishing and operating a high-capacity R&E network in the EU's Eastern Neighbourhood. Most of the other projects are connected to European e-infrastructures, in particular the projects supporting the delivery of the European Open Science Cloud (EOSC). The number of NRENs engaging in European projects, and which individual NRENs, have not changed significantly in the last four years, meaning that about a third of NRENs have little involvement at the European level beyond the GN4-3 project.

Traffic

The importance of research and education networks manifests in the volume of traffic NRENs carry. Traffic volumes have increased continuously over the past years, across all NRENs. However, the COVID-19 crisis left a mark on these numbers: over the years before COVID-19, traffic within the R&E networks and traffic from outside the R&E networks grew in lockstep; in

2020, the latter stagnated and even dropped slightly, while the former grew by 30%, following the trend visible in the years before. This likely reflects the reduced presence of students and employees at the R&E institutions. A similar development can also be seen in the 2021 numbers from the GÉANT network.

Nevertheless, NRENs expect the upward trend to continue into the medium term: for the years 2021–2024, virtually all NRENs who responded to the survey forecast traffic growth, and more than half of them anticipate a growth of 50% across all organisations within the NRENs' remit. As with last year, high growth is expected to come from schools, with an anticipated traffic growth of more than 80%, but unlike previous years, high growth is also expected to come from research institutions, with 72% traffic growth, and universities, estimated to grow by 69%.

Capacity

While traffic volumes grew significantly during the past year, the capacities of NRENs' backbone and access networks increase at a steady but much slower rate, reflecting the longer timescale of network upgrades. It is noticeable, though, that the access networks keep increasing in capacity, especially for the non-core user types such as schools. The capacities for access to an NREN's network range from 1 Mbps up to 100 Gbps, depending on user types. Universities and research institutes are the best-connected institution types. Half of the respondents indicate that the typical capacity for university links now exceeds 1 Gbps for connected universities, and research institutes are not far behind this. In some countries, the typical connectivity for these users has reached 10 Gbps, and more than 90% of NRENs provide these high-capacity connections to at least some universities and research institutes. Other user types mostly have more modest requirements but their link capacities are increasing as well.

Services

NRENs have long since moved beyond their core role as connectivity providers, and now provide additional services, responding to technological changes and changes in the demands of the research and education community. A good example of this is the expansion and improvement of the trust and identity (T&I) infrastructure. Originally focused on securing access to R&E services, T&I infrastructures are increasingly being adapted to deal with the growth in cooperation and sharing of resources across institutions and borders. This is particularly apparent in initiatives such as InAcademia and MyAcademicID, which ascertain the student status in order to provide access to services that are not strictly speaking an R&E service domain, for example, student discounts. Another burgeoning type of T&I service is supporting student mobility, namely the MyAcademicID project.

Another such development is the ongoing commodification of ICT services that just a few years ago were relatively obscure, notably cloud services. That NRENs seek to make it easier for their users to take advantage of this trend is visible in the increasing use of the Open Clouds for Research Environments (OCRE) Framework among NRENs. Here, NRENs have moved to make their experience in procurement of these types of services available to their customers, leveraging their market size to gain discounts for their users. Cloud services are a prime example here, but procurement support extends to other areas as well.

A further trend is that NRENs are not just running infrastructure used for education, but are also supporting specific education content and services. While not all NRENs are following this path, among those that do, the development of new services appears to take on a startling pace, a trend that was accelerated by the COVID-19 crisis, which increased dramatically the

need for online teaching tools. This is shown in some detail in the section on education services (Section 9). The NRENs active in this area are becoming important gatekeepers or mediators between content/service providers and consumers in their education sectors.

While the diversity and complexity of the different NRENs can make comparisons challenging, it is the Compendium's ambition to provide an overview of and insights into this thriving, multi-faceted community. Through these annual snapshots, produced each year since 2001, GÉANT continues to monitor the growth and changes among the NRENs in a systematic way, adjusting the scope of the Compendium accordingly to provide a unique dataset with which, NRENs can inform and shape their strategic decisions.

1. ABOUT GÉANT

The pan-European GÉANT network plays a fundamental role within Europe's e-infrastructure provider landscape. As the largest and most advanced research and education network in the world, GÉANT enables scientific excellence, research, education and innovation [GÉANT]. Through its integrated catalogue of connectivity, collaboration and identity services, GÉANT, together with its National Research and Education Network (NREN) partners, provides users with highly reliable, unconstrained access to communication, computing, analysis, storage, applications and other resources. The GÉANT network's connections also ensure that Europe's research community is connected to similar infrastructures, both within and beyond Europe.

GÉANT's high-speed backbone provides connectivity with 43 NRENs during the GN4-3 project, reaching tens of millions of users in 10,000 institutions across Europe, and more than 100 countries worldwide through links with other regions. The core backbone is capable of multiple 100 Gbps over each fibre link, and Terabit connectivity can be achieved by a single node.

The network is funded by the GN4-n projects, of which the current incarnation is GN4-3 (and GN4-3N), with 39 partners[2]. The focus of the GN4 Phase 3 (GN4-3 and GN4-3N) projects [GN4-3; GN4-3N] is to provide the European research sector with an infrastructure that promotes scientific excellence through access to and reuse of research data. It also aims to make scientific infrastructures Europe-wide more cost-efficient through the promotion of interoperability with other e-infrastructures. GN4-3 and GN4-3N are funded by the EC's Directorate-General for Communications Networks, Content and Technology (DG Connect); they began in 2019, GN4-3 will continue until the end of 2022, and GN4-3N until the end of 2023[3].

In addition to the pan-European coverage, GÉANT's global connectivity enables the European R&E community to collaborate with peers and access data sources in nearly 60 countries beyond the GÉANT backbone. Intercontinental links are provided through a variety of approaches. Some links are funded by GÉANT members and the GÉANT project (e.g. to North America, see below), while others are funded and managed in collaboration with R&E networking partners. For instance, connections to China are maintained in collaboration with the Chinese networks CERNET and CSTNET, and connections to Asia-Pacific via CAE-1 are run in partnership with NORDUnet, SURF[4], the Asian networks TEIN*CC and SingAREN (Singapore), and AARNet (Australia).

A significant share of these international connections of the GÉANT network has been realised thanks to support received over almost two decades from DG DEVCO [DG DEVCO] and the Directorate-General for European Neighbourhood and Enlargement Negotiations (DG NEAR) [DG NEAR]. Through these projects alone, the GÉANT network connects to over 40 countries that would not otherwise be reached by GÉANT. The projects include:

[2] While there are 43 NRENs in Europe, only 38 of them are directly part of the GN4-n projects. The Nordic NRENs (CSC/Funet, DeIC, RHnet, Sikt/Uninett and SUNET) have formed their own regional ISP, NORDUnet, which takes part in the GN4-n projects.
[3] GN4-3 has a budget of €118,879,719 (with an EC contribution of €77,500,000); GN4-3N has a budget of €63,125,000 (with an EC contribution of €50,500,000).
[4] In 2020 the NREN for the Netherlands began a series of organisational and name changes. In the text of this document, the new name, SURF, has been used throughout; the old name, SURFnet, appears in some of the figures and tables.

- AfricaConnect3, which supports pan-African connectivity and interconnections to Europe [AfricaConnect3].
- Asi@Connect which interconnects the Asia–Pacific region and South Asia [Asi@Connect].
- EUMEDCONNECT3, in the eastern Mediterranean region [EUMEDCONNECT3].
- BELLA, for direct submarine connectivity to Latin America and the new 100 Gbps terrestrial RedCLARA network [BELLA].

Intercontinental connectivity is also funded separately by several different R&E networking partners. Routes to North America are provided by the North American R&E networks ESnet, Indiana University, Internet2 and CANARIE as well as by the European R&E networks SURF and NORDUnet; routes to Japan by NII/SINET; to India by the Indian NREN NKN; to Central Asia by the multinational R&E network overseen by the CAREN Cooperation Centre, etc. GÉANT also cooperates with its R&E networking partners around the world to enable mutual back-up arrangements, e.g. the Advanced North Atlantic (ANA) and Asia-Europe Ring (AER) collaborations.

The overall objective for the GÉANT partnership is to contribute to the effective European Research Area by making Europe the best-connected region in the world. To achieve this, GÉANT must offer European researchers the network, communications facilities and access to applications that ensure the digital continuum necessary to allow them to conduct world-class research in collaboration with their peers around the world.

2. NREN ORGANISATIONS

This section of the Compendium report considers the NRENs as organisations, looking at their annual budgets, funding sources, governance structures and staffing.[5]

2.1. Budget

Budgets are a central factor in determining what any organisation has the capacity to do, which means NREN budget figures are a hugely important part of the NREN story.

Overall, the budgets dedicated to NREN activities have increased significantly over the last five years (Figure 2.1). However, this does not mean that the trend is true for every individual NREN. The 2021 and 2020 budgets of the NRENs are shown in Figure 2.2, where the considerable variability is apparent. While the trend of increasing budgets evident in Figure 2.1 is still recognisable (20 NRENs reported an increase in budget), a look at individual NRENs reveals changes in the budgets that in some cases go well beyond the average fluctuations. These changes go in both directions and are most often related to projects or infrastructure investments[6]. However, some increases may be due to accounting changes[7].

The increase in the combined budgets of Europe's NRENs over the years can be seen as part of the overall investment in research and education infrastructure across the continent. An individual NREN's budget, however, is much more context-dependent, and is part of the story of national circumstances[8]. The roles national NRENs play vary considerably, which is reflected in their budgets.

[5] The data used in this section are mostly taken from the annual Compendium survey of NRENs. Some data come from the World Bank [World_Bank].

[6] CARNET's budget increase of more than €50 million is intended to finance the e-School project, which aims to digitalise Croatian schools; RedIRIS's budget increase of €15 million is funded through ERDF funding and will increase further in the future.

[7] The jump of €4 million in Belnet's budget is mostly due to changes in their accounting system.

[8] Some NRENs, such as GRNET, have massively expanded their service portfolio over the years. Others, such as CESNET, have widened their remit, but are now part of a collaboration with other legal entities, an example of the alignment of national e-infrastructures that has taken place in a number of countries (e.g. the UK, where the R&E network Janet has become part of the current NREN Jisc, and Estonia, Norway and the Netherlands, where comparable reorganisations are currently happening).

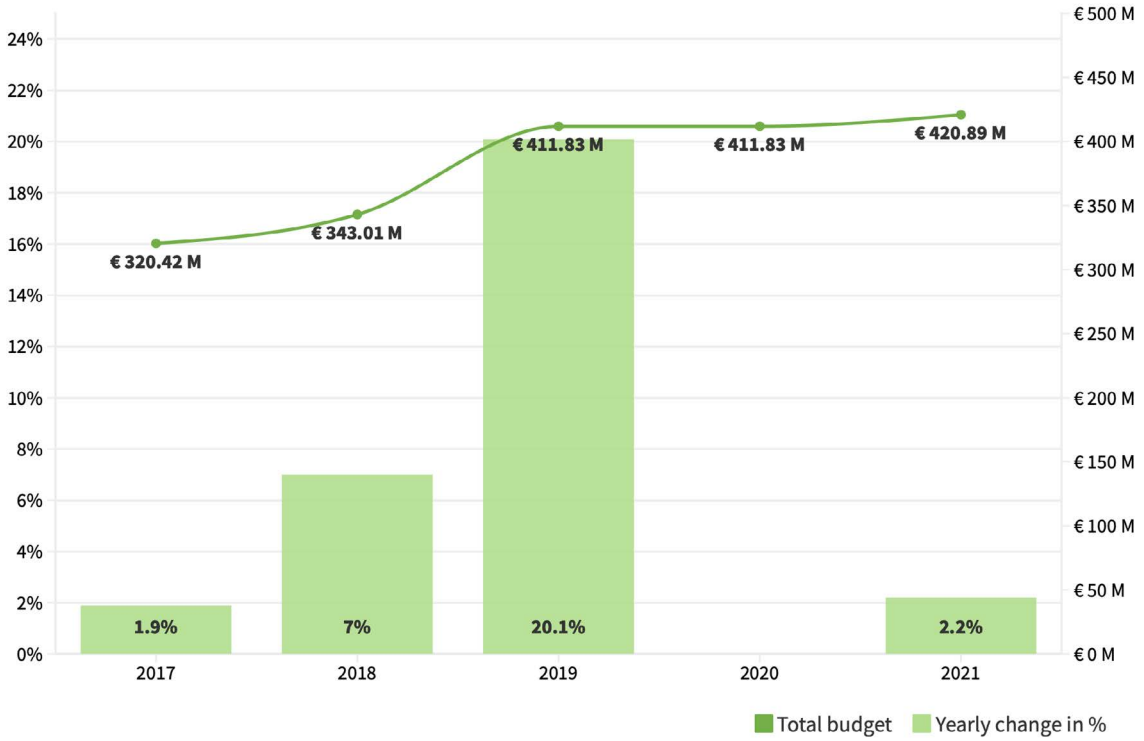

Figure 2.1: Development of total NREN budgets since 2017
The numbers are based on 30 NRENs that reported their budgets continuously throughout this period. This means that some larger NRENs are not included and therefore the actual total budgets will have been higher. (For comparison, the total budget according to the 2021 survey results based on the data for all responding NRENs that year is €555 M). The percentage change is based on the previous year's budget.

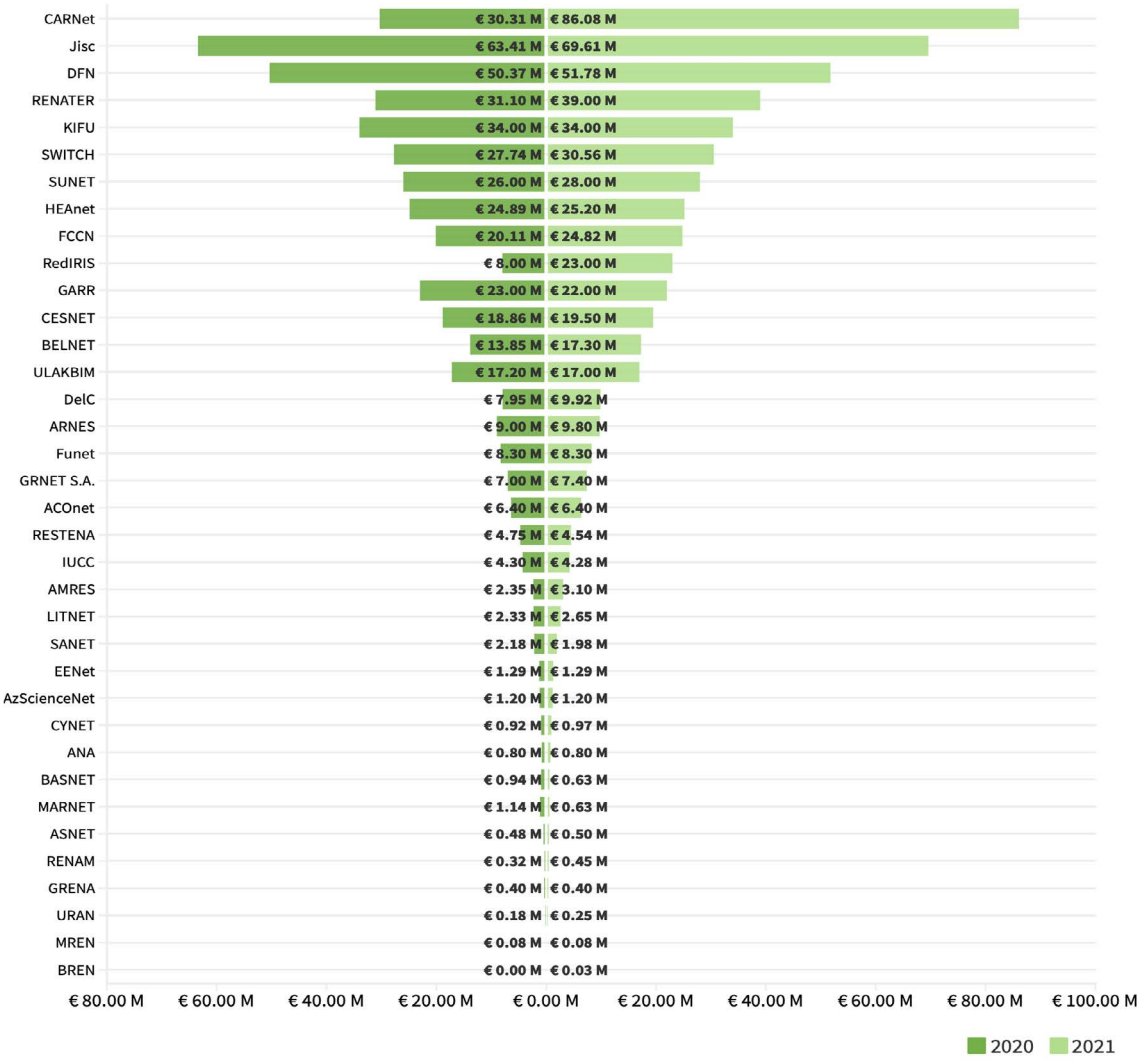

Figure 2.2: Individual NREN budgets 2020 and 2021
The figure includes NRENs that have provided budget numbers for only one of these years, hence the occasional gap. Overall, 20 NRENs reported an increase in budget, 9 no change and 7 a reduced budget. Some budgets increased considerably, mostly due to projects or infrastructure improvement. Occasionally, increases are not "real" but due to accountancy changes.

Budgets reflect the size of an NREN, but this size is, of course, also related to the size of its home country. Large countries have more R&E institutions, and therefore larger NRENs in most instances. This can be seen in the budget list shown in Figure 2.2, where NRENs from larger countries tend to have larger budgets – although there are quite a few exceptions[9]. This becomes even clearer in Figure 2.3, which shows NREN budgets normalised to Gross Domestic Product (GDP) and population. In this case, the correlation between country size and NREN budget that is still visible in Figure 2.2 disappears. Figure 2.3 orders the NRENs by budget per GDP, which allows budgets to be compared based on the economic strength of countries (as

[9] Note that the top ten budgets feature the NRENs of only four of the eight largest European countries (ULAKBIM/Turkey, GARR/Italy, RoEduNet/Romania and URAN/Ukraine are not in the top 10). NRENs from several significantly smaller countries, such as SWITCH (Switzerland), CARNET (Croatia) or HEAnet (Ireland) make the ranking instead. SURF (Netherlands) would likely make it into the top 10 as its budget is traditionally high (about €55 million in 2020) but they have not provided budget numbers for the last survey. Similarly, PSNC's (Poland) budget would likely rank in the top 10.

reflected in the GDP). As an example, UK's Jisc, which has a large budget in absolute numbers, is average in this measure, while Hungary's KIFÜ, with about half of Jisc's budget size, is in second place among all the NRENs

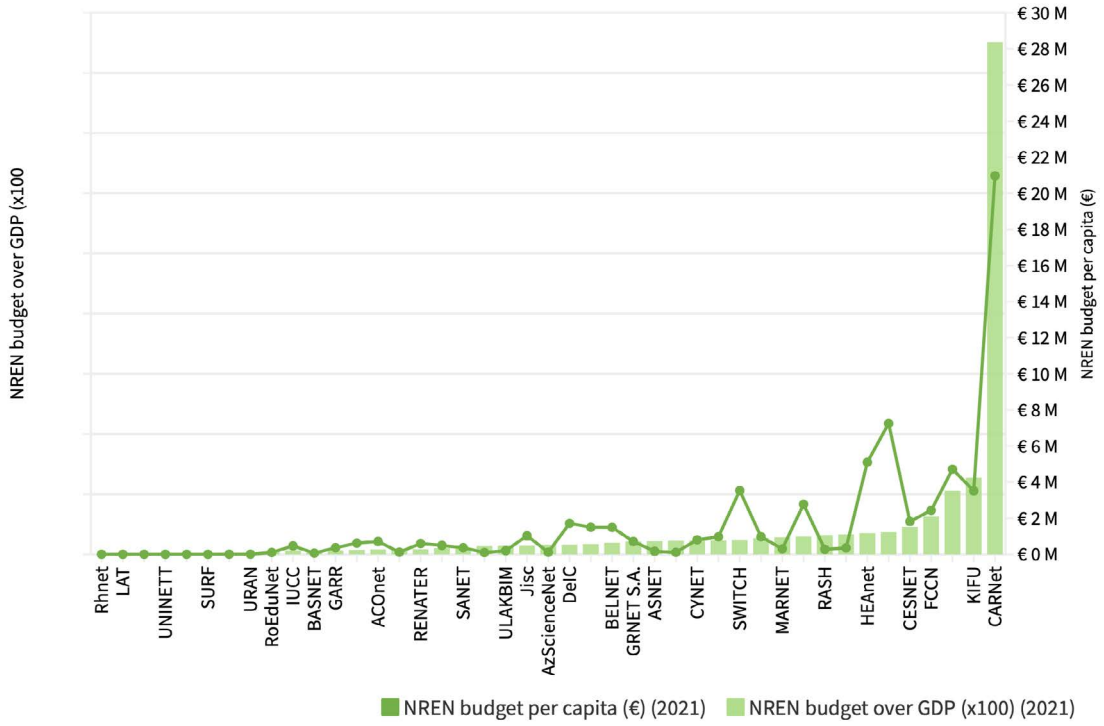

Figure 2.3: NREN budgets normalised to GDP and population

The numbers shown here are simple indices formed by dividing the NRENs' budgets by the GDP (in Billion € x100) and population sizes. Both indices give a measure of national spending on research and education networks, but are looking at different aspects. The NRENs are ordered by budget per GDP, allowing comparison based on the economic strength of countries. NREN budget per capita has a slightly different angle as it is normalised towards population size. The GDP and population numbers come from the International Monetary Fund (IMF) and the United Nations (UN), respectively.

There are a great number of factors that lead to the differences between NRENs shown in Figure 2.3[10]. Important in the context of this report is that the business models of NRENs vary, with some going well beyond their core function as an academic Internet Service Provider (ISP). The NRENs that come out at the top of either index (budget over GDP or budget per capita) in Figure 2.3 tend to provide a wide range of services to their customers that goes beyond connectivity (e.g. procurement support, computational resources, educational resources, etc.) and often also serve communities outside the traditional remit of NRENs; this requires more funds (and human resources – see below)[11].

[10] Clearly, this cannot all be captured by business data – the fundamental economic strength of a country plays a part here as well. Richer countries tend to spend more on public infrastructure, which NRENs are (in a wide sense) part of. This is at least partially visible in the population-normalised data, where NRENs from less wealthy countries tend to form the tail-end of the graph (Figure 2.3).

[11] Services that are made possible by a larger budget are provided for example by EENet/Harno and CARNET, which not only connect schools, but also provide educational resources; SURF and HEAnet, which maintain procurement schemes for their clients; and KIFÜ and ARNES, which also run HPC centres, etc.

2.2. Funding Sources

The two main income sources for European NRENs are their customers and public funds (i.e. direct government money or money coming from public bodies). Both are logical income sources given the NREN's role as a public infrastructure. In addition, a smaller but still significant source is the European Commission – this money flows through a number of different projects in which many NRENs participate (see also Section 4 Involvement in EC-Funded Projects). Finally, some NRENs generate income by providing services to commercial partners. For the European NRENs as a whole, the importance of these four income sources is presented in Figure 2.4).

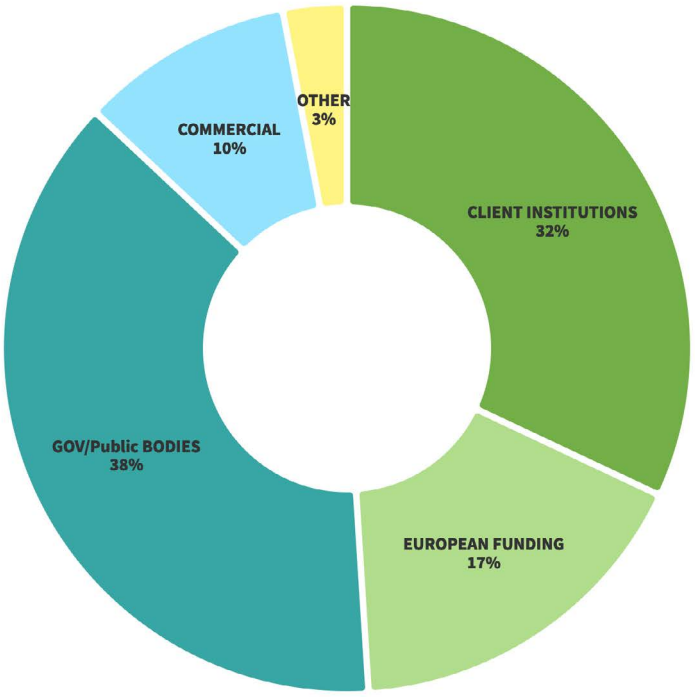

Figure 2.4: Funding sources of NRENs
This figure shows the share of different funding sources for the combined total of European NRENs' budgets. The numbers are based on the survey responses of the NRENs that provided their budget numbers as well as their income sources (36 out of 43). The percentage was calculated based on the relative sizes of the individual NRENs' budgets compared to the sum of all budgets, i.e. NRENs were weighted according to their (financial) size.

Interestingly, there have been some changes compared to 2020: the share contributed by client institutions has dropped from 38% to 32% and direct government funding has dropped from 42% to 38%. The funding through European funds has significantly increased, from 7% to 17%.

While Figure 2.4 shows that public money and money paid by the NRENs' customers are the financial mainstay, looking at individual NRENs reveals huge differences between them (shown in Table 2.1).

	CLIENT INSTITUTIONS	EUROPEAN FUNDING	GOV/Public BODIES	COMMERCIAL	OTHER
ACOnet	100%				
AMRES			100%		
ARNES		1% (5%)	87% (84%)	12% (11%)	
ASNET-AM	10%	45% (48%)	43% (40%)		
BASNET	29% (26%)	56% (64%)	15% (10%)		
Belnet	46% (39%)	0% (2%)	49% (52%)	6% (7%)	
CARNET		72% (59%)	26% (38%)	1% (3%)	
CESNET	21%	3%	73%		1% (2%)
CYNET	65% (63%)	25%	10% (12%)		
DeIC	98% (95%)	1%	1% (0%)	0% (4%)	
DFN	97% (94%)	1% (3%)	0% (2%)		1% (2%)
EENet		1% (71%)	99% (26%)		
FCCN	3%	25% (0%)	72% (96%)		0% (1%)
Funet	60%		40%		
GARR	90% (89%)	2% (4%)	8% (7%)		
GRENA	40%	50%		5%	5%
GRNET S.A.		25% (20%)	70% (75%)		5%
HEAnet	16%	0% (1%)	72% (74%)	10% (9%)	2% (0%)
IUCC	82% (91%)	12% (9%)	6% (0%)		
Jisc	20%	1% (2%)	50% (49%)	30%	
KIFÜ	4%	3% (2%)	93% (94%)		
LITNET	0% (10%)	50% (33%)	50% (57%)		
MARnet		35% (20%)	25% (56%)	40% (24%)	
MREN		20%	70%		5%
RedIRIS		41% (7%)	58% (92%)		1%
RENAM	18% (24%)	80% (74%)	2%		
RENATER	36% (11%)	4%	60% (85%)		
RESTENA	7% (6%)	2% (3%)	32% (34%)	37%	21% (20%)
SANET	7%		94% (93%)		
SUNET	70%		20%		10%
SURF					
SWITCH	58% (56%)	1% (1%)	1% (1%)	41% (43%)	
ULAKBIM			100%		
URAN	62% (67%)	16% (0%)	1% (3%)	19% (30%)	2% (0%)

Over 75%	25% TO 75%	LESS THAN 25%

Table 2.1: Income sources per NREN

The table shows the percentage share of their income that individual NRENs derived from different sources. The numbers in parentheses are the income share in 2020 and are only shown when the share has changed between the years.

The majority of NRENs have a diversified income, split to varying degrees over different categories. Despite the diversity apparent in these numbers, it is possible to distinguish different funding models. A useful categorisation can be formed based on the main funding source of the NREN being the government (government-subsidised), the NREN's users (user-financed) or a mixture of both. Figure 2.5 summarises how NRENs are distributed over these funding models.

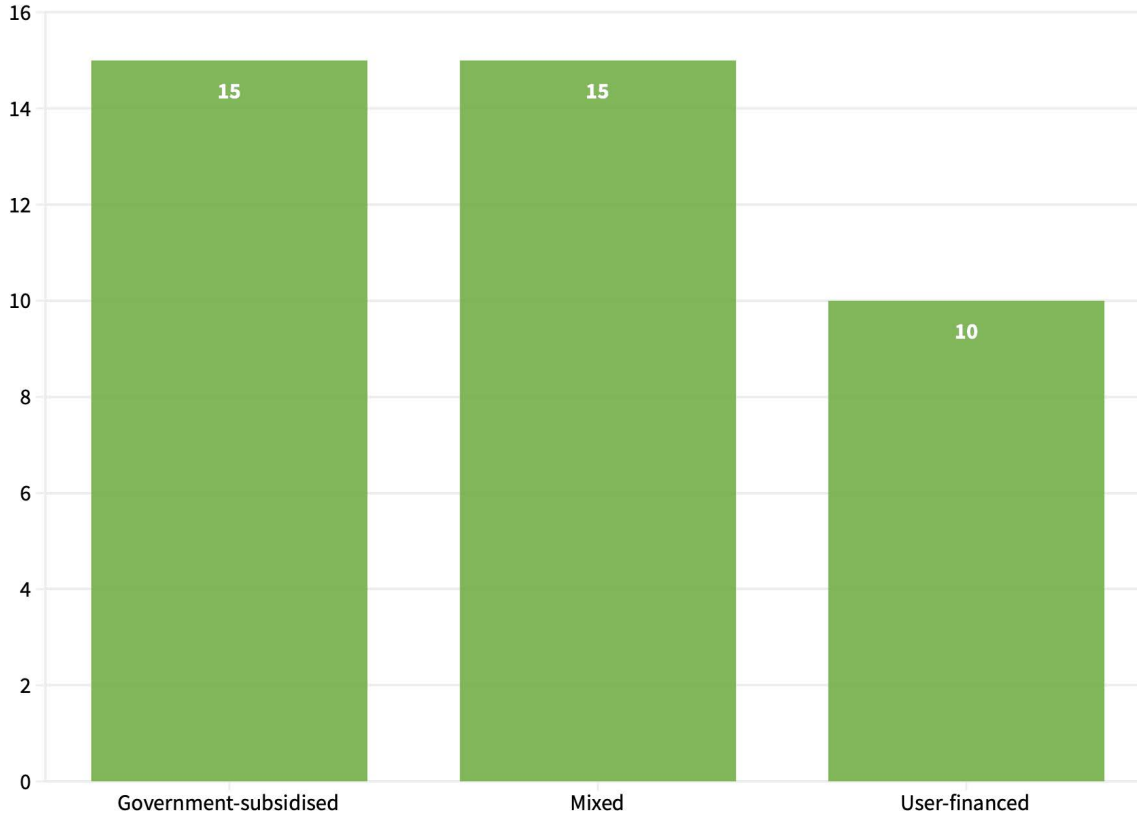

Figure 2.5: NREN Funding models
15 NRENs can be considered government-subsidised (AMRES, ARNES, CARNET, EENet, FCCN, GRNET, KIFÜ, LAT, MARnet, MREN, RedIRIS, RESTENA, RoEduNet, SANET, ULAKBIM) while 10 NRENs are mostly user-financed (ACOnet, DeIC, DFN, GARR, GRENA, IUCC, RENAM, RHnet, SWITCH, URAN). Mixed funding is used by 15 NRENs (ASNET-AM, AzScienceNet, BASNET, Belnet, BREN, CESNET, CyNet, Funet, HEAnet, Jisc, LITNET, RASH, RENATER, SUNET, SURF, Uninett[12]). Due to lack of data, two NRENs cannot be assigned to a category (PSNC, UoM).

The common appearance of European funds among the income sources reflects the strategic importance that the EC attaches to e-infrastructures, such as NRENs. This benefits NRENs in two ways: on the one hand the EC supports the development of such structures in its member countries but also in associated countries; on the other hand, NRENs are a natural source of expertise for e-infrastructures and are therefore involved in many European projects of this type. In many cases, money from the EC is an important funding source. This money, though, is connected to projects (see Section 4 Involvement in EC-Funded Projects) and therefore varies over the years[13].

[12] In 2022, the Norwegian NREN Uninett merged with other public digital infrastructure bodies from the research data and higher education sectors to form Sikt, the Norwegian Agency for Shared Services in Education and Research. Both names appear in this report.
[13] E.g. CARNET's increase in European funding is due to support for a project aimed at introducing ICT into the school system [e-Schools].

As not-for-profit organisations, only a minority of NRENs (10 of 43) have a commercial income. A variety of activities are commercialised by NRENs[14] but most commercial income of NRENs comes from generic ISP activities that are provided by the NREN as part of their duties as a national IT infrastructure. A number of NRENs are domain name registrars for national domain names[15] or run important national Internet exchanges (IX)[16].

2.3. Funding Models and Governance Structures

Both the role of users and the role of governments in the governance of NRENs can be presented by identifying categories. The role of governments can be presented in the following five categories: No representation (10 NRENs), Represented via public funding bodies (4 NRENs), Board representation (11 NRENs), Government-appointed board (7 NRENs) and Government agency (11 NRENs).

The funding models correlate relatively well with the NRENs' governance structures: user-financed NRENs usually have a strong presence of their users (i.e. universities and research institutes) in their governance structures and little formal government oversight, while NRENs that rely very strongly on direct public money, not surprisingly, reveal usually strong government oversight. The correlation between government influence and funding model becomes apparent in Table 2.2 below.

FUNDING MODEL	NO GOVERNMENT REPRESENTATION	REPRESENTED BY PUBLIC FUNDING BODY	BOARD REPRESENTATION	GOVERNMENT APPOINTED BOARD	GOVERNMENT AGENCY
User-financed	DeIC, DFN, GRENA, RHnet, URAN	GARR	ACOnet, IUCC, RENAM, SWITCH		
Mixed funding	ASNET-AM, CESNET	Jisc, SUNET, SURF	BASNET, BREN, HEAnet, RENATER	CyNet, CSC/Funet, LITNET	Belnet, Uninett
Government subsidised	SANET		AMRES, RESTENA	ARNES, CARNET, GRNET, RedIRIS	AzScienceNet, EENet, FCCN, KIFÜ, LAT, MARnet. MREN, RoEduNet, ULAKBIM

Table 2.2: Funding models and formal government involvement in NREN governance
Not too surprisingly, there is a slight correlation between government influence and funding model – increasing government influence is correlated with government funding and vice versa. Some NRENs do not appear in the table as either their governance model (RASH) or their funding model (PSNC and UoM) have not been shared.

[14] URAN offers some commercial services (e.g IP address block leasing) and the same is true for MREN and SWITCH, both deriving income from domain name registries. MREN is in addition running an Internet exchange and SWITCH also provides ICT security to the Swiss banking sector.
[15] Examples would be SWITCH, RESTENA or MARnet.
[16] Examples would be Belnet, MREN or GRNET (note, however, that GRNET does not list any commercial income in the Compendium survey).

Similarly, the role of users can be categorised into (with decreasing influence) Membership organisations (13 NRENs), Users present on the Board (16 NRENs) and No user representation (15 NRENs). While there are exceptions, there is a general trend that more government influence means less influence for user groups. This is also visible in Table 2.3, which plots the two stakeholder types against each other – as a rule of thumb, more user influence means less government influence and vice versa.

USER REPRESENTATION IN NREN GOVERNANCE	NO GOVT. REPRESENTATION	REPRESENTED BY PUBLIC FUNDING BODY	BOARD REPRESENTATION	GOVT. APPOINTED BOARD	GOVT. AGENCY
Membership organisations	ASNET-AM, CESNET, DeIC, DFN, GRENA, RHnet, SANET, URAN	SURF	ACOnet, IUCC, SWITCH		AzScienceNet
Users present on the Board	PSNC/ PIONIER	GARR, Jisc, SUNET	AMRES, BASNET, BREN, HEAnet, RASH, RENAM, RENATER, RESTENA	CARNET, CSC/ Funet, LITNET	MARnet
No user representation	UoM			ARNES, CyNet, GRNET, RedIRIS	Belnet, EENet, FCCN, KIFÜ, LAT, MREN, RoEduNet, ULAKBIM, Uninett

Table 2.3: User representation vs. government representation in NREN governance structures

2.4. Staffing

The data presented in this section show the staff engaged in NREN activities in full-time equivalents (FTE). Across the sector, staff numbers have increased between 2017 and 2021, as shown in Figure 2.6 – similarly to, and of course made possible by, budget increases. The total number of employees declared by NRENs in the 2021 Compendium survey reached 2,402

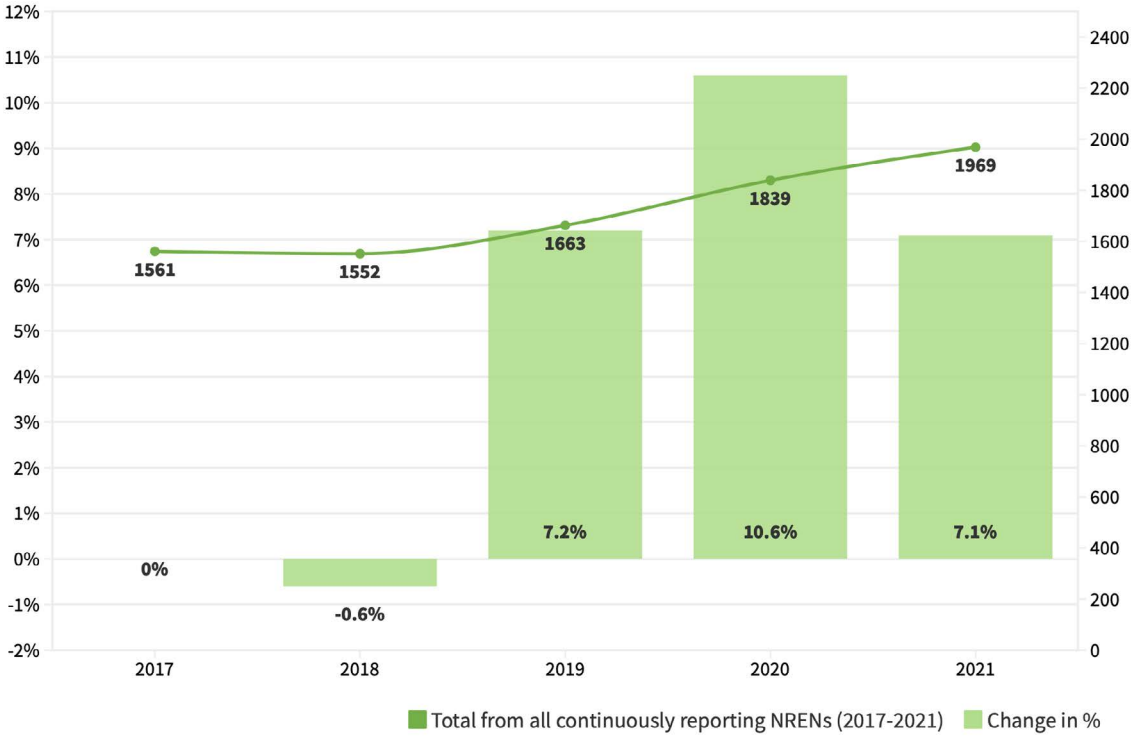

Figure 2.6: Total staff numbers of the NREN sector
The percentage change is based on the earlier year's staff numbers. While the total number of staff reported in 2021 was 2,402, the data series shown in the graph is based on those NRENs that reported their staff numbers continuously throughout this period, which means that some NRENs are not included (see footnote 1 on p. 1).

As with budget numbers, staff numbers vary considerably among NRENs, reflecting their differing sizes and the extent of the services they offer. The number of employees of individual NRENs in the years 2020 and 2021 is presented in Figure 2.7. While changes in employee numbers are apparent in these data, they are generally not as large as the swings in budget. This reflects the fact that most large budget changes are dedicated to transient projects (such as network infrastructure renewal), which are most often carried out with the help of contractors and therefore do not entail large changes in the headcount of the NREN. Of course, there are exceptions to this, usually correlated with organisational change[17]. The ratio of permanent employees to subcontracted employees varies markedly between NRENs, reflecting local circumstances, such as employment law, and business policies that are beyond the scope of this report. In general, while the overall ratio between the two employment categories has seen a slight change over the years, starting with about 10% of subcontracted positions in 2017 and increasing to about 15% in 2021, this variation might be due to the noise in the data that is generated by the variability in the survey response rate.

[17] For example, KIFÜ started an HPC centre, which entailed of course a staff increase. On the other hand, RASH reduced its staff by about a third when project funding ended. Many NRENs generally are in a challenging situation concerning staff recruitment, as public services have difficulties competing with the commercial sector for qualified staff.

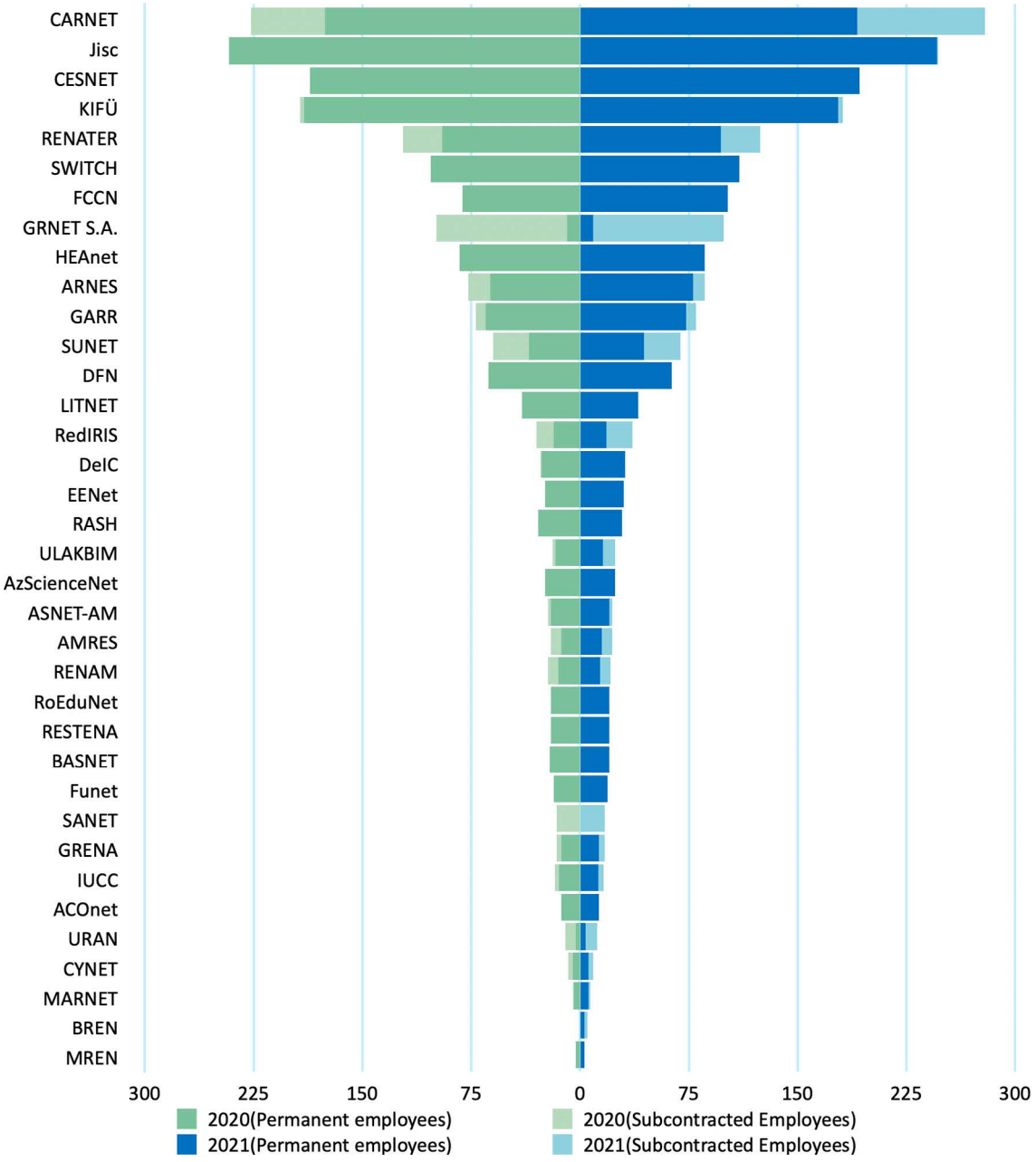

Figure 2.7: Staff numbers of NRENs in the years 2020 and 2021
The figure includes NRENs that have provided staff numbers for only one of these years, hence the occasional gap.

An interesting aspect of NREN staffing is the actual nature of the work performed by employees. For this purpose, Figure 2.8 shows staff roles broken down into two broad categories: technical and non-technical roles. Not surprisingly for network providers, the majority of positions are technical roles[18]. Nevertheless, there is considerable variation between NRENs, which again emphasises how different NRENs are from each other.

[18] At MARnet, the network management and operations roles sit within the university, hence the lack of technical staff.

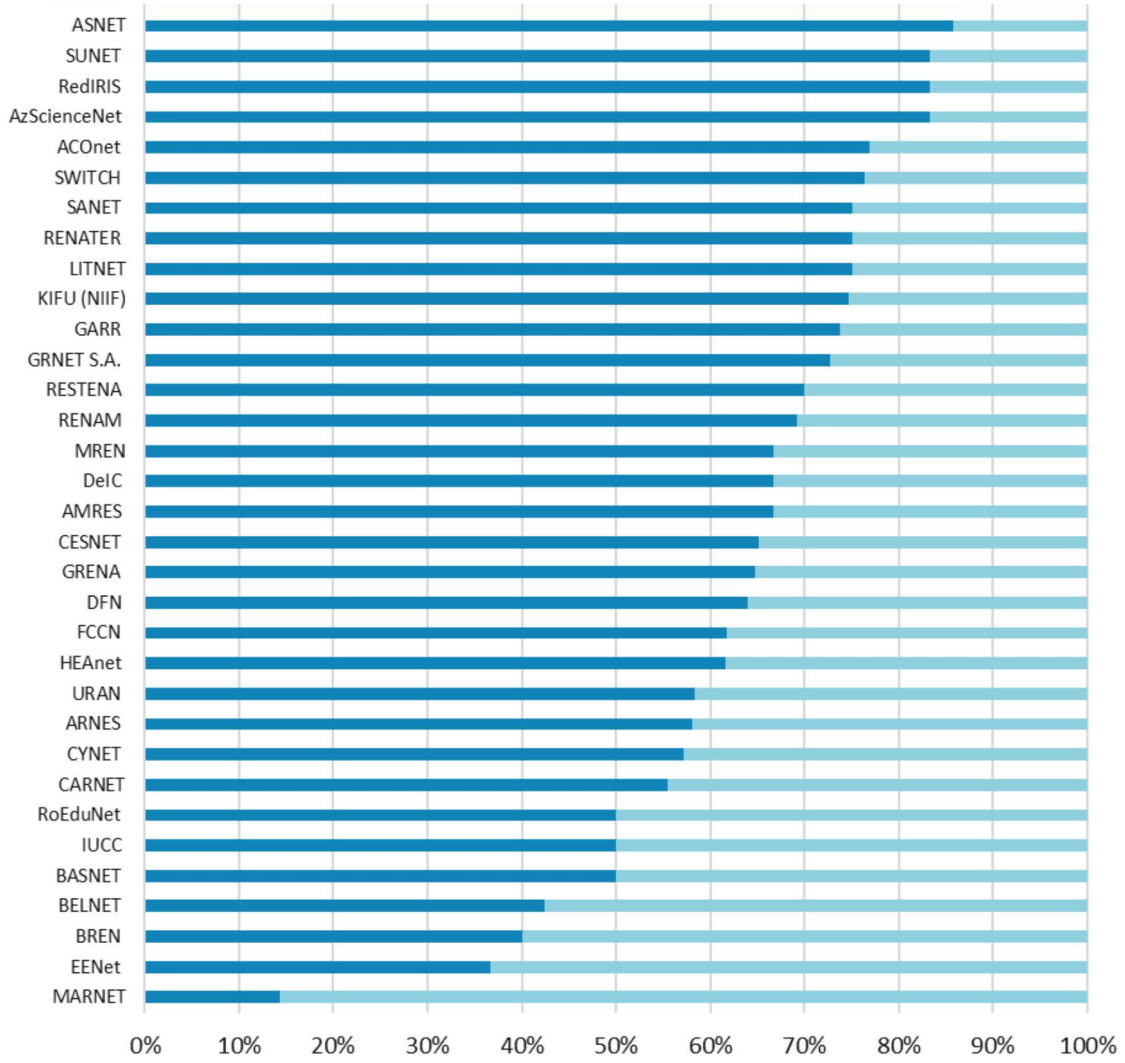

Figure 2.8: Share of technical roles among staff numbers
For the purpose of this figure, non-technical roles are e.g. legal, finance, HR and PR, while technical roles would be network operation, software development or IT security.

2.5. Summary

The NREN sector is growing in terms of both funding and staff. As the money for NREN activity comes mostly from public sources, either directly or via contributions from (mostly) publicly funded customer institutions, this shows an increasing investment in the public ICT infrastructure of the R&E sector in Europe as a whole. While this provides relatively stable income in normal times, it makes funding strongly dependent on the state of the public finances.

At the level of individual NRENs, the data presented in this section demonstrate once more the diversity of NRENs: staff numbers as well as budgets vary enormously, even when corrected for the size of the NREN's home country, reflecting the very different sets of responsibilities NRENs are charged with. This will also be visible in the following section about the NRENs' user base.

3. END USERS

Research and higher education institutions (i.e. universities and research institutes) are the core end users of the networks managed by NRENs. However, beyond this core "market", NRENs in different countries provide connectivity and other services to a wider group of constituencies as well. Generally, these are public institutions, including primary and secondary schools, libraries or government organisations. Under specific circumstances, and in some countries, NRENs also offer their services to commercial organisations.

This section provides an overview of the NRENs' formal remit, including the users and organisations that they are authorised to connect, acceptable use policies (AUPs), current market shares of the institutions connected to each NREN, and link capacities provided to different types of connected institutions. As in previous years, to allow a consistent categorisation across different national education systems, the classification in this section follows the ISCED 2011 classification system (the UNESCO scheme for International Standard Classification of Education) [ISCED 2011].

3.1. Connectivity Remit

NRENs have many different funding structures, organisational setups and business models that define their scope and service offerings. An overview of the NRENs' connectivity remit is given in Figure 3.1.

All NRENs connect universities and research institutions. Most are permitted to connect institutes of further education, cultural institutions such as libraries and museums, and government bodies. About half of the NRENs can also connect schools. Only a minority of NRENs are permitted to connect commercial organisations, often only under certain circumstances, usually when the company in question is part of a collaborative project with an academic partner. Another common circumstance under which commercial organisations are connected is where the company is a start-up growing out of the research and education sector.

The remit of the NRENs can be quite dynamic. For example, several NRENs have taken on schools as part of their portfolio in recent years, expanding their user base enormously, at least in terms of absolute user numbers. Reasons for changes in the connectivity remit vary. They can happen simply due to market forces, as most organisations choose their ISP autonomously, but as NRENs are part of the "public infrastructure", the more common reasons are a desire for better utilisation of that infrastructure, expansion of value-added services that are of interest to others, and the facilitation of public–private partnerships between publicly funded and commercial research facilities. A big factor here is also what type of organisation the NREN is: those that are closely connected to the government are more likely to be considered a public infrastructure and a resource of expertise that can be repurposed.

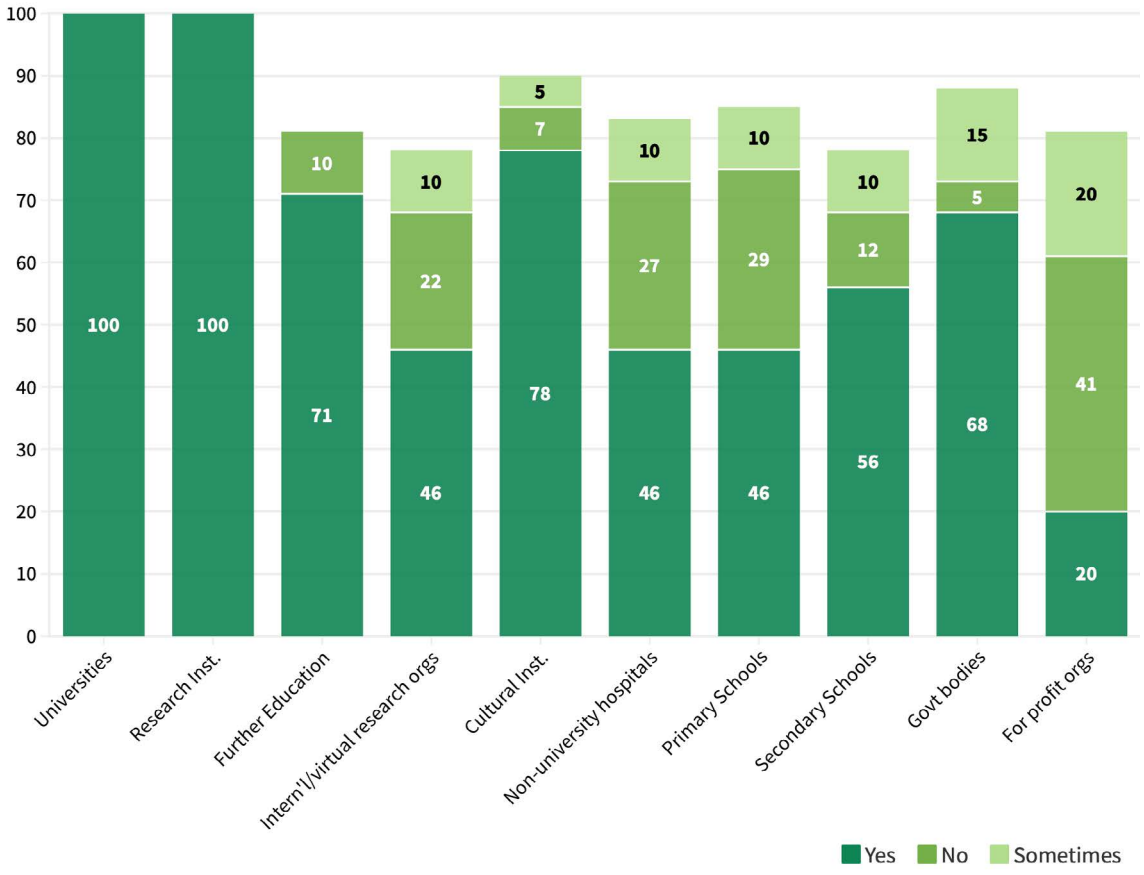

Figure 3.1: Percentage of NRENs connecting different user types
While higher education and research are clearly the core of NREN activity, most NRENs also serve other user groups in the public space.

3.2. NRENs' Acceptable Use Policy

The acceptable use policy (AUP) is a key element in defining the formal remit of NRENs in terms of which institutions they are eligible to connect. According to the 2021 Compendium data, there has been essentially no change since 2018: a large majority of NRENs have a formal AUP in place (see Figure 3.2).

An overview of acceptable use for each country, including a link to the AUP, can be found in the online version of the Compendium [COMPENDIUM] or is available on request from the Compendium team. (The AUP is also part of the organisational security requirements of NRENs and is therefore briefly discussed in Section 6 Security Services as well).

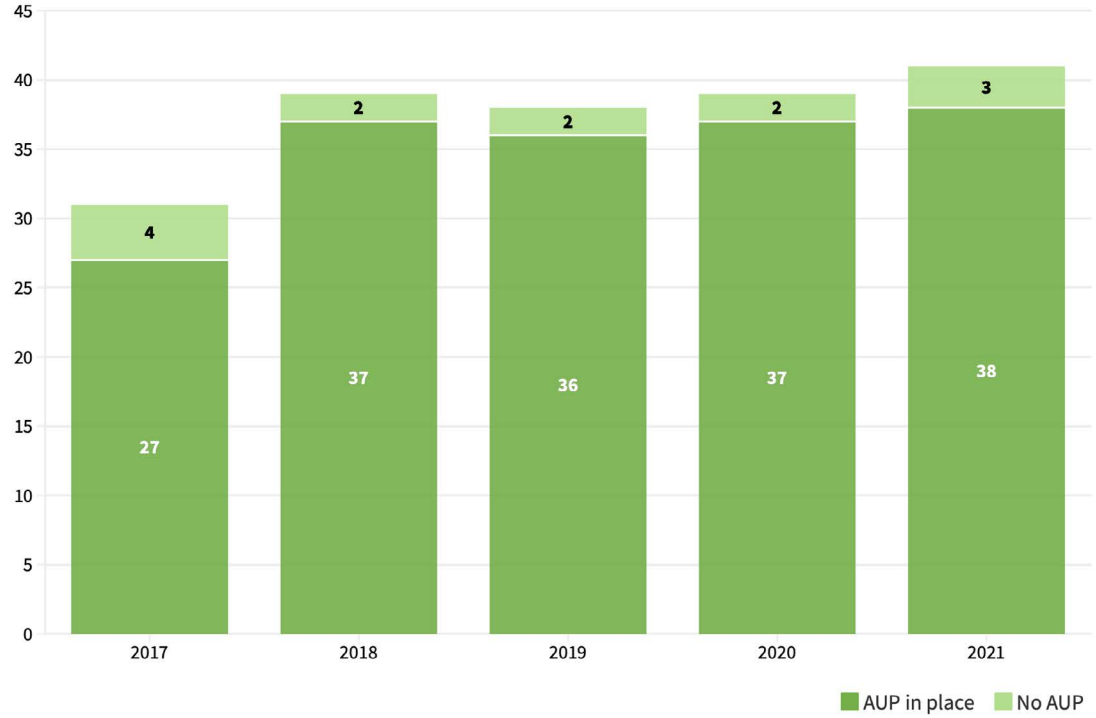

Figure 3.2: Number of NRENs that reported having an acceptable use policy (AUP) in place
The slight drop in the number of AUPs from 2018 to 2019 is due to the varying response rate. Between 2017 and 2021, no NREN has reported having abandoned an existing AUP, but some have reported that they have newly introduced a formal AUP where none existed before.

3.3. Approximate Market Shares for Different Types of Institutions

While the connectivity remit explains which institution types an NREN may connect, it does not say whether a given category of institutions makes up a sizeable part of an NREN's customer base. To determine this, the Compendium survey asks the NRENs to give an estimation of their market share for different user categories, i.e. what percentage of each category use the NREN's services[19]. The estimated market shares per institution type, per NREN, are presented in Table 3.1.

The overall market share distribution in 2021 is comparable to that of 2020. In most countries, all, or a large majority of, universities and research institutions use the NREN for their connectivity needs. As expected, given the formal remit of the NRENs, these types of institutions represent the largest market share, with full or nearly full coverage across most NRENs[20].

Where schools fall into the NREN's remit, the NREN's market share is usually very high, and the same is true for institutions of further education. This is most often the case where NRENs

[19] No commercial implications are intended by this term; it is used in the Compendium survey as a convenient shorthand.
[20] There are exceptions. URAN and AzScienceNet only connect about a third of the Ukrainian and Azeri universities, respectively (URAN is competing with a second NREN) and only 50% of Israel's universities are making use of IUCC's services.

are a directly state-funded "public infrastructure", which makes them a natural resource to turn to when ISP services are needed for public institutions. Note that the estimated market share for for-profit organisations is limited, at less than 2%.

Overall market shares are not very dynamic, and large jumps are rare; in most cases, noticeable changes take several years[21].

An example of where an NREN has increased its market share is provided by LITNET which has increased its market share among further education institutions to 90% (from 80% in 2020 and 60% in 2019).

	Universities	Research Ins.	Further Education	Inter'l research Inst	Libraries	Hospitals	Primary Schools	Secondary Schools	Government	For-Profit Orgs
ACOnet	80				40	60	90	90	60	
AMRES	80	80	90		50	3	97	97	2	
ANA	74	13			4				7	
ARNES		93			87		97	100	10	
ASNET-AM	45	90			30					
AzScienceNet	40	90								
BELNET	90	75	1		1	5	5	5	20	
BREN	50	100								
CARNet	100	98	10		1	94	98	99	81	1
CESNET	95	97	8	90	2	25	1	6	11	
CYNET	100	70	40							
DeIC	100	25	33	50	10	60		1	5	1
EENet	89	4	66		7		11	44	9	
GARR	65	80		20	0.5	4.4	2.9	6.6		
GRENA	62	50								
GRNET S.A.	100	100	50		2	40	100	100	4	
HEAnet	100	50	5				98	100	1	
IUCC	50									
Jisc	100		100							
KIFU (NIIF)	80	99	2	100	90	5	96	96	5	
LITNET	90	100	80		18	10	17	59	10	1
MARnet	40									
RedIRIS	90						45	45		
RENAM	72	80	11		9	7		0.01	5	
RENATER	100	100								
RESTENA	90	80					90	100		
RoEduNet	95	80	50		60		60	70	10	
SANET	99	70	95		20	15	15	45	5	1
SUNET	100		100							
SURFnet	100	90	90	20	5	6	8	8		2
SWITCH	100				5					
ULAKBIM	96	10			0.1				2	
URAN	30	13	5	10	4	5			2	1

Over 75%	25% TO 75%	LESS THAN 25%

Table 3.1: Estimated percentage market share per institution type, per NREN
Not all NRENs gave an estimate of their market share; empty fields therefore reflect missing responses, not missing connectivity. Note also that market share differs from the connectivity remit of NRENs (Figure 3.1). Theoretically, an NREN could count, for example, hospitals within its connectivity remit, but not connect a single one.

[21] It is not always easy for NRENs to estimate their market share in a particular area, especially when large numbers of individual institutions are involved, e.g. schools or libraries. Sometimes, therefore, reassessing the market share with new methods can yield different results without a change in the situation on the ground.

3.4. Typical and Highest Capacity of Connected Institutions

This section discusses the links from the NRENs' user institutions to the NRENs' backbone network. The capacity of these links is an important parameter as it determines the amount of data transfer they can support. Typical link capacity for connected institutions ranges from 1 Mbps up to 100 Gbps (Figure 3.3). Looking at both the typical and the highest capacity links (Figure 3.4) provided to different types of institutions shows a pattern that reflects the needs of the respective institution categories. Generally, universities and research institutions are provided with the high-capacity links needed to meet their requirements, whereas schools have lower-capacity links.

While these findings are not surprising, it is interesting to look at the development across the last few years. Figure 3.5 provides a timeline of how the typical link capacity provided to universities and research institutes has developed since 2016. Throughout this period the most common link capacity has been around 1,000 Mbps; the absolute numbers of NRENs offering each of the capacity bands have not changed much during this time. However, the last two years have seen an uptick in the number of NRENs providing their users with link capacities in excess of 1,500 Mbps and a decrease in the 500–1,500 Mbps range (by far the most common capacity in this category is 1,000 Mbps). This is due to some NRENs having upgraded their offers, which has shifted some former "low-capacity" NRENs into the "mid-capacity" range (e.g. ULAKBIM) and some "mid-capacity" NRENs into the "high-capacity" range (e.g. EENet and Funet). In line with this trend is also the decrease of link speeds below 500 Mbps.

Interestingly, the rates at which traffic increases are considerably higher than the pace at which link capacities increase (for details, see Section 5 Network). Fast traffic growth has of course been a constant for years and to accommodate this, networks have a significant over-capacity when they are designed.

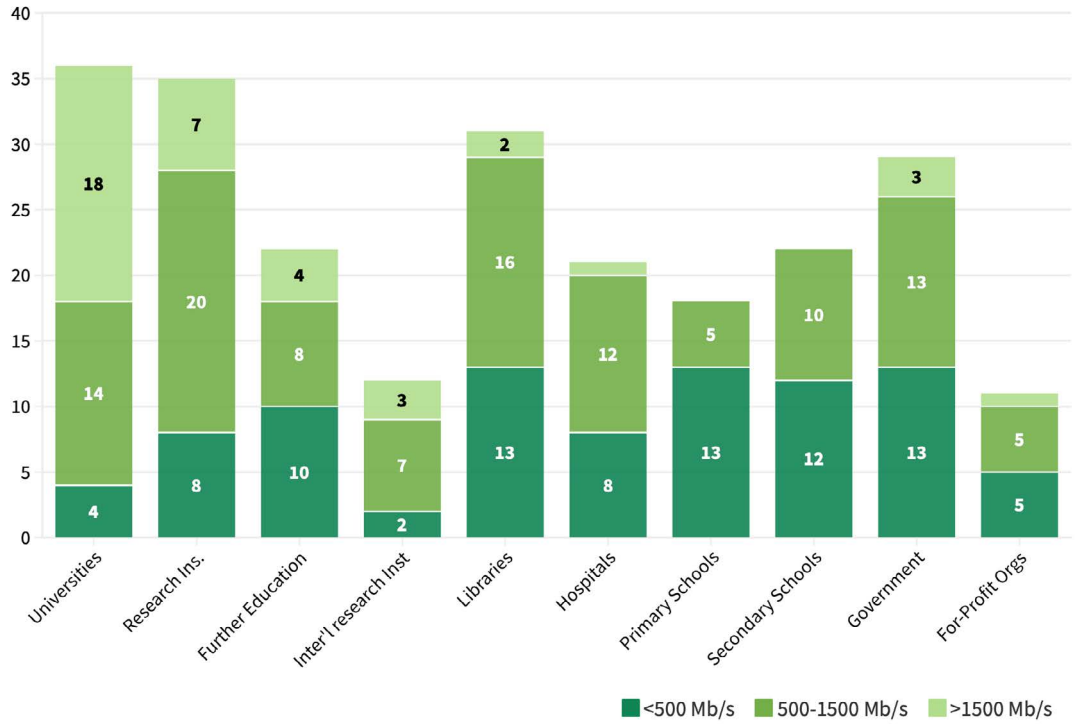

Figure 3.3: Typical link capacities provided by NRENs to different types of connected institutions
For the purpose of this figure, link capacities have been grouped into three capacity categories: less than 500 Mbps, 500–1,500 Mbps and beyond 1,500 Mbps. Most NRENs typically provide their core users (universities and research institutes) with high-capacity links, reflecting the capacity needs of these institutions. Other user groups (e.g. libraries or schools) have lower needs and therefore generally receive lower-capacity links; in addition, schools are often not connected by the NREN itself but via commercial links.

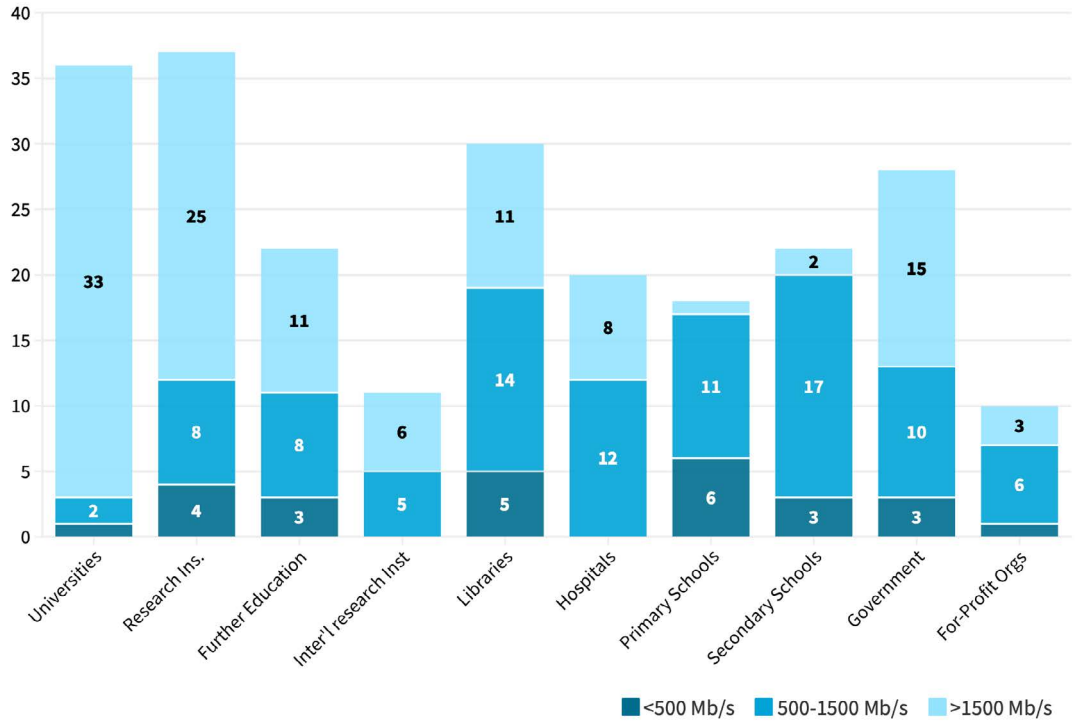

Figure 3.4: Highest link capacities provided by NRENs to different types of connected institutions
For the purpose of this figure, link capacities have been grouped into three capacity categories: less than 500 Mbps, 500–1,500 Mbps and beyond 1,500 Mbps.

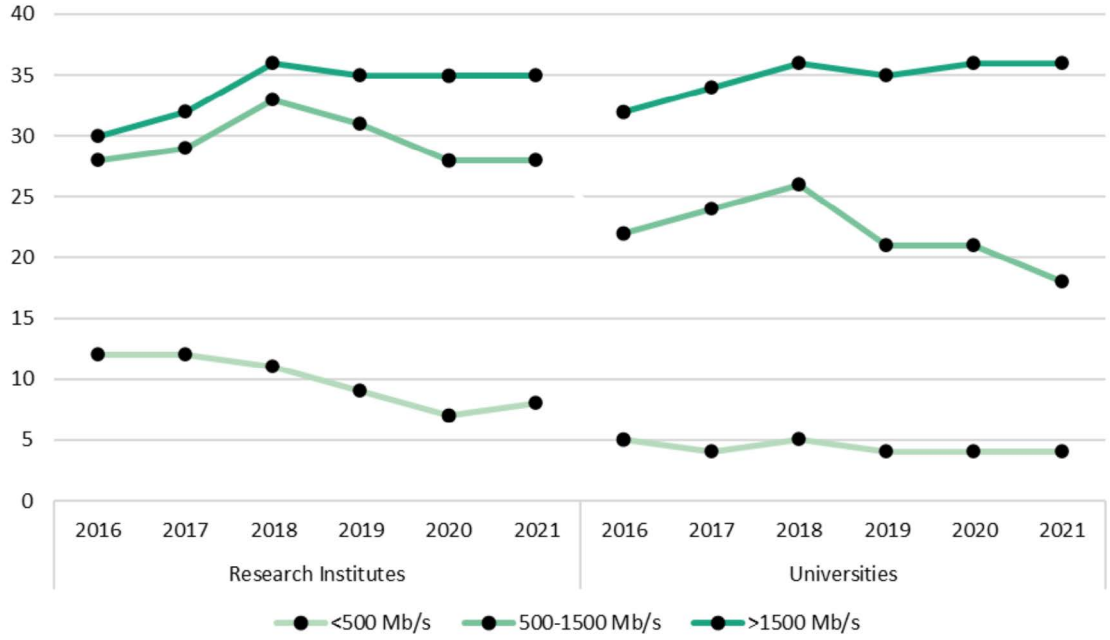

Figure 3.5: Development of link capacities for universities and research institutes 2016 to 2021
The numbers show how many NRENs provided their research institutes (left panel) and universities (right panel) with typical link capacities of <500 Mbps (light-green line), 500–1,500 Mbps (darker-green line) and >1,500 Mbps (darkest-green line) in the years 2016–2021. The decrease seen in 2019 is due to the overall lower number of NRENs responding to this question that year.

3.5. Access Link Carriers

As access links are a crucial piece of infrastructure, it is interesting to look at how NRENs provide them for their users. There are two main options: an NREN can provide the necessary link directly, or rely on a third party for this service. The third party can be a commercial provider (which often means that the users have to pay for the link) or the role can be fulfilled by local networks (e.g. local or regional research and education networks (RENs) or metropolitan area networks (MANs) (Table 3.2). Looking at the numbers, most NRENs provide the access links for their users themselves or through local providers (except schools – see below), while commercial access links are used by only 4 NRENs. NRENs tend to apply the same method to provide access links regardless of the user type (again with the notable exception of schools), so most of the variation between different user types in Table 3.2 arises from the fact that not all NRENs connect all user types.

	UNIVERSITIES	RESEARCH INST.	FE	INTERN'L RES. INST.	CULTURAL INSTITUTIONS	HOSPITALS	PRIMARY SCHOOLS	SECONDARY SCHOOLS	GOVERNT	FOR-PROFIT ORGS
NRENS provides access link	26	23	12	8	18	12	4	7	12	4
Access link by regional REN	4	4	3	2	5	3	4	2	3	1
Commercial providers	4	5	7	1	4	4	10	11	7	2
Metropolitan area networks (MAN)	2	1	1	1	2	1	2	2	2	1
Other	2	1	0	2	1	1	1	2	5	4

Table 3.2: How NRENs provide access links to their users
Schools excepted, NRENs tend to be consistent across their user spectrum when it comes to the carrier types. With regard to schools, a majority of NRENs opt for commercial traffic carriers to provide the access links, a reversal of the situation seen among the other user types. Note that not all NRENs connect all user types.

Among the NRENs that use different methods, most provide the access links to universities themselves (RENAM, ULAKBIM) while using commercial providers for the rest (ACOnet, LITNET, RENAM, RoEduNet, ULAKBIM). Belnet uses a MAN for all institutions within the Brussels area. Some NRENs have not provided this information and are therefore not present in this table (BREN, LANET, RHnet, Uninett, UoM).

As mentioned above, schools are an exception to both of these rules of thumb. Here, the majority of NRENs use commercial providers to provide access links and only a minority provide the access links themselves. This of course reflects the huge difference in numbers between schools and any other user type: while universities – even in large countries – are counted in the hundreds, school numbers are about two orders of magnitude above that.

3.6. User Numbers

While NRENs provide their services to institutions, not to individual users, the question of how many individual users are actually making use of an NREN's network and other services is nonetheless important. Because their relationship to the end users is indirect, NRENs cannot in all cases easily or reliably answer this question. However, some NRENs provided estimates of how many people use their networks via the different institutions the NRENs serve (Table 3.3).

	Universities	Research Institutes	Further Education	International Research Institutions	Cultural Institutions	Hospitals	Primary Schools	Secondary Schools	Government	For profit organisations
AzScienceNet	100,000	9,000			1,200					
BELNET	532,300	30,485	900	2,011	18,560			61,796	146,036	1,215
BREN	150,000	5,000								
CARNet	200,000	5,000	1,000	100	300	14,000	400,000	205,000	53,000	500
CESNET	390,000	50,000	5,000	500	2,000	5,000	3,000	22,000		
CYNET	70,000	100	500							
DeIC	150,000	1,200	100,000	100	1,000	80,000		7,000	1,000	100
FCCN	401,174						802,133	297,610		
Funet	360,000	24,000			1,000				4,000	
GARR	1,500,000	30,000		2,800	1,000	8,000	121,500	292,700		
GRENA	90,000	2,500								
GRNET S.A.	300,000	40,000	20,000	200	12,000	25,000	100,000	100.000	2,000	1,000
HEAnet	230,000						450,000	350,000		
IUCC	140,000									
Jisc	2,500,000		2,500,000							
KIFÜ	100,000	50,000	1,000	200	200,000	5,000	600,000	600,000	100	
MARNET	60,000									
MREN	20,000									
RENAM	74,500	2,900	850					208		
SURFnet	750,000	120,000	430,000	10,000	20,000	30,000	60,000	60,000		10,000
SWITCH	328,154		770							
ULAKBIM	3,850,000	5,500							5,000	
URAN	500,000	1,600	1.000	200	180	1,000			170	1,000

Table 3.3: Estimates of the number of individual users per institution type
Remarkably, some NRENs provide connectivity to a quite significant number of end users in the commercial sector

While there are many gaps in the data that NRENs can provide about the number of end users, it is possible to estimate the number of end users using the market share estimates provided by NRENs (Table 3.1) and the number of students in Europe in schools and universities, as these make up by far the largest user group in terms of headcount. A smaller, but still significant, contribution comes from the staff of universities and schools. Using publicly available numbers of students and an assumed staff-student ratio of 1:12.5, the number of end users of NREN networks and services in Europe amounts to about 40 million users[22].

[22] The formula used is the following: market share (schools, universities, FE sector) x student numbers (schools, universities, FE sector) x 1.08 (staff-student ratio factor).

3.7. Summary

In general, NRENs dominate their core customer-base category of universities and research institutions while other fields show a more varied picture. Overall, market shares are not very dynamic (with individual exceptions), reflecting the NRENs' function as a public infrastructure rather than a for-profit enterprise.

Increases in the user base could come from expanding into additional areas of the public service sector, as happened some years ago when several NRENs started providing services to schools, but currently, no such general trend can be identified.

The student numbers for European countries are based on publicly available Eurostat and UNESCO sources. The staff-student ratio is equally based on publicly available data from the same sources. The ratio varies considerably between countries, so the number of 12.5 is based on the Eurostat estimate for the average across the 28 EU states (2018). Where NRENs have not provided an estimate of their market share (with DFN and PSNC/PIONIER this includes two NRENs from countries with large student populations), a market share for universities of 80% has been assumed (possibly an underestimate) and a 0% market share for schools (which is true for DFN but unclear for PSNC/PIONIER). Another assumption is that all of the other user groups (research institutes, hospitals, government bodies, etc.) have a much lower headcount compared with schools and universities, so adding them would not significantly change the estimate. That this assumption is plausible is also illustrated by the end-user estimates in Table 3.3.

4. INVOLVEMENT IN EC-FUNDED PROJECTS

NRENs participate in a number of projects funded by the European Commission beyond the Framework Partnership Agreement (FPA) projects GN4-3 and GN4-3N, which include all European NRENs. This section analyses those activities and draws conclusions based on the trends. The figures are taken from the responses to the Compendium survey but have also been validated by cross-checking with CORDIS, the European Commission's primary public repository and portal to disseminate information on all research projects funded by the European Union (EU)[23].

The data show that 35 individual NRENs participated in a total of 100 unique projects, which means the number of participating NRENs has increased compared with 2020, when 31 NRENs reported project participation, while the number of projects has decreased slightly compared with 2020, when 103 projects were recorded. The increase in the number of participating NRENs reflects a general upward trend: in 2019, the corresponding numbers were 29 NRENs and 78 projects. Many of the projects are related to EOSC and Open Science, underlining the growing importance of above-net services to many NREN portfolios.

Figure 4.1 provides an overview of NREN involvement in EC-funded projects other than GN4-3. The graph shows that many NRENs have multiple commitments to collaborations in international science. However, this also necessitate a level of resources that is not available to every NREN. It is also worth bearing in mind that most EC-funded projects are not fully funded by the EC and that the NREN needs to contribute a certain level of its own resources to participate. It is therefore no surprise that the NRENs that contribute to multiple EC-funded projects tend to be large and well-equipped, with a substantial budget, though the data also suggest a pattern that some smaller NRENs have an active strategy to participate in many projects. The growing level of engagement is therefore impressive. GÉANT itself is also involved in 12 of the 21 EC-funded projects.

The five NRENs involved in the most EC-funded projects are CSC/Funet, GRNET S.A., PSNC/PIONIER, CARNET and CESNET. Data derived from CORDIS also led to reporting projects for NORDUnet, an international collaboration representing the NRENs of the five Nordic countries, which does not ordinarily appear in the Compendium.

[23] Data were cross-checked for 21 projects/initiatives, as well as for membership of the EOSC Association, since some respondents simply stated involvement in EOSC. This cross-checking revealed under-reporting of project participation in the Compendium survey in several cases. The 21 projects/initiatives for which data were validated against CORDIS and/or membership registries were: EaPConnect2, the BELLA programme, EOSC Future, EOSC Enhance, PRACE, NI4OS, EOSC-hub, EGI-ACE, EuroCC, DICE/EUDAT, EOSC Synergy, OCRE, EUMEDCONNECT3, CLONETS, EOSC-Nordic, HPC-Europa3, HPC-GIG, EOSC-Life, EOSC-Pillar, PaNOSC and the EOSC Association (Members/Observers and Mandated Organisations). The corrected numbers have been used in this section.

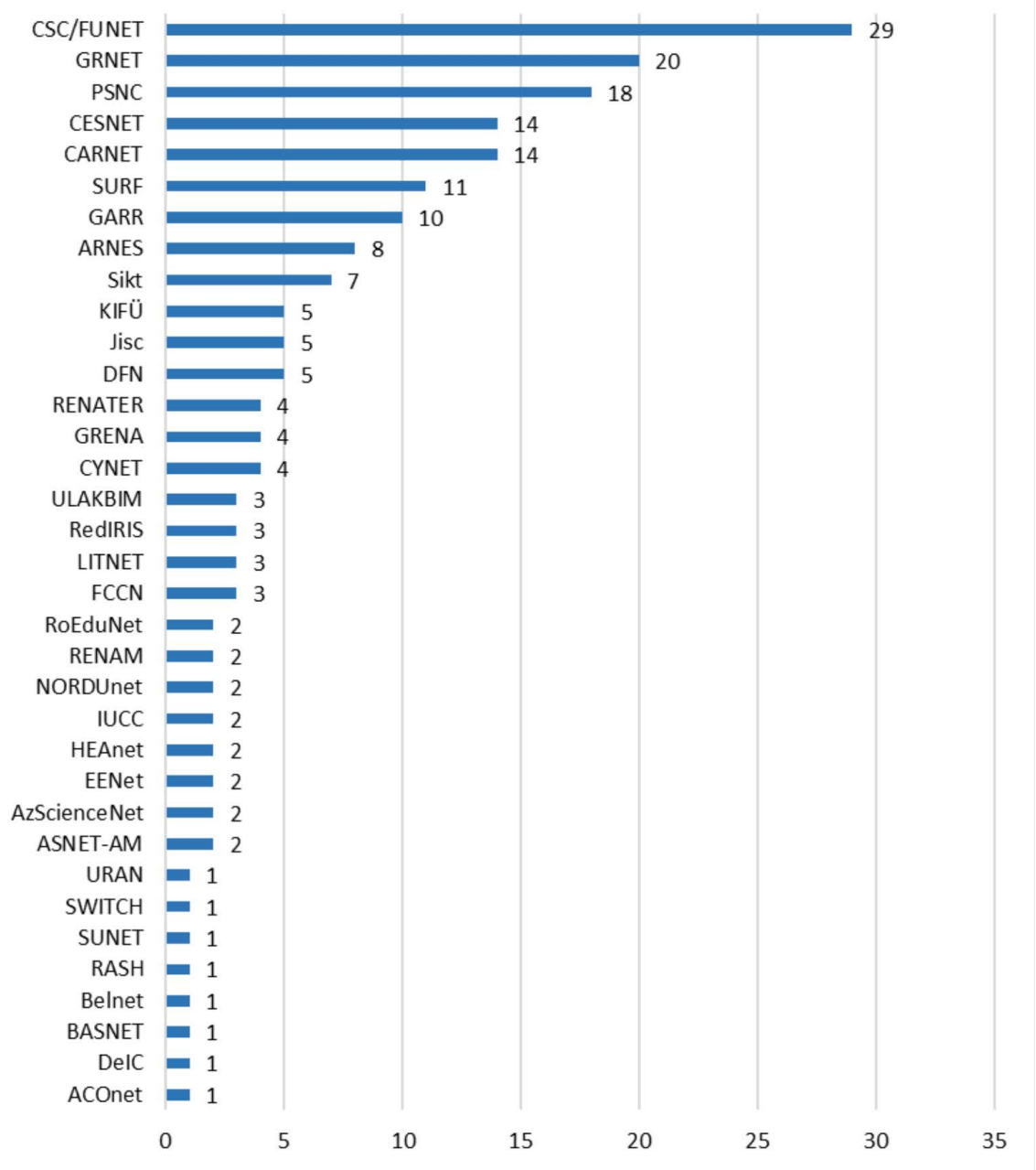

Figure 4.1: NRENs' participation in EC-funded projects other than GN4-3 – total number of projects per NREN

4.1. Overview of Top EC-Funded Projects

This section gives a brief overview of eleven of the most popular EC-funded projects in terms of NREN participation. All these projects have multiple partners, i.e. the NRENs are by no means the only contributors to these projects. Several are EOSC-related (EOSC Future, EGI-ACE, DICE, NI4OS, OCRE, EOSC Synergy and EOSC-hub), while others address the network, regional collaborations or computing.

PROJECT	NO. OF NRENS PARTICIPATING
EaPConnect 2	15
EOSC Future	12
EOSC-hub	8
PRACE	8
NI4OS	7
EGI-ACE	6
EuroCC	6
DICE/EUDAT	5
OCRE	5
EOSC Synergy	5
BELLA programme	5

Table 4.1: Summary of the projects with most NREN participants
EOSC-hub and the BELLA programme ended in 2021. PRACE, EuroCC, OCRE and EOSC Synergy will end in 2022, though additional iterations of these projects are possible. (For the purpose of this list, the Compendium survey responses were cross-checked and supplemented with CORDIS).

European Open Science Cloud (EOSC)

The European Open Science Cloud (EOSC) is an EC-funded initiative to create a pan-European platform that acts as a web of FAIR data and services for research. To accomplish its far-reaching goal, the EC has invested in a wide range of EOSC projects. Several of these have enlisted NRENs among their supporters.

An overview of projects in which NRENs participate is provided in Table 4.2. All of these projects receive EC funding through the EU Horizon 2020 (H2020) programme, under the INFRAEOSC calls. The projects are grouped by type in the table. As mentioned above, the lists of contributing NRENs have been validated against CORDIS, since many affiliations were missing in the self-reported Compendium data.

PROJECT	PROJECT PROFILE	CONTRIBUTING NRENS
Primary EOSC infrastructure and service projects Several projects exist to deliver the core infrastructure and services to provide the Minimum Viable EOSC. They may be developing new infrastructure, operating services such as AAI, or providing free access to storage and compute.		
EOSC Future [EOSC_Future]	EOSC Future is an EU-funded H2020 project that is implementing the European Open Science Cloud (EOSC). EOSC will give European researchers access to a wide web of FAIR data and related services. EOSC Future runs from 1 April 2021-30 September 2023.	CESNET, CSC/Funet, DFN, GRNET, HEAnet, Jisc, KIFÜ, NORDUnet, PSNC/PIONIER, SUNET, SURF, Uninett
EOSC Enhance [EOSC_Enhance]	Activities to design, develop and improve the functionality of the EOSC Portal, connecting thematic communities to EOSC.	CSC/Funet, GRNET, PSNC/PIONIER
Advanced Computing for EOSC [EGI-ACE]	Advanced Computing for EOSC (ACE) is coordinated by EGI. This project has a mission to empower researchers from all disciplines to collaborate in data- and compute-intensive research through free-at-point-of-use services.	CESNET, GRENA, GRNET, Jisc, SURF, ULAKBIM
Data Infrastructure Capacity for EOSC [DICE]	Coordinated by CINECA, this project offers personal workspaces, data archives, repositories and data discovery services free at the point of use.	CESNET, CSC/Funet, GRNET, SURF, Uninett
EOSC-hub [EOSC-hub] (finished in 2021)	The creation of the framework for a portal through which the EOSC ecosystem can be accessed – ideally all or a majority of the EOSC resources should be accessible through the hub.	CESNET, CSC/Funet, EENet, GRNET S.A., Jisc, SURF, ULAKBIM, Uninett
EOSC Regional Projects Several projects exist in which institutions have come together to create the organisational and technical infrastructure to make their offers available through EOSC; these are bundling regional (in a very wide sense) resources or subject-specific resources. They were funded under the INFRAEOSC 05b strand.		
EOSC Nordic [EOSC_Nordic]	Bundling initiatives from Finland, Sweden, Norway, Denmark, Iceland, Estonia, Latvia and Lithuania	CSC/Funet, NORDUnet, Uninett
EOSC-Pillar [EOSC-Pillar]	Bundling initiatives from Austria, Belgium, France, Germany, and Italy	GARR
EOSC Synergy [EOSC_Synergy]	Bundling initiatives from Spain, Portugal, UK, Czech Republic, Slovakia, Poland, the Netherlands, and Germany	CESNET, FCCN, Jisc, PSNC/PIONIER, RedIRIS
NI4OS Europe [EOSC_NI4OS]	Bundling initiatives from Cyprus, Slovenia, Croatia, Bosnia Herzegovina, Montenegro, Serbia, Albania, North Macedonia, Greece, Bulgaria, Romania, Hungary, Moldova, Georgia, Armenia	ARNES, ASNET, GRENA, GRNET S.A., KIFÜ, RASH, RENAM
Disciplinary clusters NRENs are also active in some of the five disciplinary cluster projects which exist to provide tools and services to specific domains. These were funded under the INFRAEOSC 04 strand and also play a key role in the EOSC Future project.		
PaNOSC [EOSC_PaNOSC]	Collaborations between 6 European Photon and Neutron Research Infrastructures	CESNET
EOSC-Life [EOSC-Life]	Collaboration of 13 European Research Infrastructure in the Life Sciences (ESFRI research infrastructures)	CSC/Funet

Table 4.2: Overview of EOSC-connected projects and NRENs participating in them

The NREN community is well represented in EOSC projects, either in regional and disciplinary clusters, or in the core e-infrastructure initiatives to deliver the portal, and support governance and coordination. The activities they undertake in these projects vary, but include policy analyses, legal studies, procurement, service development, delivering authentication and authorisation infrastructure (AAI) and stakeholder engagement. Seven NRENs also reported that they offer services via EOSC, up from 5 in the 2020 survey.

In addition, GÉANT and the NRENs are active in the governance structures of the EOSC Association[24].

GÉANT was one of the founding members and is represented on the Board of Directors, along with the Finnish NREN CSC/Funet. In the first year of the EOSC Association, HEAnet was also represented on the Board. It is hoped that more NRENs will stand for Board positions in future years, given their engagement in EOSC initiatives. Eleven NRENs (and GÉANT) are Members of the EOSC Association and a further 11 NRENs have been appointed as Mandated Organisations to represent national interests. This is a significant proportion, given that there are only 25 Mandated Organisations in total, reflecting a recognition of their role as national service providers and representation of community interests. GÉANT and the NRENs are also well represented on the 13 EOSC Association Task Forces. Five of the 29 co-chairs[25] and 50 of the members come from the NREN community. Similarly, the NREN community is represented in 12 of the 13 Task Forces (all except Data Stewardship), with higher levels of participation in those Task Forces that are significant to NREN activities, as shown in Table 4.3. Moreover, two NRENs (CSC and Belnet) are participating in the forthcoming EOSC Focus consortium, which is the Coordination and Support Action being led by the EOSC Association from June 2022.

EOSC ASSOCIATION TASK FORCE	NO. OF GÉANT COMMUNITY MEMBERS	TOTAL NO. OF TASK FORCE MEMBERS
AAI Architecture	11	34
Financial Sustainability	7	29
FAIR Metrics and Data Quality	3	26
Infrastructures for Quality Research Software	1	41
Long-term Data Preservation	5	36
PID Policy and Implementation	4	24
Research Careers, Recognition and Credit	1	27
Researcher Engagement and Adoption	4	42
Rules of Participation (RoP) Compliance Monitoring	3	22
Semantic Interoperability	3	44
Technical Interoperability of Data and Services	4	64
Upskilling Countries to Engage in EOSC	4	25

Table 4.3: Overview of GÉANT and NREN participation in EOSC Association Task Forces
A detailed description of the remit of the Task Forces can be found at [EOSC_AG].

[24] The EOSC Association was founded in Brussels on 29 July 2020 as an international non-profit association (AISBL). It is composed of 159 Members and 73 Observers (figures accurate as of 8 April 2022) representing research-performing organisations, service providers and funders. It acts as an umbrella organisation to coordinate the various EOSC initiatives and, as part of the tripartite collaboration with the EC and Member States, provides the legal entity needed to maintain contractual arrangements to make the EOSC ecosystem sustainable. More information can be found at [EOSC].

[25] The EOSC Association Task Force co-chairs from the GÉANT community are Helen Clare of Jisc in the Upskilling Countries to Engage in EOSC Task Force, Christos Kanellopoulos of GÉANT in the AAI Architecture Task Force, Jan Meijer of Sikt in the Financial Sustainability Task Force, Themis Zamani of GRNET in the PID Policy and Implementation Task Force, and Raimundas Tuminauskas of PSNC in the Rules of Participation (RoP) Compliance Monitoring Task Force.

EaPConnect

Eastern Partnership Connect (EaPConnect) [EaPConnect], started its second iteration, EaPConnect2, in 2021, which aims to decrease the digital divide within Europe by establishing and operating a high-capacity broadband Internet network for R&E across six EaP partner countries in the EU's Eastern Neighbourhood: Armenia, Azerbaijan, Belarus, Georgia, Moldova and Ukraine[26]. Part of the role of EaPConnect is to support the deployment of eduroam and to stimulate the integration of GÉANT services generally. The project will also facilitate the participation of local scientists, students and academics in global R&E collaborations.

EaPConnect2 partners – in addition to the NRENs of the six partner countries (ASNET, AzScienceNet, BASNET, GRENA, RENAM, URAN) – are DFN, EENet of Harno, GARR, GRNET, LITNET, PSNC/PIONIER, RoEduNet and SURF, who provide extra support and expertise.

BELLA

Building the Europe Link with Latin America (BELLA) [BELLA] is the project to deploy a submarine cable between Europe and South America to satisfy the long-term interconnectivity needs of European and Latin American research and education communities. BELLA resulted in a long-term Indefeasible Rights of Use (IRU) for spectrum between the two regions and deployed a 100 Gbps-capable research and education network across Latin America.

The BELLA programme is being implemented by a Consortium of the Regional Research and Education Networks (GÉANT/Europe and RedCLARA/Latin America) and the NRENs of Brazil, Chile, Colombia, Ecuador, France (RENATER), Germany (DFN), Italy (GARR), Portugal (FCCN) and Spain (RedIRIS).

BELLA receives funding from the European Union through the Horizon 2020 programme. The Bella-S1 project, which involved 30 NREN members of GÉANT, finished 31 December 2021.

PRACE

The Partnership for Advanced Computing in Europe (PRACE) [PRACE] is a project and an organisation which organises the access to supercomputing capacities among 25 European Union Member States. PRACE creates a pan-European supercomputing infrastructure, through which users can access computing and data management. PRACE systems are available to scientists and researchers from academia and industry globally. The NRENs ACOnet, CSC/Funet, DeIC, GRNET S.A., IUCC, KIFÜ, PSNC/PIONIER, SURF and Uninett are partners in PRACE.

PRACE project partners have received, or are receiving, EC funding through a number of implementation projects. The current project is the 6th PRACE Implementation Phase Project, which runs until 30 June 2022.

EuroCC

The EuroCC project will set up a network of National Competence Centres in HPC across Europe in 31 participating, member and associated states [EuroCC]. The objective of the EuroCC project is to create an infrastructure for the access to high-performance computing (HPC), high-performance data analytics (HPDA) and artificial intelligence (AI) in the participating countries. High-performance computing is the ability to process massive data and perform complex calculations at high speed to solve large problems in science, engineering and business.

[26] BASNET, the Belarusian NREN, was suspended from the EaPConnect2 project in March 2022.

ARNES, CSC/Funet, GRNET, KIFÜ, Sikt and SURF are partners in EuroCC[27]. The EuroCC project is funded 50 per cent through H2020 (EuroHPC Joint Undertaking JU) and 50 per cent through national funding programmes within the partner countries. EuroCC will run until 31 August 2022.

EuroHPC JU

The European High Performance Computing Joint Undertaking (EuroHPC JU) [EuroHPC_JU] is a joint initiative between the EU, European countries and private partners to develop a world-class supercomputing ecosystem in Europe. As a Joint Undertaking, the EuroHPC JU administers its own work plan and distributes funding accordingly. Grant funding falling within the Connecting Europe Facility (CEF) programme requires appropriate co-funding levels from EU Member States. To GÉANT and NRENs, generally being funded through Framework Programme grants (such as H2020 in the past and Horizon Europe between 2021 and 2028), this constitutes a new way of working. EuroHPC JU is to deliver the supercomputing ecosystem for Europe, which includes the aim of hyperconnectivity (terabit connectivity) across all 27 EU Member States, as well as a solution for AAI. Five NRENs are involved in the infrastructure advisory group (INFRAG) of EuroHPC (CSC/Funet, PSNC/PIONIER, Sikt, SURF, ULAKBIM). However, EuroHPC includes a multitude of projects and Member State participation, and contributions are still being defined, making it difficult to state exactly which NRENs are involved at this point in time[28]. EuroHPC hyperconnectivity requires connectivity to and from the designated HPC centres in Europe. This will involve the GÉANT network and the networks of the relevant NRENs. These efforts are orchestrated in the monthly EuroHPC NREN coordination meetings held between GÉANT and the NREN community.

4.2. Summary

The diversity of EC-funded projects presented in this section and the large number of NRENs that participate in them show that the community is very active at the European level. Through their participation, NRENs are shaping Europe's digital infrastructure on many levels, providing expertise and insights coming from their day-to-day business as service providers to the R&E community. This is underlined by the widespread participation of NRENs in the projects related to the European Open Science Cloud. Indeed, several NRENs play roles in multiple EC-funded projects. The involvement in PRACE and in other high-performance computing projects such as EuroHPC is also pertinent, as this is seen as a growing area of relevance.

A programme of coordination meetings and infoshares has been underway since 2019 to support NREN engagement and alignment in EOSC, and a similar series was initiated on EuroHPC in 2021. These continue, and current priorities, such as the procurement calls, are being discussed. In addition, the transition from GÉANT as the pioneer that paves the way in these new areas to NRENs increasingly taking the lead is now being seen. NRENs are growing their involvement in projects and are taking on more roles in EOSC governance, such as Board director and Task Force chairs and members

[27] In addition to the direct involvement of NRENs, organisations that are closely associated with local NRENs are partners in EuroCC, e.g. TUBITAK (Turkey) and FCT (Portugal). The direct involvement of NRENs in the European HPC infrastructure will grow in the coming years.
[28] EuroHPC is the effort for developing pre-exascale and exascale computers. PRACE, while also about supercomputers, is a project that runs a system to share the use of existing computing facilities.

5. NETWORK

At the core of each NREN's work is its network; interconnecting users and making the delivery of services possible. Networks are not uniform; they are composed of a broad spectrum of infrastructure and communications technologies.

NREN networks, like the countries in which they reside, are unique and tailored to fit the community they serve, within the limits of the resources at their disposal. This section presents an overview of NREN network traffic, infrastructure, and services.

5.1. Network Traffic

This section considers the rate of growth of NREN traffic, and how the traffic type and destination have changed over time. Figure 5.1 shows the total amount of traffic into the NRENs from NREN end users (upper graph) and from external networks (lower graph) for 2019 to 2021. While these figures are only representative of a subset of NRENs, the developments visible in the graphs are indicative for NRENs as a whole. The yearly two-digit growth rates of traffic coming from NREN users (mostly from universities and research institutes) continue a long-standing trend that suggests a doubling of this traffic within approximately 5 years. Interestingly, this trend is broken in the traffic coming from external networks, which very likely reflects the effect of the COVID-19 pandemic and the resulting shift to working and studying from home.

Naturally, the absolute contributions to these figures differ considerably between NRENs, as can be seen in Figure 5.2. At the extremes are Jisc, with about 670,000 Tbytes of data from outside the NREN, and RASH, with just 219 Tbytes. The volume of traffic is driven by several factors, including the size of the country, the quality of their R&E infrastructure and the geographic position, which makes some countries natural traffic hubs. Therefore, NRENs from large, well-developed countries such as Germany, France and the UK carry a lot of traffic, though clearly this is not the only factor here, as the order does not neatly follow country size.

Overall, the volume of traffic that NRENs carry continues to rise (despite the pandemic dip). Out of the 26 NRENs that provided traffic numbers, 16 reported an increase in traffic (at the top here was Belnet, reporting an increase in overall traffic of 205%) while 5 NRENs (HEAnet, GARR, GRNET, RedIRIS and ULAKBIM) reported decreases.

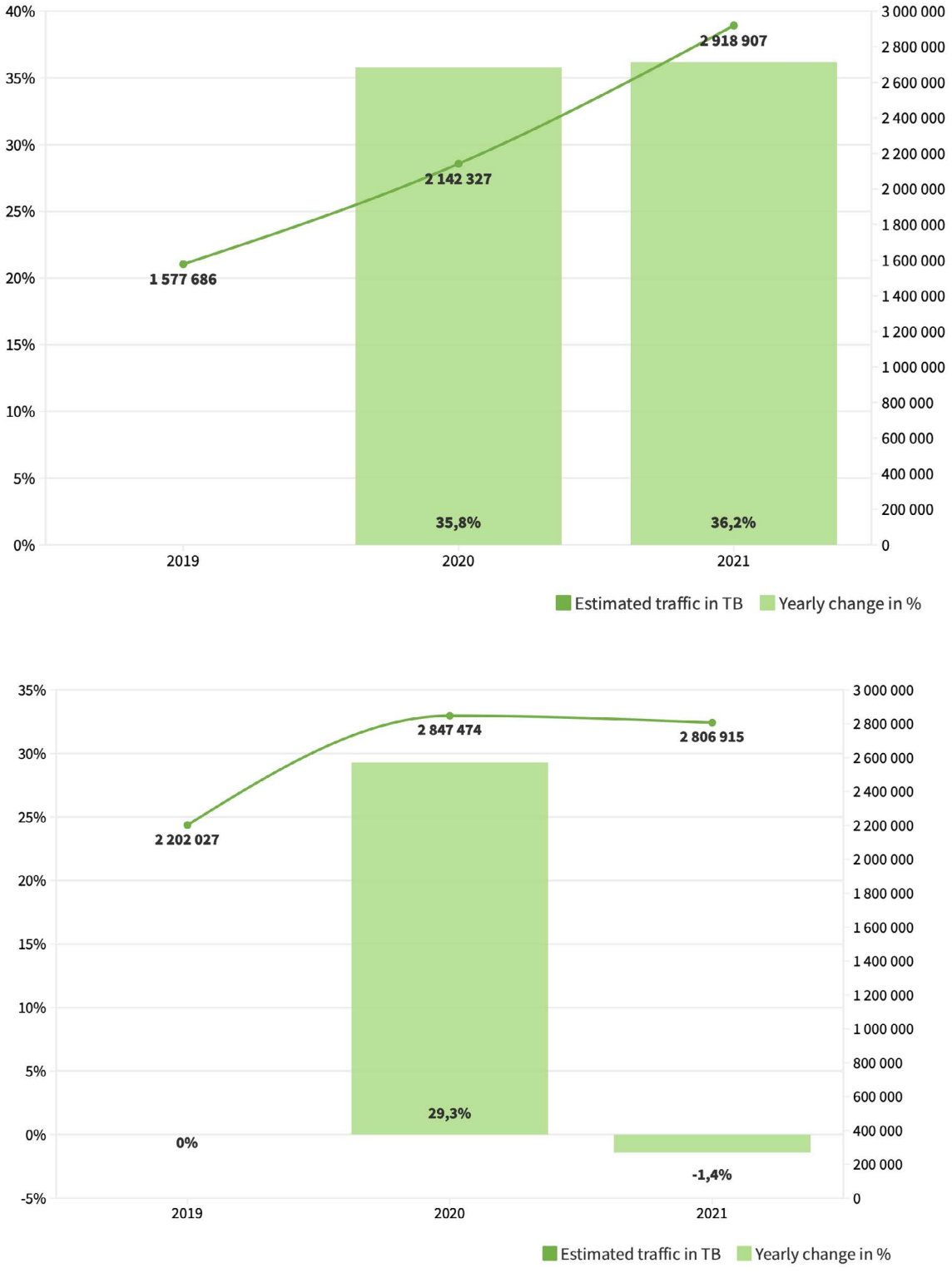

Figure 5.1: Increase of traffic into the NRENs from NREN end users (upper panel) and external networks (lower panel) 2019 to 2021

"External networks" denotes sources that are outside the NREN's domain, such as GÉANT, general/commercial Internet, Internet exchange, peerings, other NRENs. "NREN customer" denotes sources that are part of the remit of an NREN's domain. The figures are based on traffic data from 19 NRENs for which there are continuous traffic records from 2019 to 2021 (BASNET, Belnet, CARNET, CESNET, DFN, FCCN, GARR, GRENA, GRNET S.A., HEAnet, Jisc, RASH, RedIRIS, RENAM, RENATER, RESTENA, SURF, SWITCH, ULAKBIM).

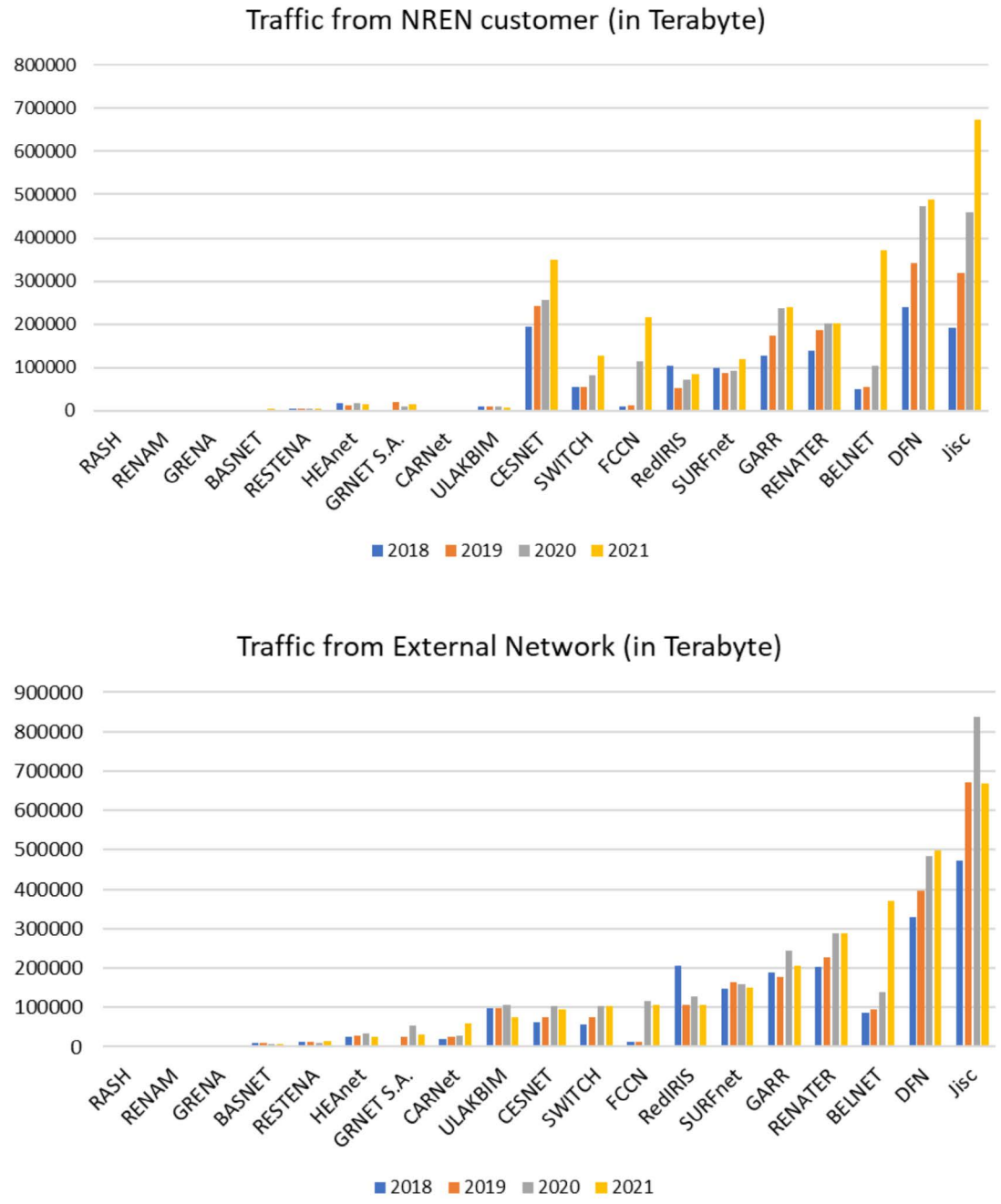

Figure 5.2: Traffic per NREN from NREN end users (upper panel) and external networks (lower panel) 2018 to 2021
The figure shows all NRENs that reported their traffic volumes in the 2021 survey; where available, data from the years 2018 to 2020 are shown as well. As in the previous figure, "External network" denotes sources that are outside the NREN's domain, such as GÉANT, general/commercial Internet, Internet exchange, peerings, other NRENs. "NREN customer" denotes sources that are part of the remit of an NREN's domain.

5.2. Traffic Growth Forecast

Since 2017, the Compendium survey has asked NRENs to provide an estimate of the growth in their traffic, by institution type, over the coming three years[29].

NRENs expect traffic to grow in the medium term: all 31 NRENs that provided estimates expect traffic growth over the three years 2022 to 2024, 13 of them by more than 50%, across all organisations within their remit. The highest growth is expected to come from schools (which are divided into primary and secondary schools, with an anticipated growth of 80% and 83%, respectively) (see Figure 5.3). The traffic for the core users of all NRENs, universities and research institutes, is expected to grow by 69% and 72%, respectively.

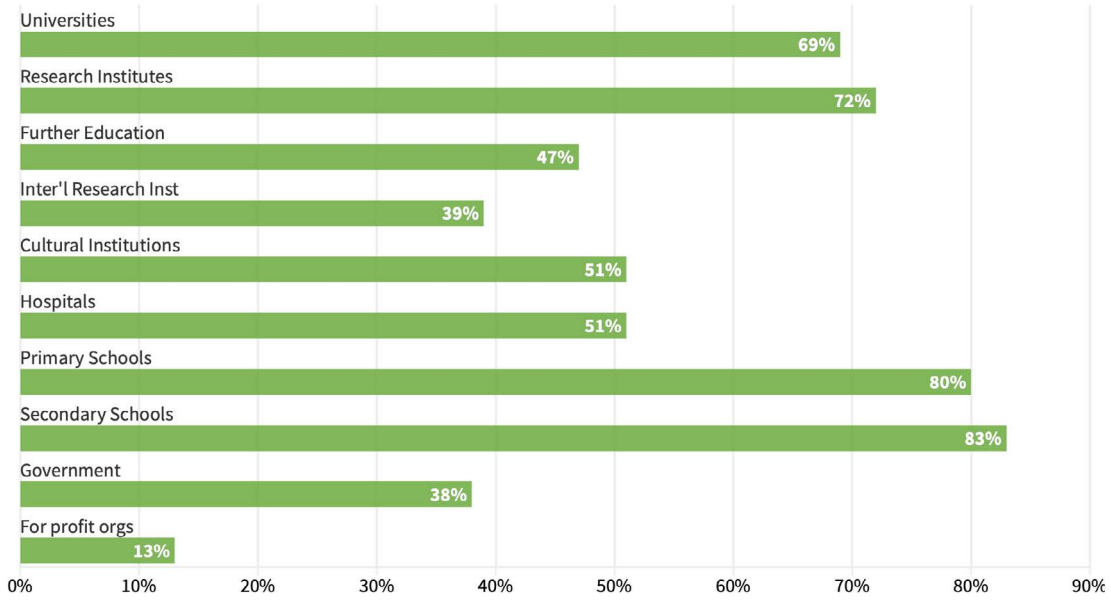

Figure 5.3: NRENs' forecast traffic growth for the years 2022 to 2024, by institution type
(Based on 31 responses). Note that these forecasts were made in 2021 and therefore likely include the effects of COVID-19.

The continued traffic growth in the research sector, especially from research institutes, reflects the accelerating trend of data digitalisation and possibly the increasing role of centralised research facilities. The anticipated high growth rate in the school sector similarly reflects the increased use of digital resources, a trend accelerated by the COVID-19 pandemic. The traffic growth rate forecast in other categories is lower, but still significant. Note, however, that these growth numbers are percentages – the absolute expected growth in the volume of traffic is vastly bigger for universities and research institutions than it is for schools, the latter having much more modest needs.

Table 5.1 below gives an overview of the expected growth in traffic over the three-year period 2022 to 2024, by NREN, and by institution type.

[29] Projections like these are of course an important tool as they provide the foundation for determining how much investment in the network infrastructure will be needed.

	Universities	Research Ins.	Further Education	Inter'l research Inst	Cultural Institutions	Hospitals	Primary Schools	Secondary Schools	Government	For-Profit Orgs
ACOnet	100	75	70		50	50	100	100	50	
AMRES	90	90	90		90	90	300	300	30	
ANA	40	30	20		10				10	
ARNES	20	50	1	10	15	15	20	20	15	10
ASNET-AM	80	80		20	40				30	
AzScienceNet	100	100			100					
Belnet	150	150	100	100	150	200	100	150	150	100
BREN	5	5								
CARNET	30	30	40		20	30	40	40	30	50
CESNET	20	20	15	10	20	20	15	15	10	
CYNET	30		10							
DelC	120	100	100	100	50	200			50	
EENet	10	50	10		5		10	10	10	
FCCN	50	50		20				20	50	
Funet	30	50			30				50	
GARR	100	100		100	50	100	100	100	20	
GRENA	60	60		60	60	60		60	60	
GRNET S.A.	50	30	40		10	200	500	500	40	
HEAnet	10	20	10							
IUCC	50	30			30					
Jisc	100	100	100	50	50	50	100	100	50	50
KIFU (NIIF)	200	200	200	20	200	100	200	200	100	
MARnet	100	100								
MREN	100	50			50				50	
RedIRIS	60	60	60	10	30	30	60	60	30	
RENAM	10		10			10				
RENATER	220	400	220	400	220		220	220		
SANET	70	60	50		60	40	40	50	40	40
SUNET	45	75	40		15	1				
SWITCH	35	35	35	35	35	35	35	35	35	35
ULAKBIM	100	80			50				80	

Table 5.1: Forecast traffic growth by NREN and institution type for the years 2022 to 2024

5.3. IPv6

Internet Protocol version 6 (IPv6) [Ipv6] is the most recent version of the Internet Protocol (IP), the underlying network protocol used by all applications and devices that communicate over the Internet.

With the IPv4 address space exhausted, the adoption of IPv6, with its significantly larger 128-bit addressing, is very important to facilitate the future growth of the Internet and support the availability of globally unique IP address space for tens of billions of devices.

Having first been published as an IETF standard back in 1995, the core IPv6 specification was republished as a full Internet Standard, RFC8200, in 2017, confirming its high degree of technical maturity and a widely held belief that it provides significant benefit to the Internet community. IPv6 is usually deployed to run in parallel with "traditional" IPv4 networking, a

model known as "dual stack". Sites therefore do not need to remove IPv4; they can initially benefit by running dual stack, particularly on their public-facing services.

The deployment of IPv6 among networks around the world is geographically very uneven, reaching more than 50% in some places (e.g. India) but usually being much lower. The R&E networks have a higher rate of deployment on their backbone networks, with at least 85% of NRENs carrying IPv6 traffic, while the GÉANT backbone network is also fully IPv6-enabled.

IRU

Indefeasible Rights of Use (IRU) is the long-term lease of fibre (generally dark fibre when it comes to NRENs, though it can technically be about other communication systems) that cannot be undone (hence "indefeasible"). With an IRU, the NREN essentially becomes the owner of the fibre for the duration of the contract, which is almost always long term, 10 years or longer (the current median among NRENs is 15 years). An IRU owner needs to cover operating and maintenance costs for the duration of the lease, which makes this a long-term commitment of capital.

Overall, around 35% of Internet traffic is IPv6, based on a variety of measurements from different sources such as the Asia Pacific Network Information Centre (APNIC) and Google, which can be found at the World IPv6 Launch site [WIPv6LM]. The past three to four years have seen a shift where commercial IPv6 Internet traffic has significantly overtaken NREN IPv6 traffic, as the commercial ISPs and content providers have adopted IPv6 and the campuses and networks connected to GÉANT's NRENs generally have not[30]. Therefore, with IPv6 widely available in R&E backbones, the challenge now is to see its deployment grow on campuses.

That said, R&E networks have recently started to show some substantial increases in traffic using IPv6. In April 2018, the GÉANT network was transferring an average of 20 Gbps of IPv6 traffic (approximately 6% of total traffic); 12 months later, this had increased to an average of 110 Gbps or 22% of total traffic – a five-fold increase. The average for the year to March 2022 showed 119 Gbps of IPv6, representing 25% of the total traffic, a smaller increase, but an increase nonetheless. The peak IPv6 traffic was over 300 Gbps, and the level is getting closer to the worldwide average.

Figure 5.4 shows the IPv6 traffic average into GÉANT from its partners for the year to March 2022. The traffic is reported by NREN, which hides the origin of the traffic; five NRENs source more than half the incoming IPv6 traffic to GÉANT. The CERN experiments, where the Worldwide Large Hadron Collider Computing Grid (WLCG) has set a policy to dual-stack its sites around the world, have 83% of their Tier2 storage sites IPv6-enabled [CERN_IPv6], and well over 50% of transfers are using IPv6. While CERN itself sources significant volumes of IPv6, the large majority is sent via the LHCOPN optical circuits directly to the Tier 1 sites, so this is not seen on the GÉANT IP backbone. The ultimate aim for the WLCG is to move to IPv6-only.

GÉANT believes that flagship examples of IPv6 deployment such as the WLCG will bring benefits to the community and help spread best practices to ensure the sustainability and robustness of the networking infrastructure.

[30] This is likely due to IPv6 being most widely deployed to date in mobile and residential ISP networks, rather than enterprises, which is the area NRENs serve by connecting their member campuses.

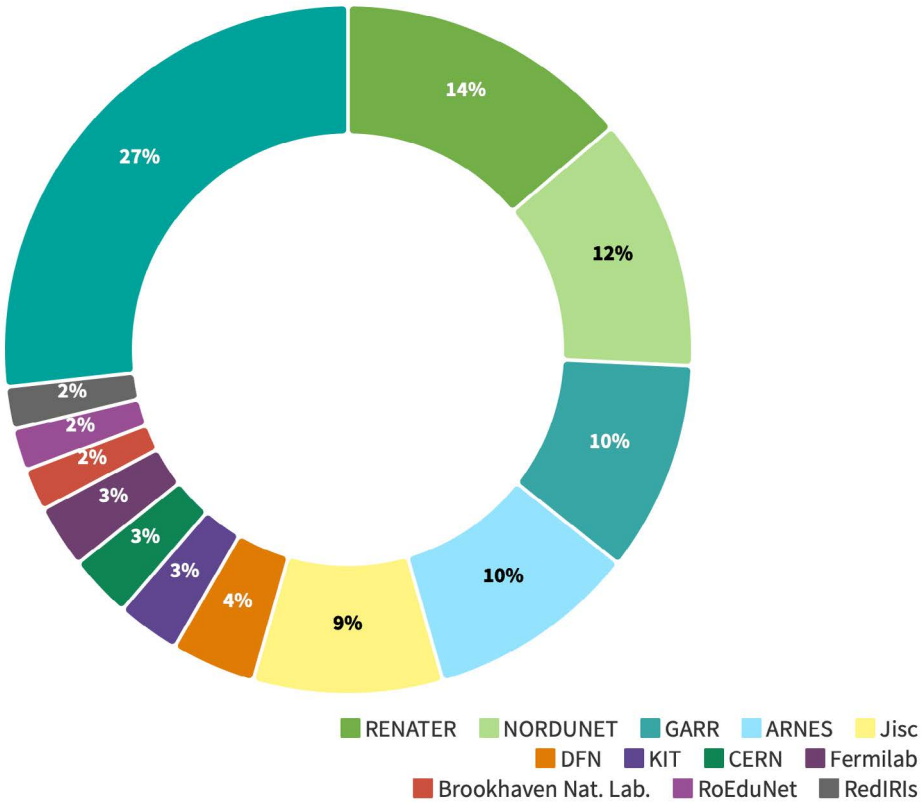

Figure 5.4: Top 12 GÉANT IPv6 traffic sources between March 2021 and February 2022
The total IPv6 traffic for this period was 119 Gbps, which represented 25.2% of all traffic [Source: GÉANT Kentik tool].

5.4. Network Infrastructure: Dark Fibre

Dark fibre refers to fibre optic cable leased or purchased from another supplier in the dark state (i.e. unlit), hence the name "dark" fibre. The fibre is then lit by the NREN using their own equipment (generally dense wavelength division multiplexing (DWDM) transponders and amplifiers). This term is used mostly interchangeably (if not fully accurately) with Indefeasible Rights of Use (IRU) (see textbox).

While not all NRENs use IRUs,[31] as a whole the NREN community has gradually increased its ownership of dark fibre over the years. Changes in IRU use among NRENs are slow, reflecting the considerable costs involved, and the long-term commitment of capital that is required. The increase is documented in Figure 5.5. In 2021, the NRENs reported a total of over 150,000 km of dark fibre. Figure 5.6 below shows the number of kilometres of fibre each NREN reported in its own network. This NREN-operated fibre interconnects with GÉANT's 11,000 km of intercity dark fibre, forming a strong community infrastructure (see Section 5.8 GÉANT Network Updates).

[31] NRENs affirmed their use of IRUs in the Compendium survey, while 8 NRENs stated that they did not use IRUs (BASNET, BREN, CARNET, CyNet, GRENA, LITNET, MARnet, ULAKBIM).

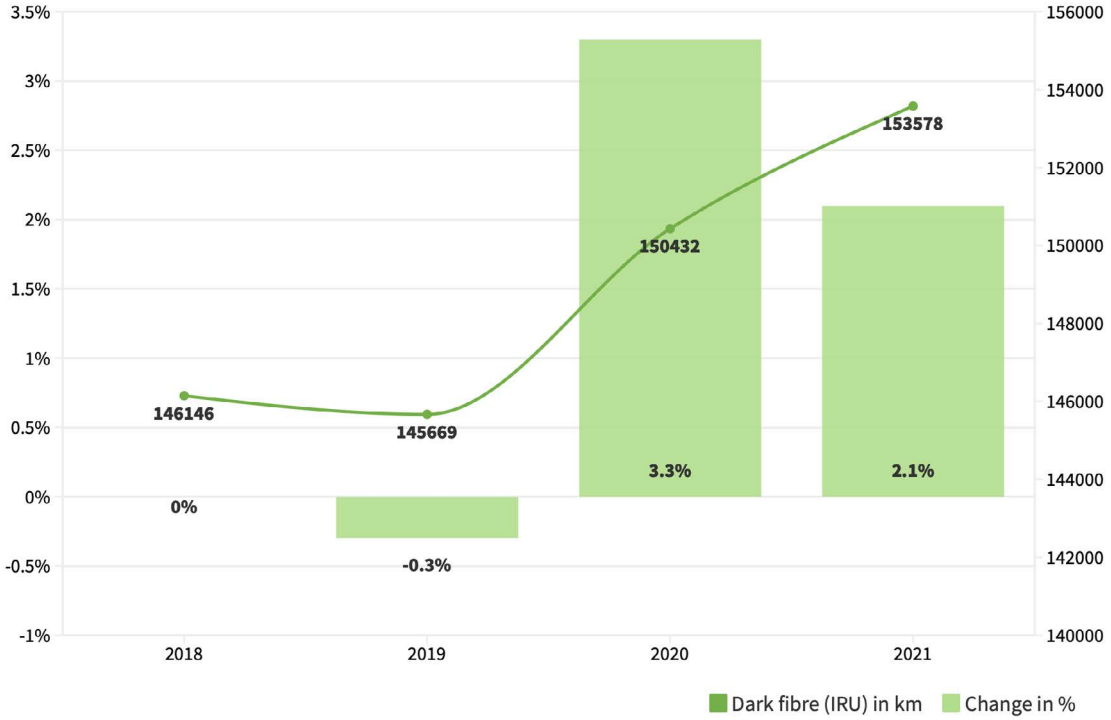

Figure 5.5: Development of the NRENs' IRU networks 2018–2021

To make numbers comparable across the years, the figure shows only the IRUs of NRENs that have provided IRU data in all Compendium surveys from 2018 to 2021. Note the total length of the fibre network is even greater, as only IRUs are counted here, but some connectivity is provided by rented fibres – some NRENs even completely rely on rented connectivity over IRUs (BASNET, BREN, CARNET, CyNet, GRENA, LITNET, MARnet, ULAKBIM).

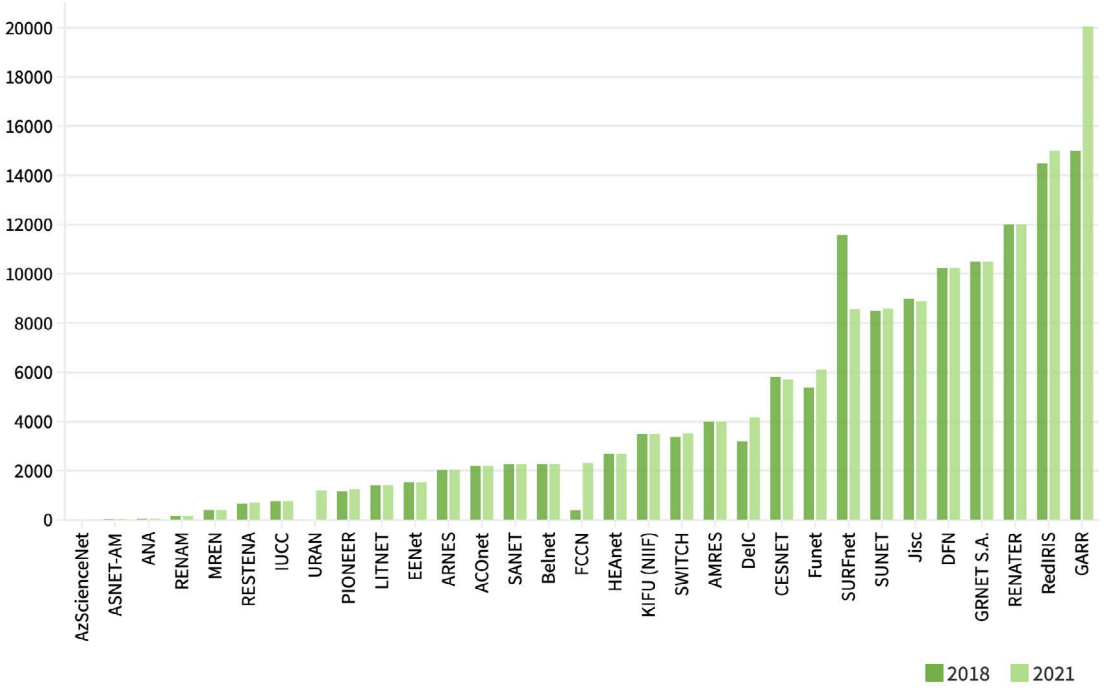

Figure 5.6: Number of kilometres of IRU network per NREN 2018 and 2021

For visual clarity, the years 2019 and 2020 were omitted from the graph. Even so, it is clear that overall, only small changes have taken place, though GARR reported significant additions to their network during this period. The figure shows numbers for all NRENs that reported on their IRU network in the 2021 Compendium survey, i.e. NRENs that reported in previous years but did not do so in 2021 are missing.

5.5. Alien Waves

In the optical network world, the term "alien wavelength" or "alien wave" (AW) is used to describe wavelengths in a DWDM line system that pass through the network, i.e. they are not sourced/terminated by the line-system operator's equipment (hence "alien"). This setup is in contrast to traditional DWDM systems, where the DWDM light source (transponder) operates in the same management domain as the amplifiers.

Alien waves are an important part of infrastructure sharing, as the use of this technology is an important prerequisite for dark fibre spectrum to be shared between multiple research network providers[32]. According to the survey results, 10 NRENs are currently making use of alien waves within their network and 5 are planning to do so. This number has not changed over the last few years: 2020 was still the same as in 2019 and 2018 (15 NRENs), which means that the majority of European NRENs that responded are currently not using this technology[33].

Examples of spectrum sharing currently in use in the NREN community include:

- GARR has adopted alien wave technology since 2017 (namely, an Infinera super-channel over a Huawei backbone) in order to scale up the core backbone and GÉANT links' capacity to multiple 100 Gbps at marginal costs and reduced operational effort.
- NORDUnet has taken steps towards building its entire network using spectrum provided by its local NREN members (DeIC, Funet, RHnet, SUNET, Uninett).
- Planned for 2022, GÉANT will offer a new service in GN4-3 called the Spectrum Connection Service. This service will allow NRENs to inject coloured DWDM light directly into the GÉANT network without the cost of optical–electrical–optical (OEO) conversion at the GÉANT/NREN interface.
- GÉANT will make use of as much NREN spectrum as possible when building the new network in 2020–2022. More details about this can be found in Section 5.8 GÉANT Network Updates below.

5.6. IP Backbone Capacity

Principal data routes, to which customers are connected, are the backbone of an NREN's network. This means that the capacity of the network has to fit the needs of a country's research and education sector. As a consequence, the different capacities of the NRENs' backbones reflect the size of this sector – as well, of course, as factors such as the funding that is available. An overview of the typical backbone capacity of individual NRENs is shown in Figure 5.7.

NRENs that serve a large research and education sector are increasingly using 100G technology to light their fibre. Sixteen NRENs have reported having typical backbone capacities of

[32] The same technology allows the sharing of infrastructure between NRENs and GÉANT that is discussed in Section 5.8 GÉANT Network Updates. This also means the sharing of fibres between NREN networks and the GÉANT network is limited to those networks where this technology is available.

[33] NRENs that use alien waves within their network are: ARNES, CESNET, DeIC, Funet, HEAnet, LITNET, PIONIER, RENATER, SUNET and SURF, while BREN, EENet, GRNET, KIFÜ and RENAM have plans to introduce the technology in the future.

100G or more. Overall, the average capacity of backbones has increased over the years (as can also be seen in Figure 5.7). This is also reflected in the median capacity across NRENs, which has now reached 40 Gbyte/s having hovered around 20 Gbyte/s for the past several years. However, this increase is slow, which reflects that there is a long tail of relatively small NRENs that do not necessarily have the need for high capacities (or, in some cases, might lack the means to achieve them). Also, increases of the typical capacity result from network renewals, which are undertaken only in intervals of several years.

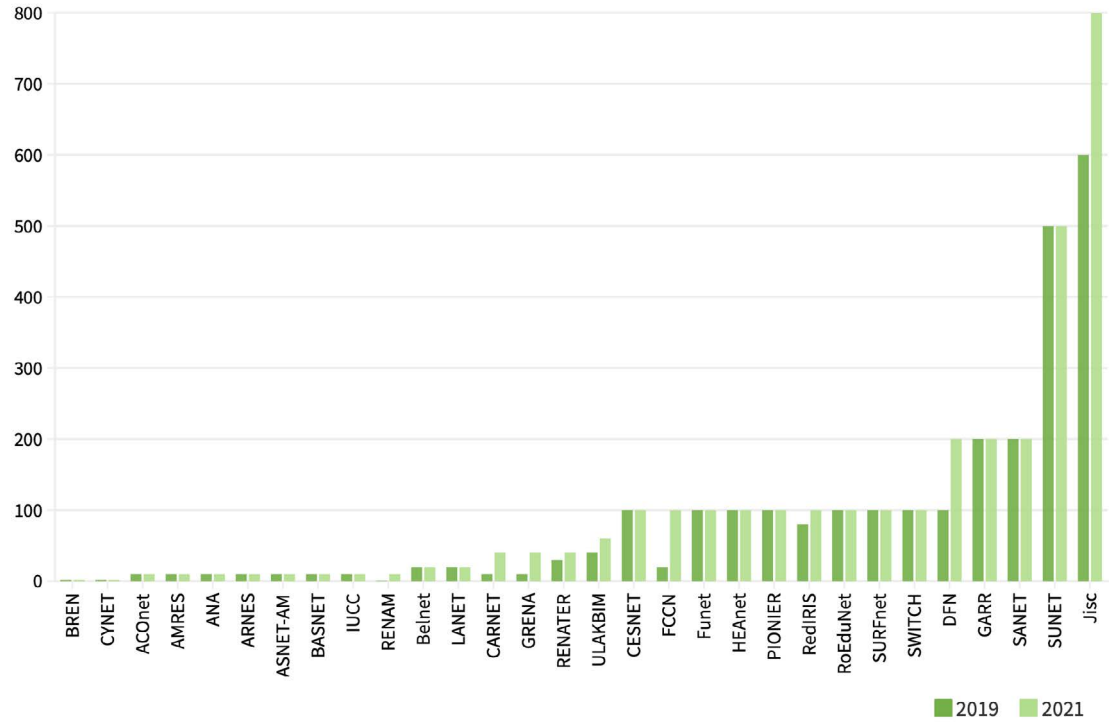

Figure 5.7: NRENs' typical core usable backbone IP trunk in Gbps 2019 to 2021

The figure shows all NRENs that provided data on their trunk capacity in the 2019 and 2021 surveys; NRENs that reported in previous years but did not do so in 2021 are missing. For visual clarity, the 2020 data were omitted from the graph. It is clear that most NRENs' backbone capacity has not changed. However, there are some notable increases: RENAM, CARNET, GRENA, FCCN and Jisc have significantly increased their capacity, and smaller increases have been implemented by RENATER, ULAKBIM and RedIRIS.

5.7. Network Peering

"Network peering" refers to the direct exchange of Internet traffic between two networks. For this to be possible, the two networks need to be physically connected, which often happens via an Internet exchange point (IXP) (public peering), but other arrangements are possible as well, e.g. by a direct point-to-point connection between the two networks (private peering). A peering agreement usually waives any fees for network traffic between the two networks.

Most NRENs have at least some direct peering agreements with commercial networks and content providers. The number of peering networks will also vary according to specific needs. Many NRENs aim to cover general Internet use with their peering agreements and will therefore have peering agreements with large international and regional networks. Some NRENs include academic collaborations with, for example, commercial entities in their peering agreements, which can lead to very large numbers[34].

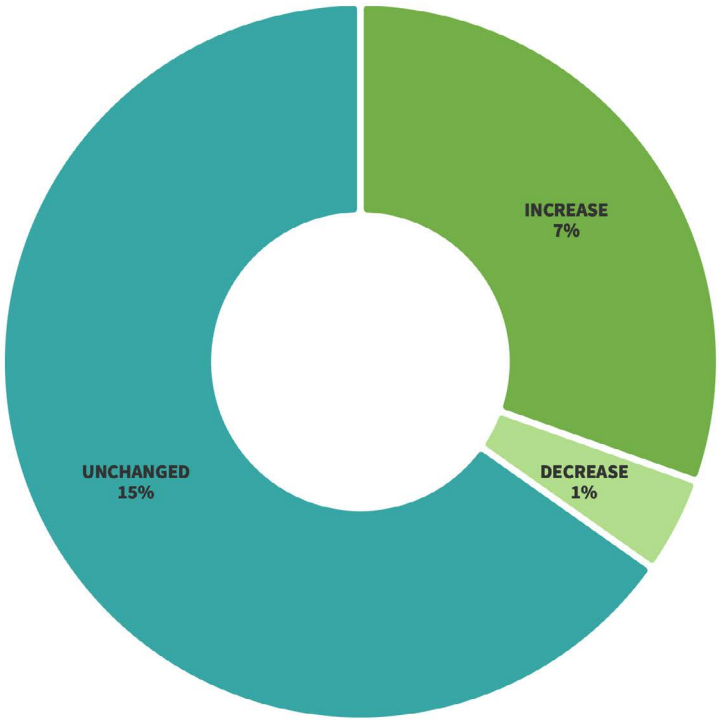

Figure 5.8: Non-R&E network peering development of NRENs 2020 to 2021

In the 2021 survey, of the 24 NRENs responding to this question, 7 reported an increase in the number of non-R&E peering networks, 1 reported a drop, while the remaining 15 NRENs did not see a change in the number of peering agreements (see Figure 5.8). The number of peering agreements per NREN is shown in Figure 5.9.

In terms of absolute numbers, the number of peering agreements across all NRENs has decreased for the first time in years: while it increased from 2,393 in 2018 to 2,615 in 2019, and

[34] NRENs can negotiate peering agreements with any number of networks and some NRENs maintain many such agreements. Another solution that is available to NRENs is peering services provided by GÉANT. In this case, GÉANT has negotiated peering agreements with a number of commercial networks for its members. Some NRENs make use of both options, possibly complementing the more internationally oriented peering possibilities of the GÉANT services with local peering agreements.

to 3,417 in 2020, it has dropped to 2,974. Most of this movement is due do one NREN: SWITCH alone is responsible for more than 50% of any of those changes, with the number of peering agreements jumping from 722 in 2019 to 1,380 in 2020 and then falling back to 836 in 2021. An overview of the changes from 2019 to 2021 is shown in Figure 5.9.

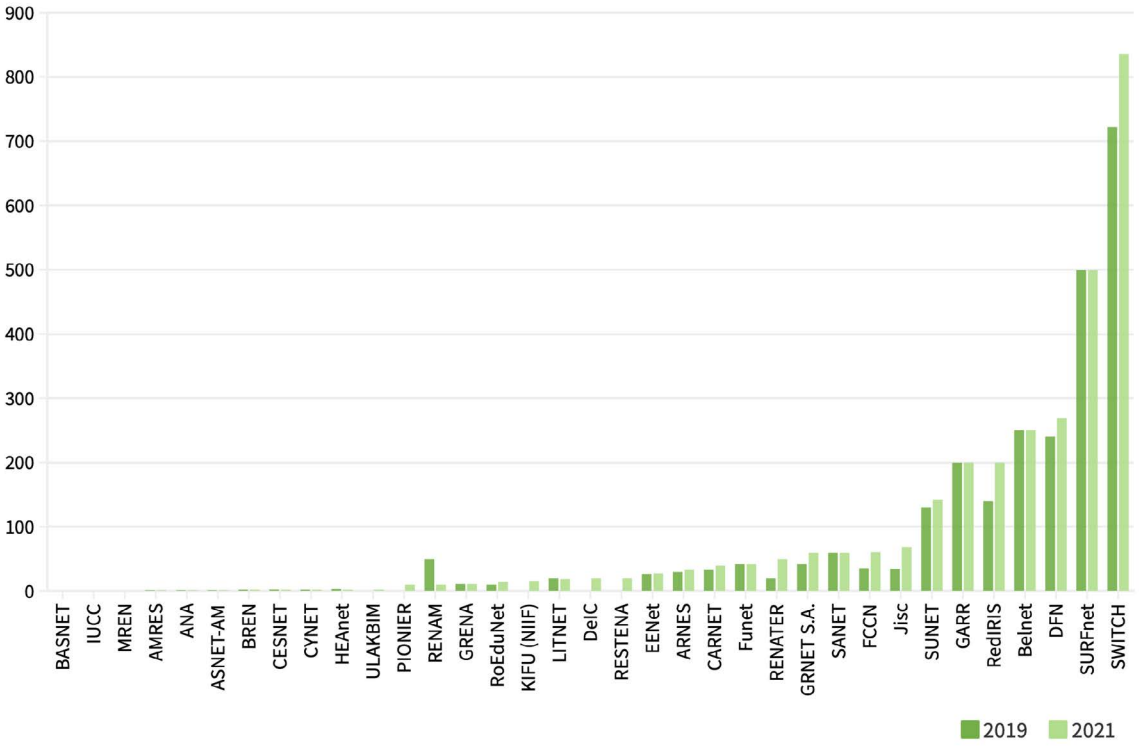

Figure 5.9: Number of non-R&E peering networks 2019 to 2021
The figure shows numbers for all NRENs that reported on their peering agreements in the 2021 Compendium survey; NRENs that reported in previous years but did not do so in 2021 are missing in the graph. For visual clarity, the 2020 data were omitted from the graph. Generally, the number or peering agreements has increased for most NRENs between 2019 and 2021, but in most cases only modestly.

5.8. GÉANT Network Updates

The GÉANT network interconnects 43[35] research and education networks in Europe (a topology map is shown in Figure 5.10) and has 39 active routers and 19 Infinera (DTN-X) transmission nodes. This section presents a snapshot of the GÉANT network, including statistics such as IP/MPLS traffic growth, and an overview of the ongoing network refresh activities as part GN4-3N.

5.8.1. Current GÉANT Network and Statistics

5.8.1.1. Current GÉANT Network Structure

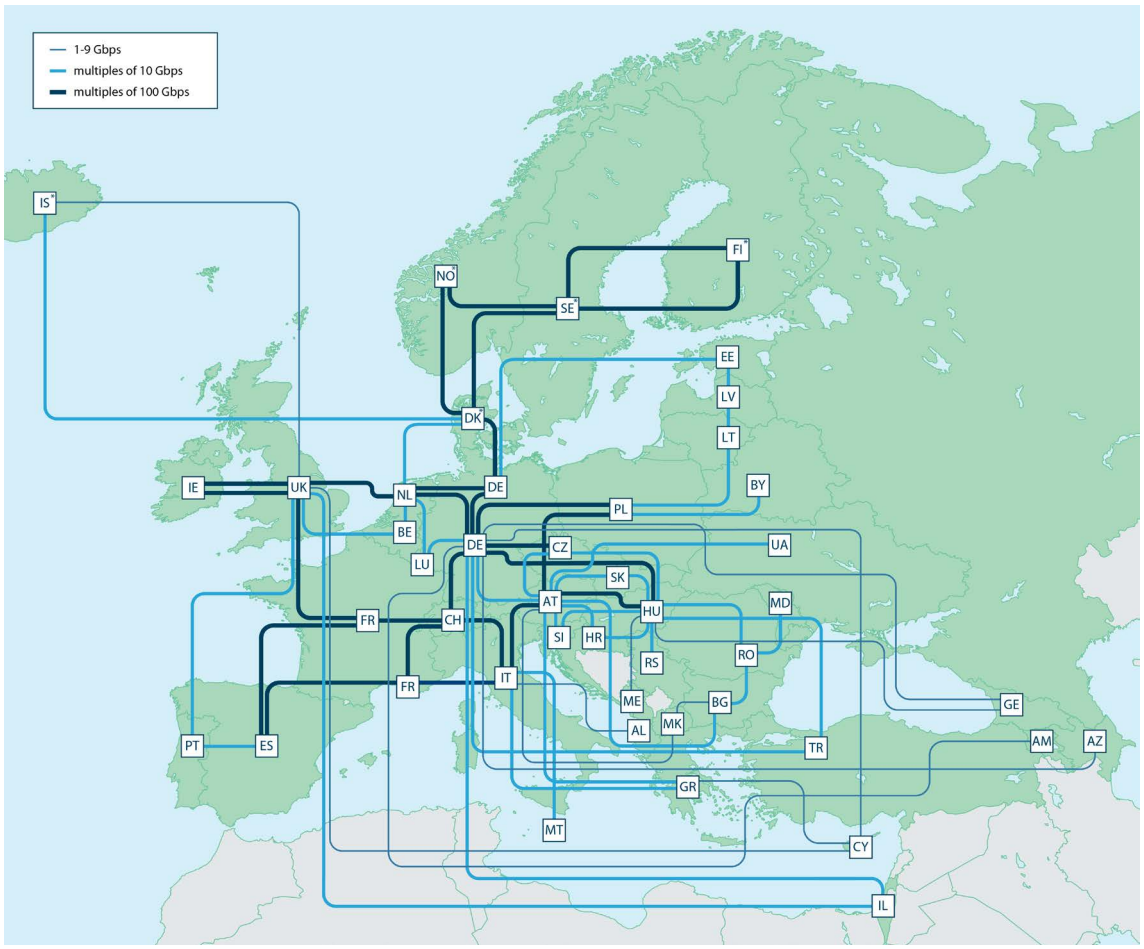

Figure 5.10: GÉANT pan-European network topology map (December 2018).

The GÉANT network is divided into two parts, as shown in Figure 5.11: the Infinera dense wavelength division multiplexing (DWDM) network and the Juniper-based Internet protocol / multiprotocol label switching (IP/MPLS) network [Infinera; Juniper].

The DWDM network runs over dark fibre and provides 10G and 100G capacity-guaranteed, point-to-point connections. These are used either by GÉANT as backbone links for the IP/MPLS network, or are provided directly to NRENs/customers as Lambda services. Consequently, Lambda services are only available where GÉANT-operated fibre exists. With the exception of these Lambda services, all other data services are provided by the IP/MPLS network.

[35] The five Nordic NRENs form their own regional ISP, NORDUnet. It is NORDUnet that is a member of GÉANT, while the Nordic NRENs are associates.

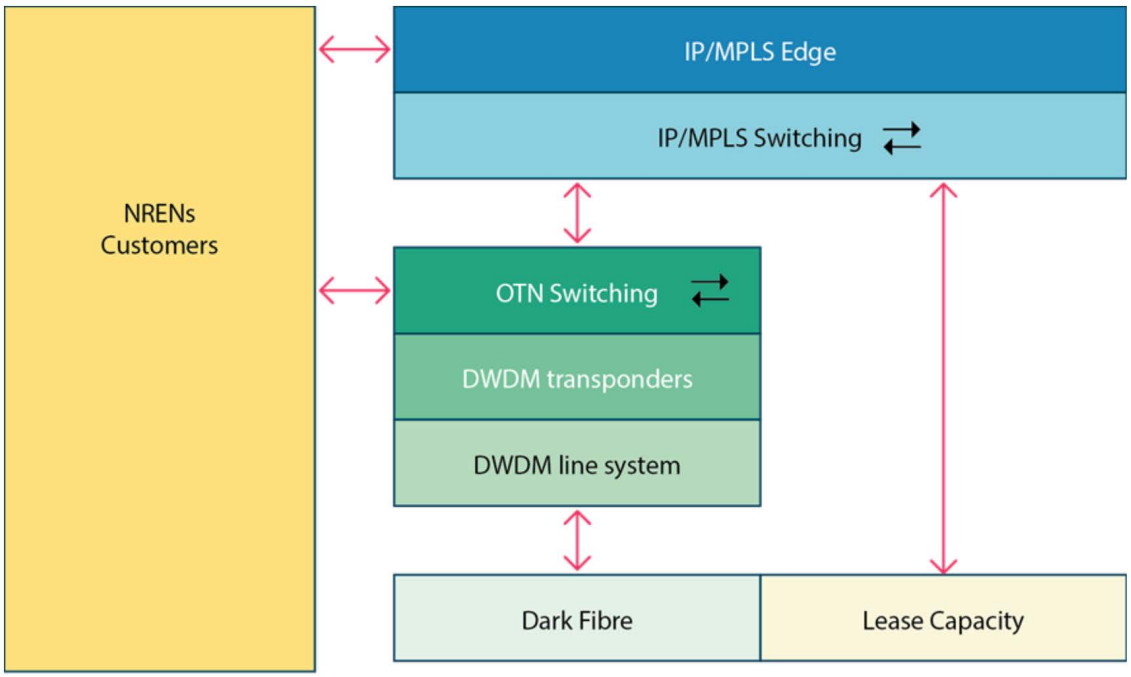

Figure 5.11: The current layered structure of the GÉANT network
The IP/MPLS routing part of the network, provided by Juniper MXs, is shown in blue, while the optical transport network (OTN) / DWDM part, provided by Infinera, is shown in green. The arrows represent demarcation points between building blocks as well as showing the points of interconnection between NRENs/customers and GÉANT.

5.8.1.2. GÉANT Network Statistics

In 2021 the GÉANT network received 2.57 Exabytes of traffic, representing an increase of 9.5% from the previous year's figure. Figure 5.12 shows the year-on-year traffic growth from 2015 to 2021. After continuous growth until 2019, a significant drop in traffic is followed by a sequence of 7 quarters with comparatively low traffic levels. The decline is due, to a large extent, to the impact of COVID-19 and the subsequent move of users from locations where connectivity is provided by GÉANT (universities, research centres, etc.) to residential settings. This assessment is corroborated by the results of the traffic analysis for the major categories of traffic carried by GÉANT, where mostly user-dominated data traffic types have decreased while machine-to-machine traffic, such as LHCONE,[36] has remained relatively strong. The increase of LHCONE traffic during the same time period is shown in Figure 5.13.

However, traffic has grown again in 2021, especially in the fourth quarter, following the lifting of most public health related restrictions. While the total traffic levels for 2021 remain below those seen in 2019, Q4 2021 alone has the highest traffic for any quarter measured so far, possibly reversing this trend.

[36] The LHC Open Network Environment (LHCONE) network is part of the infrastructure that underlies the global collaboration of computing centres that provide global computing resources to store, distribute and analyse the massive volume of physics data generated by the Large Hadron Collider (LHC) experiments at CERN.

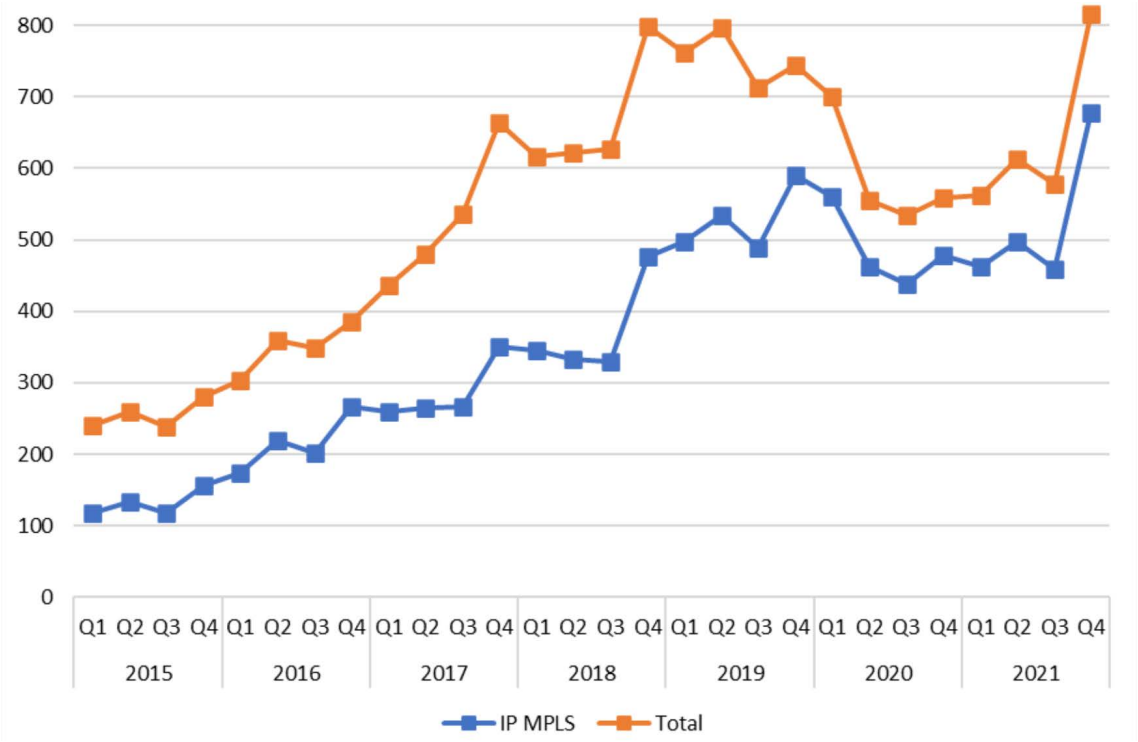

Figure 5.12: Quarterly view of data received by GÉANT (in PetaBytes)
The data were aggregated by quarter, starting from Q1 2015 up to Q4 2022. The difference between IP/MPLS and Total is the traffic carried by 10G and 100G Lambda services.

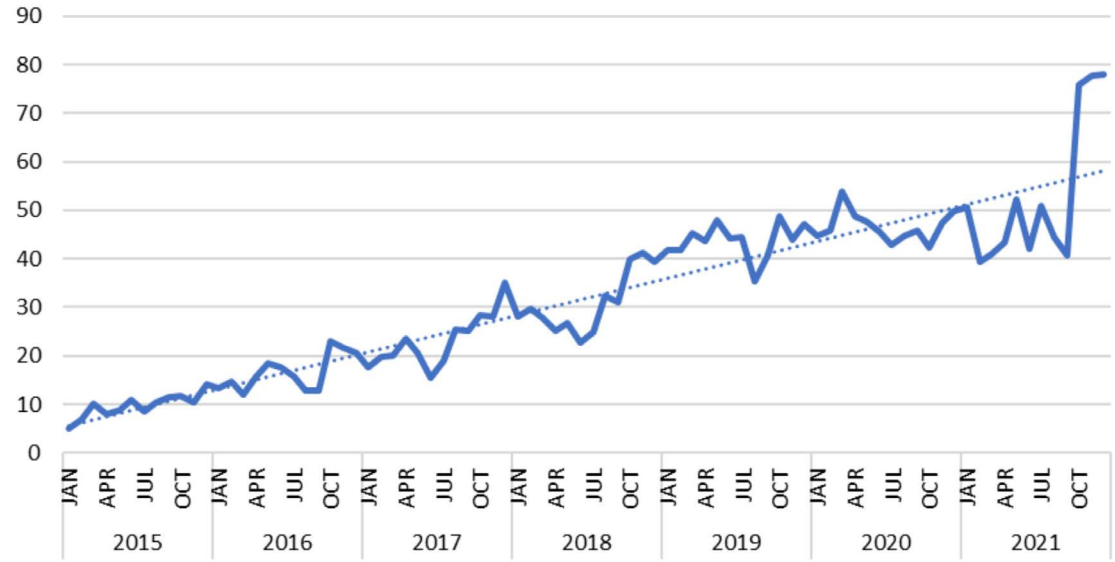

Figure 5.13: LHCONE Traffic in PetaBytes
The figure shows monthly LHCONE traffic from January 2015 to December 2021. The impact of the COVID-19 pandemic on the traffic in this part of the network has been relatively limited, with volumes mostly slightly below trendline. This can be compared with the graph in Figure 5.12, where the impact of COVID-19 on the overall GÉANT traffic is shown.

5.8.2. Evolution of the GÉANT Network

5.8.2.1. Network Topology

As part of the network refresh activity, funded under the GN4-3N project, GÉANT is expanding and bringing long-term stability to its network footprint by acquiring infrastructure on a long-term IRU basis.

The new GN4-3N topology has been developed in close collaboration with the NRENs. The new network footprint will be based in large part on fibre or spectrum (fibre shares) under long-term contracts (15 years or longer), which will connect many areas previously covered by lease capacity (normally procured on short-term contracts of 1 to 3 years).

Figure 5.14 below presents an overview of the progress of GN4-3N as of March 2022, showing the status of completion of the routes that were part of the original reference topology for GN4-3N (original scope).

The number of countries connected directly via GÉANT fibre is planned to increase from 14 to 25+ with dark fibre / spectrum routes doubling in number and tripling in length (see Figure 5.14 for details).

It is important to note that a considerable number of connections planned to be part of the new network will be provided by NRENs, sharing existing infrastructure with GÉANT. This will ensure that GN4-3N funding can be directed towards places where it is most needed and infrastructure duplication is minimised[37]. Full details can be found in the GÉANT Network Evolution Plan [D7.1].

In 2021 a revised reference topology (scope of the project) was approved. This new reference topology sees the addition of 6 new phases as well as improvements to some of the original phases (namely, Phase 8 – Ireland and UK) (see Figure 5.14)

GN4-3N
Together with GN4-3, GN4-3N is the most recent iteration of a series of projects (GN1, GN2, GN3, GN3plus, GN4-1 and GN4-2) that have helped develop the pan-European network of the GÉANT project. The GN4-3N project will restructure the GÉANT backbone network through exploration and procurement of long-term Indefeasible Rights of Use (IRUs), leased lines and associated equipment. It will be the most significant refresh of the GÉANT network in a decade, designed to support the needs of Europe's research and education community for the next 15 years.

Spectum
Spectrum services (or spectrum) are a way to better utilise the capacity of optical fibres. Just as in mobile networks, where network operators use different frequency blocks of the radio spectrum, it is possible to divide the optical spectrum in a fibre network, assigning different frequency bands to different users.
Spectrum provides most of the benefits of a dark fibre without the need for acquiring and running a full dark fibre link. The provider of the spectrum service (usually the owner of the dark fibre) is responsible for running the line system, while the client/customer is responsible for owning and operating the transponders.
Spectrum fills the large gap that exists technically and financially between a dark fibre link and leased capacity.

[37] GN4-3N funding can only be used to cover costs paid to commercial providers. With the use of IRU-type contracts, where a considerable amount of the overall contract costs are paid at the start as capital costs, this means that wherever connectivity can be provided without making use of commercial entities, GN4-3N funding remains available and can be deployed elsewhere, where adequate NREN infrastructure is not available.

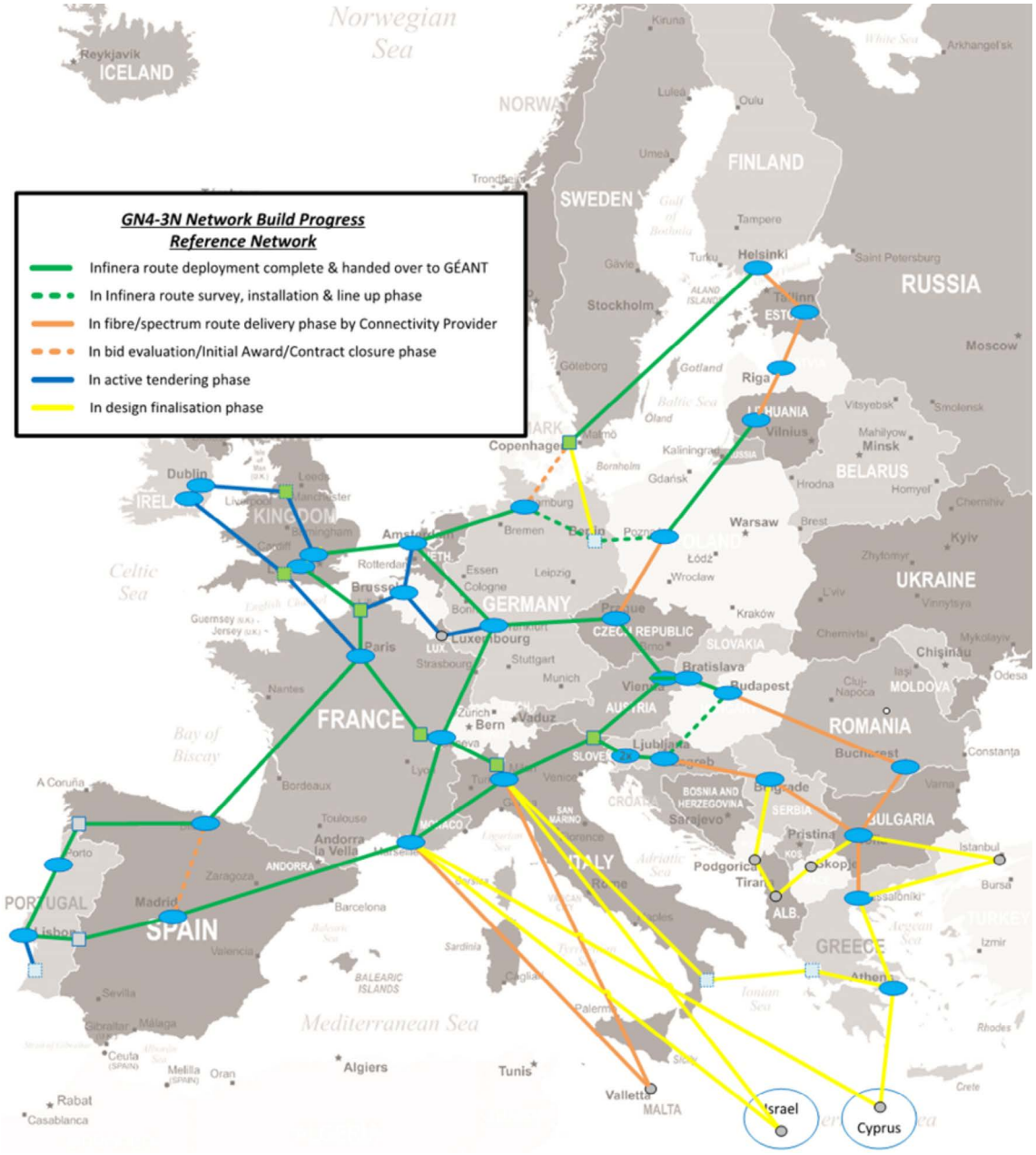

Figure 5.14: A view of the revised reference topology for GN4-3N

The map was revised in 2021, and some of the previously classed improvement projects are now part of the main scope of the project. The map shows only the GÉANT backbone; it does not include infrastructure run by NORDUnet, EaP countries, other projects. The project is divided into Phases, shown by the various colours in this map.

5.8.2.2. Transmission/DWDM

Together with the acquisition of a new fibre/spectrum footprint as part of GN4-3N, GÉANT has recently awarded a contract for the commissioning and provisioning of a new network DWDM system to Infinera.

As part of this contract, Infinera is deploying its most recent open line system (OLS), FlexILS, combined with transponders in data centre interconnect (DCI) form factor.

This new system will replace the existing DTN-X (OTN switching) based system, and will continue GÉANT's transition towards a disaggregated system where the transponders and line system are separate building blocks. This transition will allow GÉANT to manage the two building blocks more efficiently, allowing selection of the "best of breed" for each block, including having multiple vendors.

The new system (shown in Figure 5.15) will also enable GÉANT to share spectrum with NRENs. An activity in GN4-3 is working on defining the parameters of this new service.

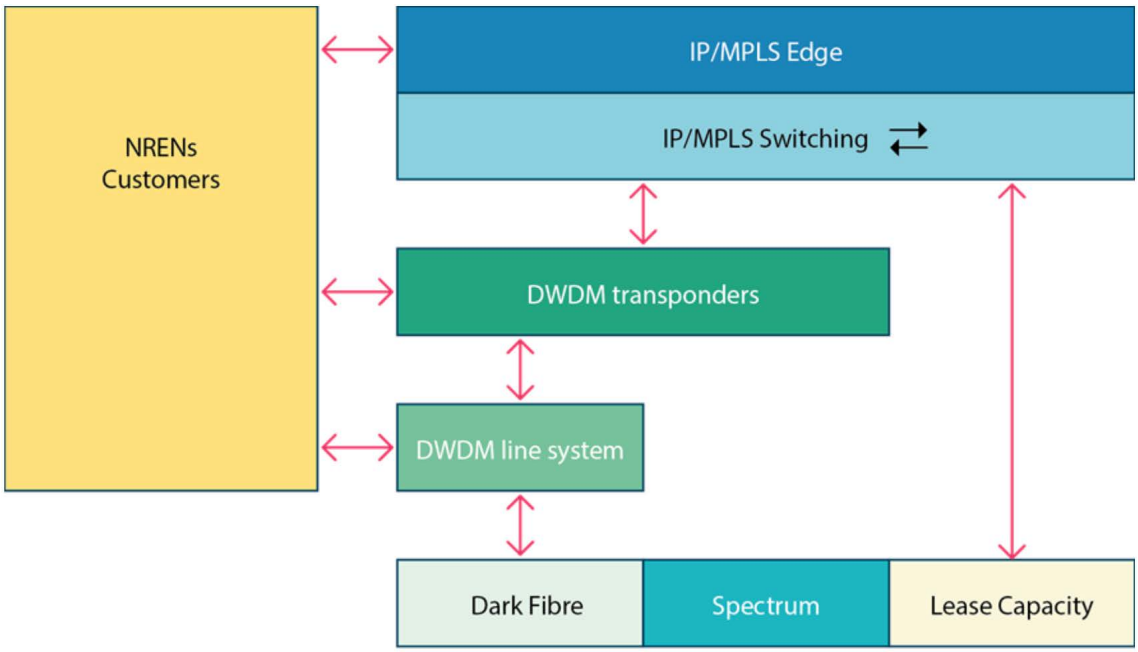

Figure 5.15: Layers of the network as it will be after the transition to a partly disaggregated DWDM system
The three layers are transport, transmission (in green) and packet (in blue). The transmission portion of the network will be composed of only two blocks (OTN switching having been removed), which will be independent of each other. NRENs (and other customers) will be able to connect to either block to access existing point-to-point high-capacity Ethernet services (today, Lambdas) as well as the new upcoming Spectrum Connection Service (when connecting directly to the DWDM line system).

As part of the tendering process for the new network DWDM system, GÉANT has also established a new procurement framework to replace the PRISM framework, which had been in place since 2015. Using the new framework agreement, both GÉANT and the NRENs will be able to procure transmission layer equipment from a selection of vendors under preferential conditions.

5.8.2.3. Packet Layer

A refresh of the packet layer (IP/MPLS Edge and IP/MPLS Switching in Figure 5.15) is not in scope for the GN4-3N project. Any change in this area, therefore, is covered by the regular GÉANT network evolution activities.

Based on the current generation of Juniper MXs, the packet layer has provided GÉANT with a good-value and high-performance IP/MPLS system for the last 8–10 years. With the arrival of 400G Ethernet, however, the current system is starting to show its limits, with a replacement required in 2023/2024.

GÉANT is actively looking at a successor to the current MX platform. A new IP/MPLS platform will be needed to support the connectivity requirements of the largest sites in the longer term. GÉANT is now working on the planning for a significant procurement activity for this part of the network to take place in GN5. Structured market engagement activity has already started and will be ongoing for the next year, with a view to running the procurement in 2022 and expected outcome in early 2023[38].

5.9. Summary

Reflecting the ever-increasing importance of digital services in the R&E world, network traffic is expected to keep growing in the coming years. To allow for the expected traffic growth, network capacity is built based on such estimates so that there is headroom for traffic growth. Also, R&E networks, like GÉANT, are overprovisioned by design, to ensure that bandwidth is no limitation to data exchange or processing and that additional traffic can be accommodated. While the overall increase of network capacity seems modest year on year, some significant updates of individual networks are taking place. Among them is the ongoing update of the GÉANT network, which will not only massively improve the pan-European backbone but also add to the capacity of local backbones.

[38] As shown in Figure 5.12, the COVID-19 pandemic has interrupted the steady increase of R&E traffic. For the GN4-3N project, that meant a windfall as the network renewal could be delayed, meaning in turn that more advanced equipment can be procured.

6. SECURITY SERVICES

Cyber security is a growing issue in any ICT environment and the R&E sector is no exception. As the central providers and enablers of ICT services for the research and education sector, NRENs regard security as a key competency and recently identified security as the number one topic of strategic interest (26th GÉANT General Assembly, 23–24 March 2022). In the past few years, there has been a large number of (successful) major cyber-security attacks on R&E institutions, both universities and research organisations[39]. In most of these cases, the NREN is involved in one way or another in controlling the incident and in sharing information with its constituents to prevent other victims succumbing to similar attacks.

The COVID-19 pandemic caused an even greater dependency on online connectivity with the massive move to online education and remote working. Having a demonstrably trustworthy and secure service becomes inescapable; the stakes are high.

Security for NRENs has two aspects:

- Organisational security. The NREN sits in a hub position among many users. These users could potentially be affected by any lapse in cyber security by the NREN.
- Security services. As service provider and ICT experts, NRENs are also well placed to provide cyber-security services to their customers.

However, the exact role of an NREN in cyber security also depends on the fields in which it operates. Most NRENs limit their activity to the R&E sector and therefore are mainly involved in cyber-security effort concerning the R&E community. On the other hand, some NRENs are also responsible for critical national infrastructure such as the top-level domain (TLD) registry (e.g. Belnet, RESTENA, SWITCH), or the NREN is considered critical infrastructure in itself. The latter is more or less automatically the case when the NREN delivers (networking and other) services to government bodies (e.g. Belnet). Another factor that might have an impact on the reach of an NREN's cyber-security measures is its organisational model: some NRENs are government bodies (e.g. Belnet, FCCN, RedIRIS, Sikt), while others are not autonomous legal entities but part of large organisations, usually universities (e.g. ACOnet, UoM (see also the discussion about funding and governance in Section 2.3).

Such differences are reflected in the way cyber security is dealt with, both in and for the NREN: whether or not ISO certification is needed, what and how many services are provided, the level of contribution in the GN4 project, the available skill set, and the risk of becoming the target of attacks.

The European Union also recognises the need for good security practice and is preparing additional legislation and directives to stimulate and regulate trust in digital infrastructures. This upcoming legislation will also affect research and education. The Network and Information Security Directive (NIS2) is still in the preparation phase and a definitive draft of the proposal is not expected before summer 2022.

Even without an overarching security directive in place, however, there is a growing de-

[39] To give some examples: there have been ransom attacks on the Dutch Research Funding organisation nwo (Feb '21) and Maastricht University (Dec '19), hacktivist attacks on Italian universities (Feb '20), attacks that might have been politically motivated on Polish military universities (June '20) and Belgian political and scientific institutions (May '21). Other published incidents were attacks on Universities in Thessaloniki (May '17), Northumbria/UK (Sept '2020) and Rijeka/Croatia (Nov 2020). It should also be noted that not all incidents become public as the information policies around security issues vary.

mand to show compliance in a number of areas of information security, one example being the General Data Protection Regulation (GDPR), which regulates the processing of sensitive personal information. And while a number of NRENs have already achieved formal security certifications against international standards[40], so far they are a minority (see Figure 6.1).

The data presented in this section illustrate the current efforts of the NRENs in the two broad areas mentioned above: organisational security and security services. The data originate from the NREN Compendium survey, where NRENs provide data about their service portfolio, from GÉANT's Partner Relations team, and from the Trusted Introducer (TI) programme[41].

6.1. Organisational security

The data about the organisational security of NRENs are presented by area – policy, people, threats and operations – in alignment with the security framework laid out in the Security Baseline for NRENs document [D8.2][42].

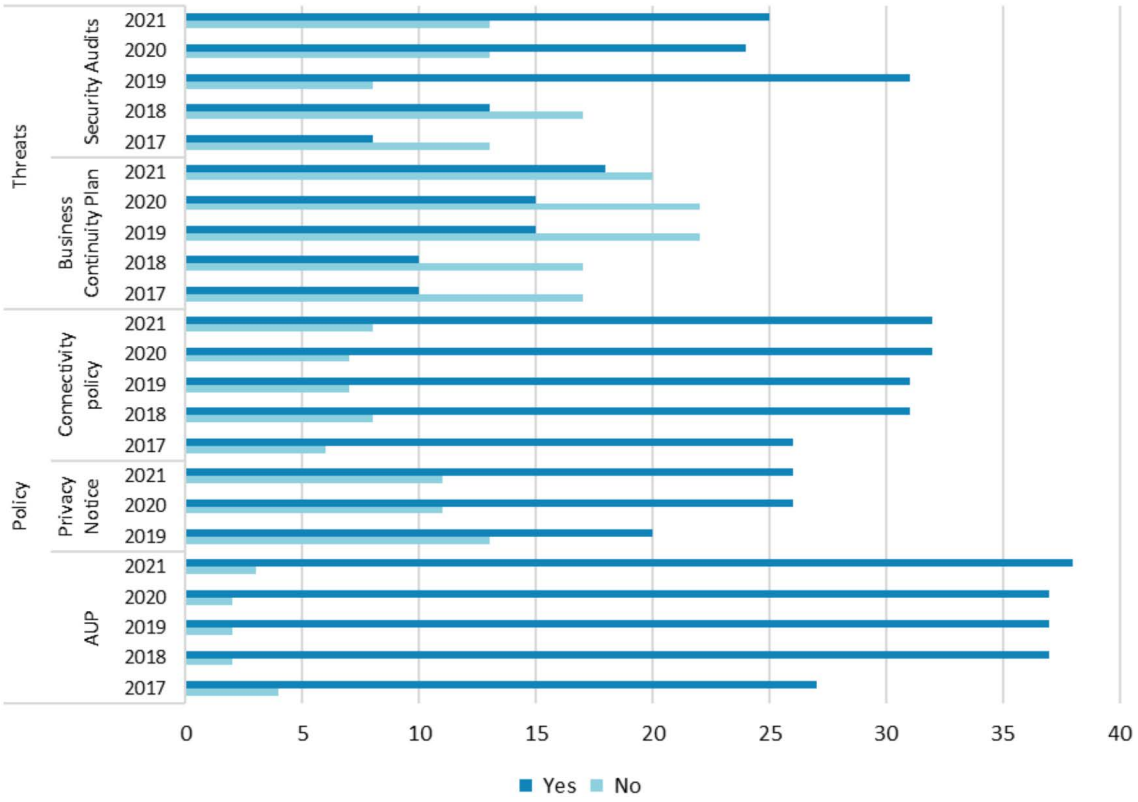

Figure 6.1: Development of the adoption of organisational security features by security area
Not all data are available for all years. The number of surveyed NRENs was 43 for all years. Numbers missing from that count are due to non-responding NRENs. A privacy notice is now a legal requirement but was not in the years before 2018 and was therefore not part of the survey questionnaire.

[40] Certification against ISO 27001 for the whole organisation or for a part of its processes, for example NRENs that also manage a national top-level domain registry. At least 13 NRENs reported having an ISO 27001 certification or are working on it.
[41] Services for security and incident response teams [TI]. The TI programme has a maturity scheme for Computer Security Incident Response Teams (CSIRTs). Teams can be listed, accredited, or certified.
[42] Only some of the sub-topics defined in Security Baseline for NRENs can be assessed using the data available in the Compendium, and only at a limited level of detail, so a full evaluation of NREN security competence is not within the scope of this report.

Policy

An Acceptable Use Policy (AUP) and a Connectivity Policy are important security-related policies. The number of NRENs with such policies has increased since 2017; almost all NRENs have this in place now (see also Section 3.2 NRENs' Acceptable Use Policy).

Another important policy area is the adherence to the GDPR or similar privacy regulations for non-EU countries. Part of the GDPR is the requirement for a Privacy Notice, so this can be taken as an indicator of efforts in this area. In 2021, about 60% of the NRENs stated having a privacy notice and 11 explicitly stated a lack thereof – which seems stable now, in the light of the figures from 2022. That means some NRENs do not yet fulfil this particular legal requirement.

There are of course limitations to these data. The survey only asks for the existence of policies, not details of their content. Nonetheless, the existence of dedicated policies can be taken as commitment to best practice. In that regard, the relatively high numbers are encouraging. Arguably, however, they should be higher (as mentioned above, a Privacy Notice is required by law in most jurisdictions, so the numbers can be expected to change in the coming years as NRENs will catch up with regulations).

People

An important factor with regard to improving IT security is training[43]. Some opportunities are provided by GÉANT, which offers some security training (e.g. TRANSITS, CLAW)[44] which some members are using, but many other training options are available.

Within the framework of the GN4-3 project, research has been done in the training needs for NRENs [D8.1]. As a result, a number of online webinar trainings have been offered, aimed at systems and network administrators. To date, in 27 one-hour online webinars there have been 159 unique participants from NRENs and universities; these trainings are ongoing and NRENs continue to take part.

Threats

Large strides have been made in terms of threat management, where a growing number of NRENs operate a Security Operations Centre (SOC) function or are preparing to do so. In 2020, 10 NRENs reported using SOC / Security Information and Event Management (SIEM) tools for operating a SOC. Most NRENs have some kind of security audit of their organisation (often according to international security standards such as ISO 27001) and most (33 out of 43) also have a Computer Security Incident Response Team (CSIRT) (see Figure 6.2). The number of certified teams (10) has not grown in 2021. This may partly be caused by the pandemic, as getting certified can involve a full-day on-site workshop, which was more complicated due to restrictions in international travel. Those NRENs that do not have a CSIRT usually have this function covered by closely associated organisations.

[43] Unfortunately, there are no numbers available that would document how NRENs make use of training opportunities.

[44] TRANSITS are courses designed for Computer Security Incident Response Team (CSIRT) personnel which are offered regularly but they are not limited to NRENs. The material used in these courses is freely available on an open-source licence which enables other providers to offer equivalent courses [TRANSITS]. However, it is not possible to track how many NRENs participate in such courses. CLAW is an annual workshop on crisis management for NRENs, which has taken place since 2017.

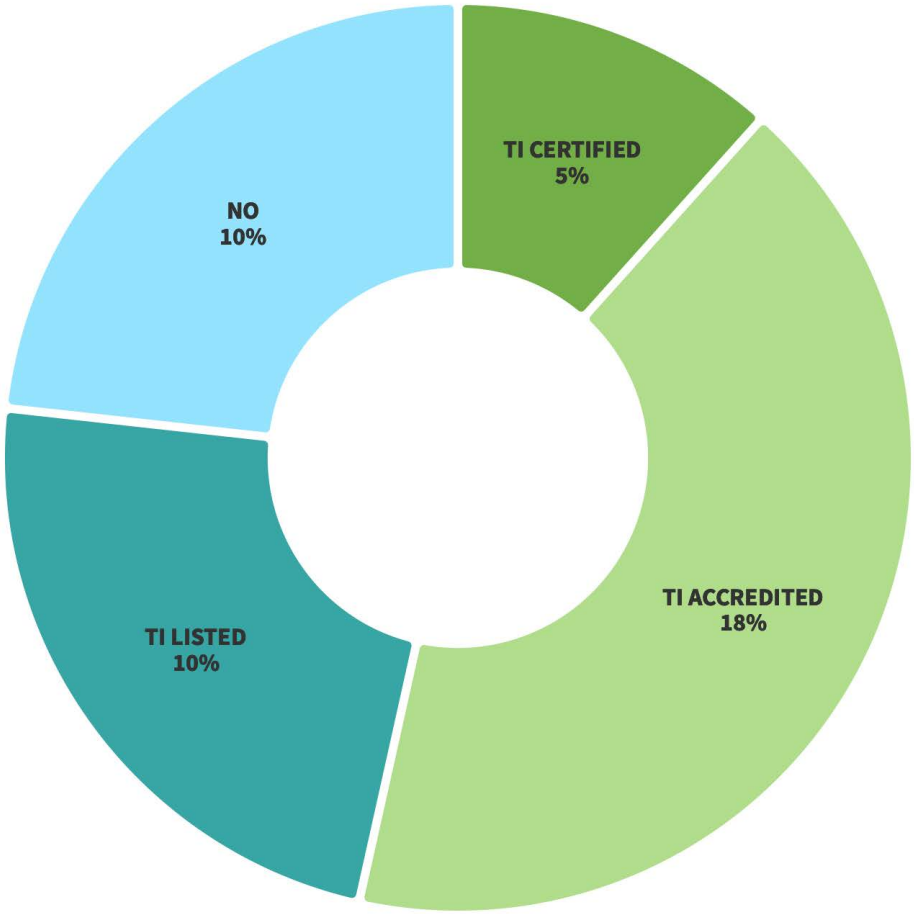

Figure 6.2: Numbers of NRENs with CSIRTs and their level of TI participation
33 out of 43 NRENs have a CSIRT that is participating in the Trusted Introducer (TI) programme. In December 2021, 5 CSIRTs were certified, 18 were accredited and 10 were listed. "Listed" means that contact information is listed in a central, public register. When a team hands in a basic set of documentation which is proof of a defined level of best practices and acceptance of the established TI policies, then the team becomes accredited. A team can be certified if they have been accredited before and can prove a confirmed level of maturity as defined by the TI Security Information Management (SIM) framework, by means of an external audit. The number of certified teams has not grown in 2021; this may partly be caused by the pandemic.

The area where there is clearly work still to be done is business continuity plans: while the number of NRENs stating they have one has increased, this still represents only a minority of NRENs. Again, this could be covered elsewhere if the NREN is part of a bigger organisation (as some are) but the relatively low number is an area to be addressed[45].

Operations

Services and tooling are seen as a major instrument in the fight against cybercrime [Register_BIIC] and the Compendium survey asked the NRENs about the use of security tools as part of their operations. Thirty-seven NRENs named at least one security tool; this is a high number, and as not all NRENs respond to all questions it seems likely that all NRENs utilise some kind of security tool, especially as the list of measures includes very mundane measures such as an-

[45] A guidance document for setting up business continuity has been developed in the GN4-3 WP8 Business Continuity Task [D8.12].

ti-virus suites, anti-spam and firewalls[46]. However, this is a very wide field, which also includes more sophisticated measures such as integrity checkers or network segmentation. Figure 6.3 presents an overview of how many NRENs use which types of security tool.

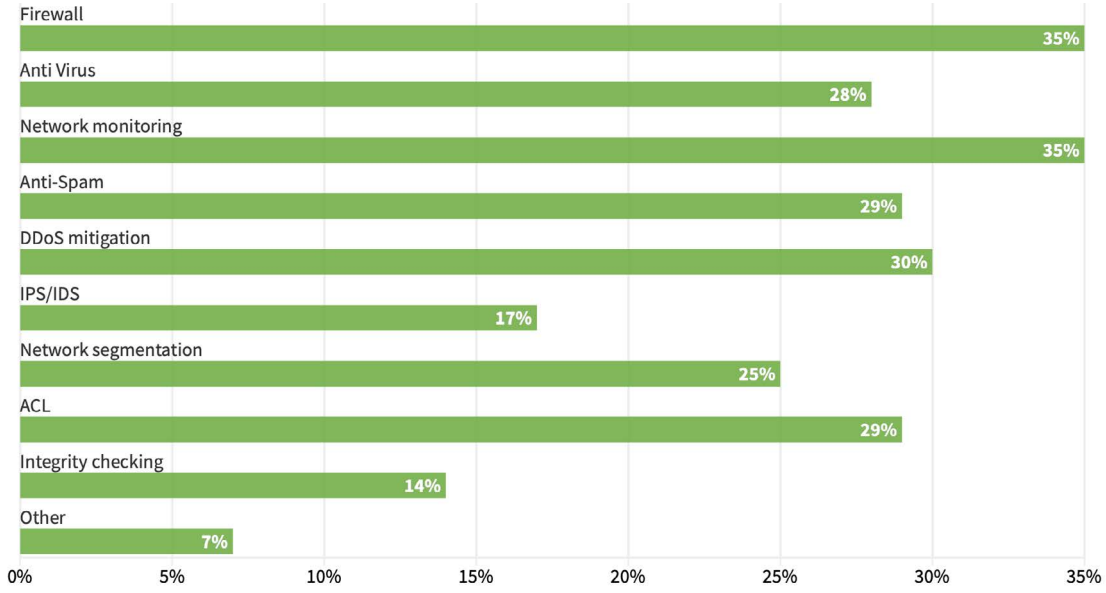

Figure 6.3: Cyber-security tools used by NRENs
The bars indicate how many NRENs are using this particular type of security tool.

6.2. Security Services

Many NRENs also run services to support their users' ICT security and more such services are in development.

One important upcoming security service type is Security Operations Centres (SOCs). Currently, 10 NRENs have reported running a SOC[47]. This is a major effort and involves considerable resources, which means it is not a service that every NREN will be able to offer. Some CSIRT services are gradually growing into SOC services. SOC services will be a major subject in GN5-1 in 2023 and 2024.

Another upcoming service is eduVPN. The COVID-19 pandemic has speeded up adoption of eduVPN both by NRENs and directly by universities. eduVPN gives the NREN/university the opportunity to offer state-of-the-art, privacy-preserving VPN services to large numbers of users[48].

In recent discussions, more interest has been shown in security intelligence sharing, DDoS mitigation, business continuity and crisis management, as illustrated, for example, by the continuous demand for crisis management events such as CLAW.

Some security-related services for the NREN community are provided by GÉANT, notably

[46] A plausible case for NRENs genuinely not using such tools would be if an NREN is part of a larger organisation that is providing the cover for the NREN. This is likely the case for NRENs such as AzScienceNet (part of the Azeri Academy of Science), FCCN (which is part of the larger research organisation FCT) and the Maltese NREN (part of the University of Malta).

[47] ACOnet, AMRES, CARNET, CESNET, DFN, GRNET S.A., Jisc, LITNET, RESTENA, SURF. Systems used are Splunk (3), Elasticsearch (2), FortiAnalyzer (1), Octacron (1) and AlienVault (1), but also self-developed systems (2).

[48] eduVPN is currently offered by 7 European NRENs and piloted by 17 more. It is also used by more than 100 universities worldwide.

Trusted Certificate Service (TCS)[49], which is currently used by 33 NRENs, and Firewall on Demand (FoD), currently used by 28 NRENs.

6.3 Security Community Groups

As with other areas of general interest to the community, NRENs meet in regular groups to discuss, share and increase their knowledge on security best practice. For security, there is a Special Interest Group (SIG) and a Task Force (TF), as detailed below:

- **Special Interest Group on Information Security Management Special Interest Group (SIG-ISM).** SIG-ISM offers Chief Information Security Officers (CISOs) of NREN organisations the opportunity to share best practice and learn from each other's experience of safeguarding their networks against security incidents and threats. Taking part in SIG-ISM can help equip NRENs with the skills to manage information security within their research and education community. Between a third and a half of GÉANT NRENs are actively involved in SIG-ISM.
- **Task Force on Computer Security Incident Response Teams (TF-CSIRT).** TF-CSIRT provides a forum where members of the CSIRT community can exchange experiences and knowledge in a trusted environment in order to improve cooperation and coordination[50]. It maintains a system for registering and accrediting CSIRTs, as well as certifying service standards. The Task Force also develops and provides services for CSIRTs, promotes the use of common standards and procedures for handling security incidents, and coordinates joint initiatives where appropriate. This includes the training of CSIRT staff and assisting in the establishment and development of new CSIRTs. As with SIG-ISM, between a third and a half of GÉANT NRENs are actively involved in TF-CSIRT, which means that not all European NRENs with TI-listed CSIRTs participate regularly.

6.4. Summary

The focus on security keeps growing. In the recent 26th GÉANT General Assembly, the NREN representatives had a lively discussion on the security ambitions for both GÉANT and the NRENs. As illustrated above, the landscape is very divided, depending on the size, operational scope and organisational position of the NREN. The challenge for all is the same: how to keep the networks secure and safe, and the challenge is clear and present. Recent geopolitical developments show that now there is not only cybercrime to worry about: state-sponsored, politically motivated threats are real and visible in day-to-day life[51].

[49] TCS takes advantage of a bulk purchasing arrangement which allows participating NRENs to issue almost unlimited numbers of certificates provided by Sectigo, a commercial certification authority (CA).
[50] It is notable that members of TF-CSIRT include not only NRENs but also R&E institutions and commercial organisations. To reflect this diversity, the TF-CSIRT community has decided to move into a more independent position; GÉANT will continue to support and promote TF-CSIRT.
[51] The 2022 Russia-Ukraine war and the international sanctions have implications of an unprecedented nature [NCSC Advice].

7. TRUST AND IDENTITY

In addition to the running of networks that connect the research and education community worldwide, trust and identity (T&I) services have become a core function of NRENs. These services enable users within the R&E community to securely authenticate and get authorised to access resources. Access to resources is managed in a federated manner, via specific authentication and authorisation infrastructures (AAIs), such as identity federations and eduroam[52].

This section outlines the NRENs' involvement in the following T&I initiatives and services:

- REFEDS
- eduGAIN
- eduroam
- eduTEAMS
- Student mobility services
- InAcademia.

IdPs, SPs and Identity Federations

Identity providers (IdPs) provide users with digital identities that enable authentication to take place. At any request for authentication of the user (log in), the IdP provides the information necessary to identify the user and her/his privileges.

Service providers (SPs) are any providers of services to users. Typical services include e-journal access; access to e-learning platforms; access to collaborative tools, such as wikis; access to storage and cloud services, and to more complex services required for science.

An **identity federation** is a framework of common identity security standards and protocols which allow the use of user identities *across different identity management* systems (hence the name federation). SPs in a federation can use IdPs in the same federation to authenticate users, which minimises the amount of user management they have to do.This enables a user registered in the identity management system of, e.g., a university to access services provided either by that university or by other institutions participating in the identity federation.

Building on the foundation of national identity federations and eduGAIN, more complex services can be created to support EOSC requirements (see chapter 4) or GÉANT services such as inAcademia or the upcoming eduTEAMs.

7.1. REFEDS

The Research and Education Federations group (REFEDS) brings together identity federations across the globe to share experience and define common practice.

In 2021 there were 83 known research and education federations worldwide, 74 of which are part of eduGAIN (see Section 7.2 below), a number that has increased steadily over the past years (see Figure 7.1). Most of the identity federations are operated by NRENs, though at least some are brokered by other non-commercial entities. Within Europe, there are 42 REFEDS members and, except for one, all of them are operated by NRENs[53].

[52] The data in this section come from the annual survey among the Research and Education Federations group (REFEDS) that is carried out by GÉANT, from the eduGAIN secretariat and from the eduroam secretariat. Note that all of these data sources reflect their worldwide use, not just their use among the European NRENs. Unlike the rest of this report, numbers here report on global uptake and use. However, to provide some context, of the 34 identity federations that responded to the REFEDS survey, 19 were European.

[53] In Croatia, AAI@EduHr is operated by the University Computing Centre of the University of Zagreb; another peculiarity is WAYF, which is operated by the Danish NREN DeIC but which also covers Iceland and Greenland. More information on REFEDS can be found at [REFEDS].

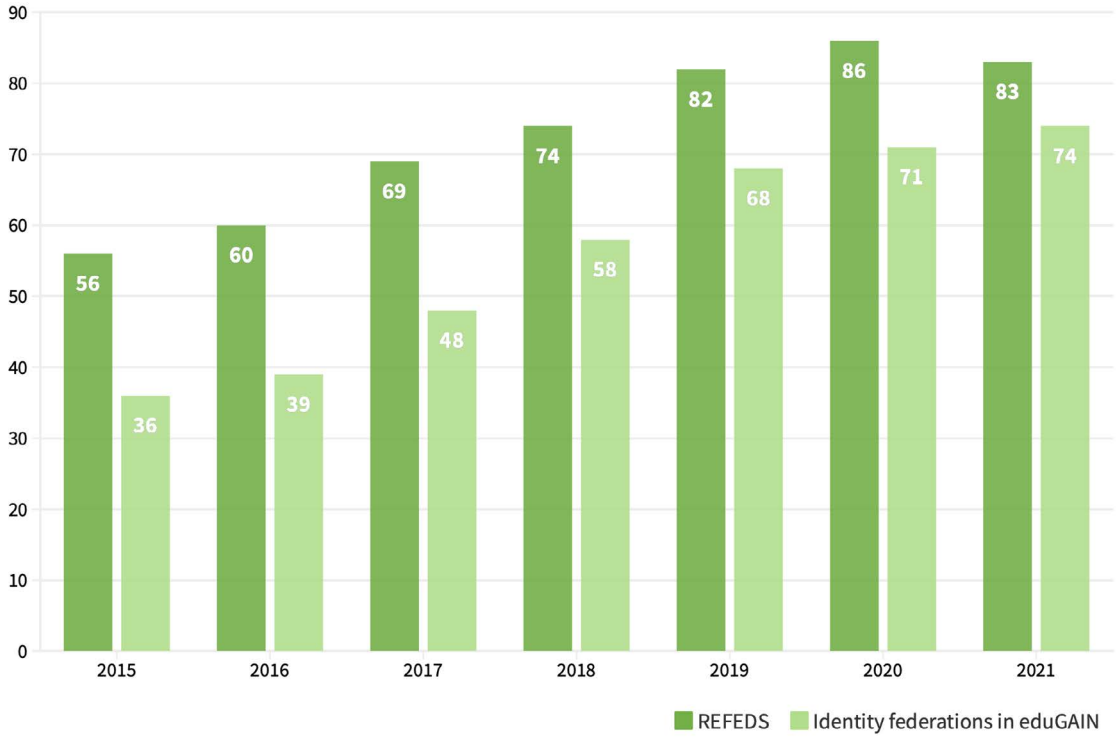

Figure 7.1: Number of known REFEDS members (darker colour) and number of identity federations using the eduGAIN service (lighter colour) 2015–2021

Note that all identity federations in eduGAIN participate in REFEDS but not vice versa. Federations will join REFEDS early on in their development process and before they reach the maturity needed to join eduGAIN, so REFEDS participation can be considered a pipeline to eduGAIN participation.

7.1.1. Security and Privacy Aspects

Running authentication and authorisation infrastructure (AAI) incurs security challenges. A measure of the preparedness of REFEDS members to deal with actual incidents is their adoption of the Security Incident Response Trust Framework for Federated Identity (Sirtfi – see Section 7.1.1.1 and also Section 7.2 eduGAIN below). To support the need to use only relevant user information in authentications and to use this data sparsely, REFEDS has conceived the Research and Scholarship (R&S) attribute release specification as a simple and scalable way for identity providers to release minimal amounts of required personal data to service providers serving the research and education community. Finally, the REFEDS Code of Conduct (CoCo) is a set of rules intended to insure that service provider organisations have taken measures to properly protect the attributes in line with regulatory requirements. These three aspects are explored in more detail below (see also Figure 7.2).

7.1.1.1. Sirtfi

The Security Incident Response Trust Framework for Federated Identity, or Sirtfi, aims to enable the coordination of incident responses across federated organisations, thereby defining a baseline for security incident response capabilities. The Sirtfi framework has seen an increase in uptake among REFEDS members in the past; overall, 64% of identity federations currently support Sirtfi.

7.1.1.2. Attribute Release Specifications and Code of Conduct

In a federated identity management system, the identity of the user is validated by the identity provider (IdP). If the authentication succeeds, the IdP will release some information (attributes) about the user to the service that initiated the authentication request. The service provider (SP) will use the information to authorise the use of the service. In order to comply with data protection regulations, SPs are recommended to request only the minimum set of attributes required to deliver the service. To support this process, the REFEDS community has defined specifications with the aim of automating the release of the attributes. One such specification is the Research and Scholarship entity for services (R&S), which enables the automatic release of a limited, specific set of attributes to services that operate in the research and education sector. To facilitate the release of attributes, REFEDS, in collaboration with eduGAIN, has also defined the Data Privacy Code of Conduct (CoCo). Service providers are encouraged to declare compliance with the CoCo, that is, to follow the principles of data minimisation and of attributes processing as defined in the CoCo[54].

Adoption of REFEDS' R&S and CoCo is only recommended, not mandatory, and only a (growing) minority of service providers in the federations that responded to the REFEDS survey comply with these standards (see Figure 7.2).

To date, the release of attributes remains a problem; services in eduGAIN have no confidence in what attributes they may or may not receive, as this is determined by the identity providers. This can have an impact on the user's experience, as they may not be able to access their desired service.

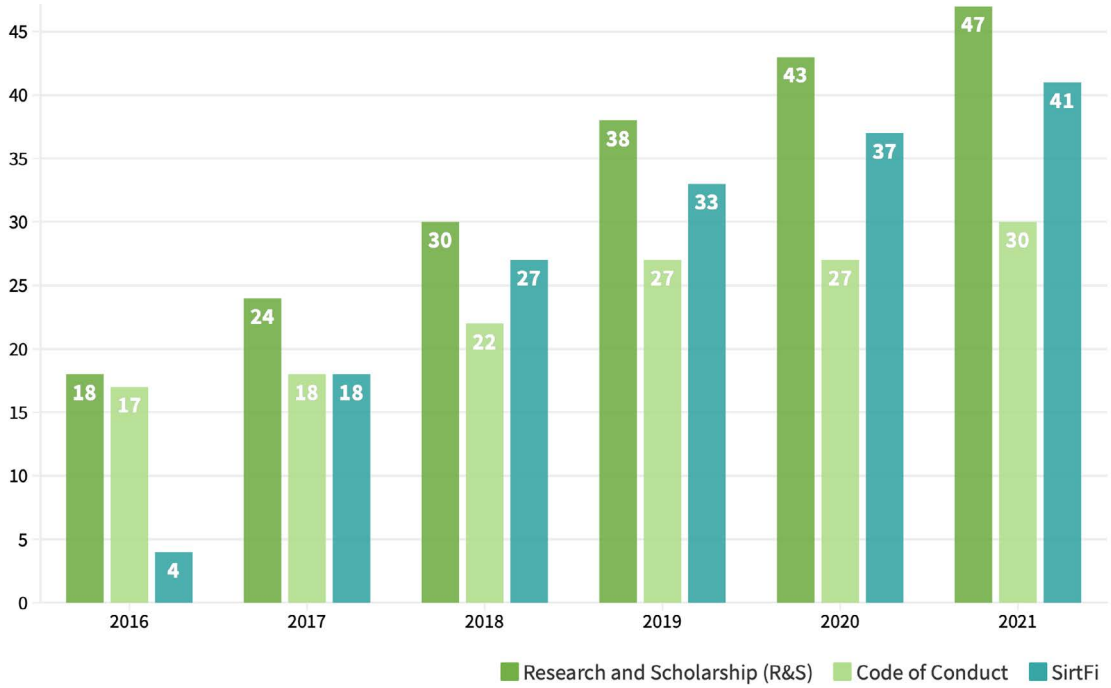

Figure 7.2: Compliance of REFEDS to policies

Shown are adherence to the Research and Scholarship attribute release schema, the Code of Conduct data protection requirements and the implementation of the Sirtfi security incident response framework. The numbers are derived from the eduGAIN metadata. This means that 64% of federations in eduGAIN support R&S, 55% support Sirtfi, 41% support CoCo; in general, compliance to the standards is on a slow but steady upward trend.

[54] A revision of CoCo started in 2020, to align it with the GDPR and to seek formal approval by the European Data Protection Board (EDPB). The new CoCo (v. 2.0) was approved by the REFEDS Steering Committee in March 2022 More information on R&S and CoCo can be found at [REFEDS_R&S] and [CoCo] respectively.

7.1.2. Identity Federation Budgets

Despite the core role that identity federations play, the budget allocated to them is still rather limited. Only a minority of the federations that responded to the REFEDS survey had a dedicated budget for this function and overall, there has been a downward trend in budget allocation (Figure 7.3). This is also reflected in staff allocated to the federations. The majority of the responding federations have only 2–3 people that are dedicated to the federation.

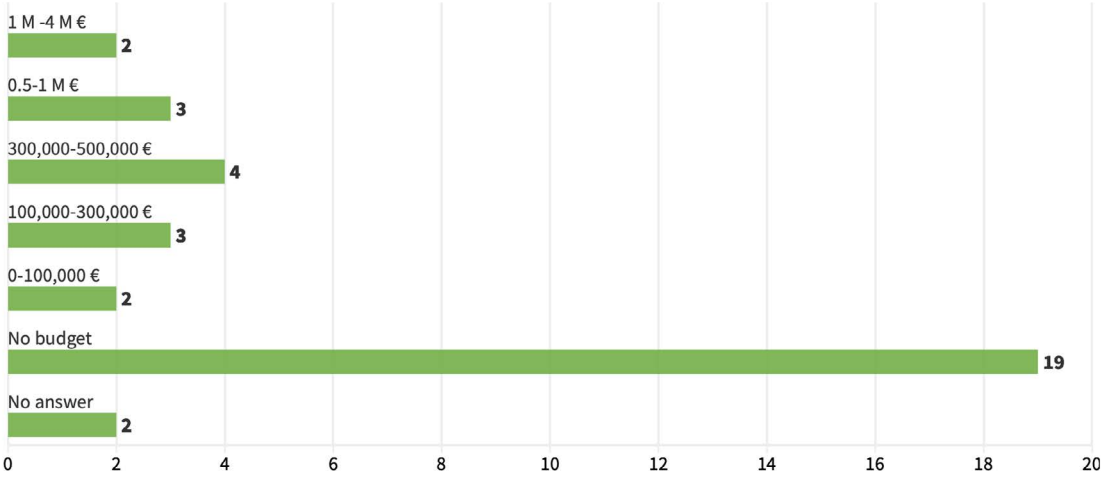

Figure 7.3: Budgets allocated to REFEDS members according to the REFEDS survey
From the survey responses, it is clear that in many cases this core function has no budget of its own. Note that only a minority of REFEDS members provided this information.

7.2. eduGAIN

eduGAIN is a key service supporting the increasingly borderless education and research sector by providing international interfederation to connect national identity federations [eduGAIN]. eduGAIN enables the secure exchange of identity information between entities (service and identity providers) of participating federations. This allows higher education institutions to offer a wider portfolio of services (those in eduGAIN) to their users: eduGAIN enables users from one federation to access services from other federations and enables services offered in one federation to be accessed by users from other federations. Established research and education identity federations worldwide participate in eduGAIN (Figure 7.1; note, though, that most, but not all, identity federations are in eduGAIN). As the service has matured, the number of identity providers and service providers added by federations has increased dramatically from about 2,500 entities at the end of 2015 to more than 8,000 in 2021 (Figure 7.4). The service continues to mature and expand its core competencies: the eduGAIN security team, established in 2020, has the main duty to provide a central coordination point at the interfederation level for the security incident response.

The team, in collaboration with the REFEDS Sirtfi Working Group [REFEDS_SirtfiWG], developed the eduGAIN Security Incident Response Handbook [eduGAIN_SIRH], which defines the process for resolving security incidents affecting eduGAIN participants involving all key stakeholders. In addition, in 2021, eduGAIN launched the eduGAIN Security Working Group, which aims to define and support an appropriate communication mechanism for proactive incident management and security warnings between the eduGAIN security team, federation operators and federation entities.

To maintain and improve the overall quality of eduGAIN, the eduGAIN Steering Group launched the eduGAIN Features Working Group to review the REFEDS Baseline Expectations document [REFEDS_BE] and make proposals for changes to eduGAIN to support the baseline laid out in the document. The WG will deliver a set of recommendations to the eduGAIN Steering Group in 2022; once this work is concluded, eduGAIN will require participating federations to comply with the baseline.

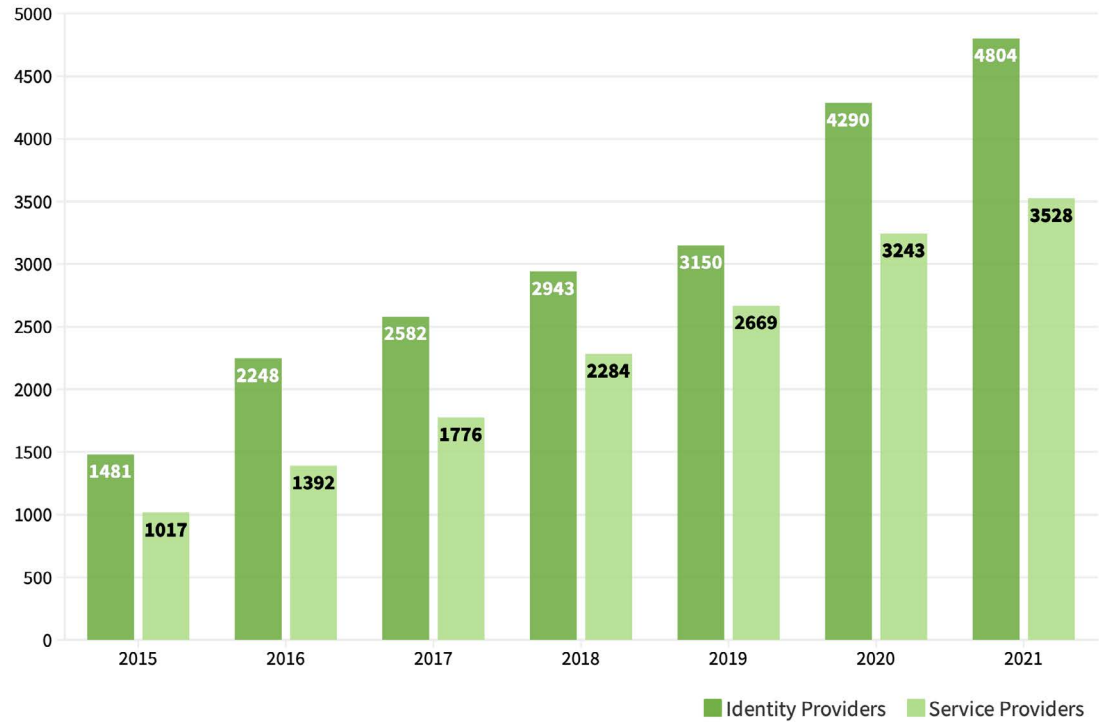

Figure 7.4: IdPs and SPs that are part of the eduGAIN service
The numbers have increased considerably over the years, with varying but impressive growth rates (increase of IdPs 2015/16: 52%; 2016/17: 15%; 2017/18: 14%; 2018/19: 7%; 2019/2020: 36%; 2020/2021: 12%; increase of SPs 2015/16: 37%; 2016/17: 28%; 2017/18: 29%; 2018/19: 17%; 2019/2020: 22%; 2020/2021: 9%)

7.3. eduroam

eduroam is a Wi-Fi roaming service that gives users seamless Internet connectivity both within their home campus and at other participating institutions [eduroam]. eduroam is a large-scale collaboration between hundreds of institutions. The national and international operation of this infrastructure is undertaken by the Roaming Operators (ROs) and a central eduroam Operational Team that is funded by the GÉANT project.

Since its inception in 2003, eduroam has expanded enormously and is now available in more than 105 territories. Globally, the service is delivered by regional confederations. The European service is operated by GÉANT for members of the European eduroam federation. This alliance comprises 51 autonomous roaming services who agree to a set of defined organisational and technical requirements that ultimately constitute eduroam.

eduroam is present in almost all European countries (exception: Bosnia and Herzegovina), and its usage is growing, with the majority of authentications happening nationally. However, the international traffic dropped significantly in 2020 for the first time since the start of the

service, as illustrated by Figure 7.5. This is clearly an effect of the COVID-19 situation. With universities moving many of their teaching activities online, the much reduced physical presence of students and staff is reflected in reduced authentications via eduroam. 2021 has seen a recovery of national authentications, though numbers have not reached 2019 levels yet. International authentications have also increased in 2021 but the recovery was not as pronounced as that seen in national authentications, indicating that recovery of international exchange activity is even further behind.

In 2021, eduroam continued engagement with OpenRoaming[55], to widen the footprint of eduroam access locations to spaces other than academic institutions and positively influence eduroam usage and traffic.

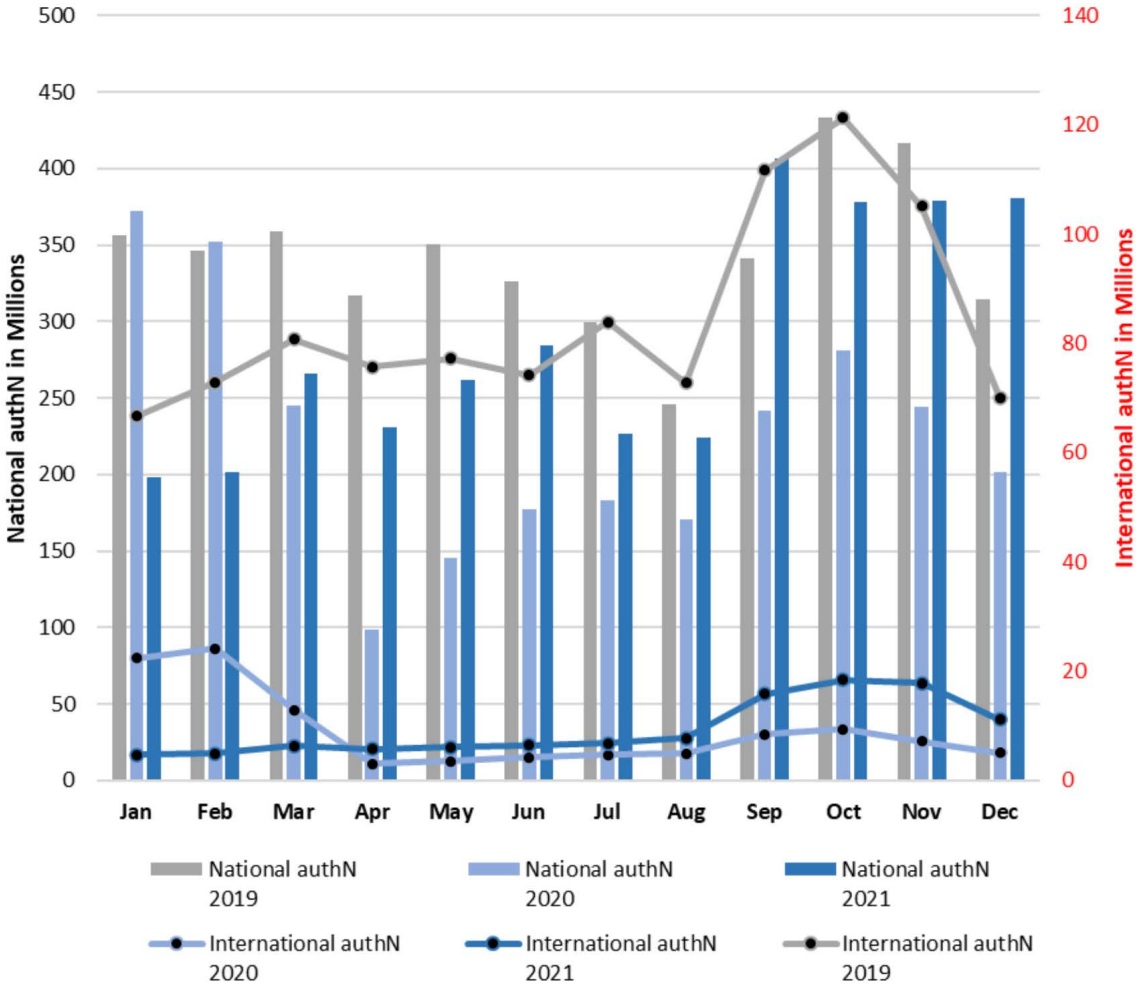

Figure 7.5: Authentications by eduroam month on month for the years 2019–2021
The majority of authentications happen nationally, while international authentications (e.g. visiting scholars, exchange students, etc.) are considerably lower, making up about 20% of authentications in 2019 and 2020 and about 10% in 2021. Comparing the three years is interesting as 2020 clearly illustrates the effect of COVID-19 on the use of campus networks. 2021 has seen a recovery of national authentications; the recovery of international exchange activity is further behind.

[55] OpenRoaming is a roaming federation service provided by the Wireless Broadband Alliance enabling an automatic and secure Wi-Fi experience globally. For more information, see [OpenRoaming].

7.4. eduTEAMS

eduTEAMS [eduTEAMS] is GÉANT's implementation of the Authentication and Authorisation for Research and Collaboration (AARC) BluePrint Architecture, BPA. eduTEAMS is an "AAI as a service" offered by GÉANT to support research collaborations, and/or virtual collaborations, and, more generally, to manage virtual teams and access to their resources. eduTEAMS continued to grow in 2021, as more and more research collaborations and infrastructures started to design and deploy an AAI that follows the AARC BPA.

Several of them decided to use eduTEAMS as the solution for their AAIs, as indicated in Table 7.1 below. eduTEAMS has evolved into a technology that can be tailored to support the specific needs of the communities that request it. This has resulted in several eduTEAMS deployments.

Table 7.1 shows the adoption of eduTEAMS by the end of 2021. In addition to the list below, eduTEAMS technology is also used by the GÉANT Association: eduTEAMS is enabling the GÉANT SP Proxy, which is used to enable federated access to several of the GÉANT services (wiki, mailing lists, etc.).

eScience	High-Performance Computing	NRENs	Education / Student Mobility
EOSC Clusters EOSC-Life panosc cessda **Research Infrastructures** EUROfusion europlanet LAGO EUROPEAN OPEN SCIENCE CLOUD	FENIX RESEARCH INFRASTRUCTURE LUMI neic PUHURI	SURF	MyAcademicID

Table 7.1: Projects and fields where eduTEAMs is used

7.5. Student Mobility Services

Student mobility has become a very important and strategic area for the NRENs and GÉANT, in light also of its higher importance at European level.

The European Commission is supporting the digital transformation of the Erasmus+ programme [Erasmus+] via the European Student Card Initiative [ESCI] and via dedicated projects funded under the Connecting Europe Facility (CEF) programmes [CEF]. GÉANT and the European NRENs have been particularly active in this space since 2019.

GÉANT continues the MyAcademicID project [MyAcademicID], which aims to design and deploy a platform to enable electronic identification (eID) and authentication of higher education students through a single European student eID scheme. The European Student eID for Higher Education is the result of the integration of eduGAIN, eIDAS (the EU regulation on electronic identification and trust services for electronic transactions in the European Single Market [eIDAS]) and the European Student Identifier (ESI), a digital identifier to uniquely identify students when they access student mobility services online; the ESI is released by the higher education institutions the students belong to.

In November 2020, GÉANT launched the MyAcademicID Identity and Access platform (MyAID IAM). The platform provides a single integration point to connect Erasmus+ services and to enable federated access to them via identity providers in eduGAIN and eIDAS. MyAID IAM paves the way for easy and secure access to electronic services, simplified administrative procedures and faster information exchange. This has become a core service to enable authentication for student mobility services. In the summer of 2021, GÉANT launched the IdP of Last Resort for Student Mobility (funded under the EDSSI project[56]) to support those higher education institutions that are not able to operate an identity provider themselves and are not able to benefit from similar solutions operated nationally.

By the end of 2021, MyAcademicID was used by 80,000 students and the IdP of Last Resort was supporting the students of 400 higher education institutions across 20 EU countries. This solution has enabled GÉANT to join forces with the NRENs to make sure that students are able to access Erasmus+ services in a federated manner. This new service is an important milestone for the European NREN community as a whole.

MyAcademicID and the IdP of Last Resort have had a positive impact on eduGAIN and on the national federations, which were able to demonstrate their value in offering authentication services for the education sector.

7.6. InAcademia

GÉANT and NRENs have worked together to launch InAcademia [InAcademia], a service that uses federated identities to validate whether or not a user is affiliated to an academic institution. The aim is to provide a service that protects user privacy while making it easier for commercial retail merchants to use federated identity, at the same time generating surplus income deriving from their exploitation of federated identities. The result of the validation is

[56] The European Digital Student Service Infrastructure (EDSSI) project, funded by the EC, has been supporting the maintenance and continuous improvement of the MyAcademicID service, and its application to the newest tools for Erasmus+ student mobility administration. The EDSSI project is one of the key projects that are contributing to the digitalisation of Erasmus+. For more information, see [EDSSI].

transferred to the connected merchants, which use this information to determine whether a user is entitled to a discount or offer. Since its launch in February 2020, the service has grown significantly, with over 1.3 million authentications processed; users in the Netherlands, Germany, Denmark, Spain, France, Italy, Sweden, Turkey and Austria can now protect their privacy when registering for a wide range of well-known global brands or when signing up to one of the world's largest student marketplace platforms.

There is now an established and growing revenue stream from services using InAcademia. It is intended that surplus income will be used to support GÉANT's T&I services in the future.

7.7. Summary

Trust and identity has been at the heart of the NREN world for a long time, but the scope of the projects and initiatives discussed in this section illustrates that the utility and importance of the field for the R&E community is still increasing. It is also clear that more recent applications such as eduTEAMS or MyAcademicID can take advantage of pre-existing T&I infrastructures such as eduGAIN and eduroam, which in turn makes the latter more attractive, in the best case creating a kind of virtuous cycle.

There is, however, something of a gap between flagship projects such as eduTEAMS and MyAcademicID and the less high-profile but nonetheless essential efforts that maintain identity federations, where coordination of stakeholders is time-consuming, improvements are more incremental and resources not always plentiful.

Nonetheless, it is clear that trust and identity remains a strategically vital area for the NRENs and will possibly even increase in importance.

8. CLOUD SERVICES

The COVID-19 pandemic years 2020 and 2021 have brought lessons learnt and experiences on a huge range of subjects. Not least of these is the value of cutting-edge research and applied science, which have saved millions of lives and are bringing societies back within reach of many normalities.

The pandemic has also demonstrated, especially in the area of knowledge work, the value of digital online services and communications platforms in enabling distributed collaboration – in short, of cloud-based services. These years have seen a step change in digital transformation, and an incredible acceleration in the development and adoption of advanced digital services and platforms. This shift is happening not only in the commercial world, but also in research and education. Demand for high-quality and high-performance digital services in R&E is here to stay, and NRENs, as the IT service facilitators for R&E, have the opportunity and the responsibility to continuously optimise the services provided to research and education institutions. This will require a reassessment and recalibration of where the finite R&E resources are best applied to maximise the outcomes of the GÉANT community's research and education efforts.

Cloud Services
There are three types of cloud services delivery:

Private Cloud, where an organisation provides a cloud service to its own staff only, and with no associated billing. This is the simplest delivery type in terms of access management and business model, and can be highly tuned for a specific set of known use cases.

Community Cloud, offered to a wider target "community", allows resource sharing between participating organisations and easy data collaboration across a greater number of users. This sets a higher standard for access management, but the financial model is most frequently organised around in-kind contribution of member organisations, or third-party/public funding. The best community cloud services offer added value specific to their target community.

Public Cloud describes commercial services available to everyone on the open market. They are typically operated in large data centres that benefit from effects of scale to reduce the infrastructure overhead payable by each user, as well as enabling "as-a-service" business models permitting each individual user a great flexibility in varying their resource usage over time. In turn, there are extremely high requirements for robust access control and security mechanisms and other "cost of doing business" items, as well as a requirement to support a great variety of use cases. Successful public cloud providers have the financial and organisational resources and a strong incentive to develop their cloud service portfolio on an ongoing basis to cover a large variety of user requirements at a very high level.

This section provides an overview of the benefits for users presented by cloud services, opportunities for NRENs, feedback from the NREN and R&E community, uptake of the GÉANT Infrastructure as a Service (IaaS) Frameworks, and the conditions determining cloud services adoption.

8.1. Benefits for Users

Location-independent use of cloud services is a benefit to individuals and teams, not only during the COVID-19 pandemic. Users benefit every day from using services that are developed and operated by providers dedicated to optimising performance, reliability, and feature development of that service. Organisations can benefit from adopting cloud offerings by reducing the need to run local IT services and focusing resources on more specific value-add

activities, while at the same time enabling the delivery to their staff of more varied, powerful, flexible IT resources at shorter response times and at improved value for money..

8.2. Opportunities for NRENs

While institutions will surely continue for some time to deliver certain specialised or sensitive services to their staff on their own (e.g., via a private cloud model), many individual users see a strong incentive to use available public cloud services for their work in an individual and ad hoc way. This may not be in the best interest of their home institutions, but these may also not feel in a position to offer viable alternative services from within their own resources. The NRENs can play one or a combination of three valuable roles in enabling and easing access to community cloud and public cloud services for their institutions: supplying community clouds, facilitating community clouds, and brokering commercial clouds. To further facilitate this journey, an NREN can develop its portfolio by fulfilling the role of cloud competence centre for their institutions. Each of these is described below.

8.2.1. Supply or Facilitate Community Cloud Services

The NREN community members across Europe have a close affinity with IT infrastructure operation, for networks and data centres. The resources and the ability therefore exist in the community to build and offer community cloud services to cover a larger target audience than simply the staff of one institution. In any one country, this may either take the form of the NREN or a central institution supplying a community data infrastructure centrally, or the NREN may create a marketplace for individual community cloud offerings from institutions willing to offer use of their resources to peers[57].

The role of an NREN as a full-stack national community cloud provider is in most cases reliant on a government-level mandate and corresponding funding and capacity building. Therefore, this path is realistically not available to an NREN purely by its own choice and, given current technology trends, may not materialise in the foreseeable future for any NRENs not already in that role today.

The model of an NREN coordinating a national marketplace for community cloud services offered by individual institutions can be successful in bringing together institutions willing to share their existing services with users looking to avoid operating their own. The service provider institutions grant access to their cloud service to third-party users within the community, to improve the utilisation of their infrastructure and generate some income to offset costs, and a number of small user communities are spared the effort of operating their own local instance. This model, however, faces a challenge often encountered by efforts to share publicly funded resources across funding boundaries, namely the difficulties of building a real business model that includes defining and collecting charges for usage from users outside the scope of the infrastructure funding. That scope may be the national borders, federal state borders within the nation, or even institutional borders. There have been successes with establishing the NREN as a financial clearing house[58], trusted by all parties involved, to handle the financial

[57] Examples of NRENs offering community cloud services are numerous, though the extent of such services varies considerably. At the upper end would be NRENs such as SWITCH, GRNET or PSNC/PIONIER, with a fairly comprehensive portfolio of cloud-based services, while NRENs such as RESTENA or Belnet offer mostly cloud storage. Other NRENs that offer cloud services of their own are CESNET, AzScienceNet, GARR, GRENA, FCCN, Jisc, SURF, CSC, Sikt, KIFÜ, CARNET and IUCC. Marketplaces where NREN users can offer services to other users have been established by, for example, DFN and SWITCH.

[58] For example, DFN-Cloud "Federated Services", by the German NREN DFN.

transactions. What remains, however, is that community cloud services provided by individual institutions struggle with offering sufficient service quality, stability and scalability to an entire national R&E community for anything more advanced than simple file-sharing.

The GN4-3 Work Package 4 Online Services Development and Delivery Task 3 Service Development: Cloud Offerings had the ambition to develop federation and resource sharing for such national community clouds across the European R&E community [D4.1]. This investigation encountered many challenges surrounding the sharing of publicly funded resources outside the scope of that funding. Ultimately, no cross-border fee model compliant with legal and funding terms could be developed. For further details, see the relevant GN4-3 deliverable [D4.3].

8.2.2. Brokerage or Procurement Support for Public Cloud

An alternative model is to establish community-specific environments on top of commodity commercial cloud infrastructures, the aim being to use finite R&E resources where they can most optimally improve research and education outcomes. The NREN is also well placed to facilitate centralised, and therefore efficient, procurement activities for commercial public cloud services on behalf of their community. The pan-European cloud tenders performed by GÉANT in 2016 and OCRE in 2020 take this approach one level further and provide NRENs with ready-made Frameworks to make available in their country.

8.2.3. Cloud Competence Centre

Independent of direct cloud procurement support activities, NRENs can add tremendous value to their community by developing into a centre of competence on matters of cloud usage. A solid base of cloud consulting capability, available to all institutions as they start their journey, is a tremendous asset to the community and a real opportunity for NRENs to establish their status as trusted adviser in digital services.

This was confirmed by NRENs at the strategic cloud and Chief Technology Officer (CTO) discussions in 2021, ratifying a cloud roadmap that placed a strategic priority on maintaining continuity for the Infrastructure as a Service Plus (IaaS+) Framework by re-tendering in 2024, and also on developing a forward-looking NREN strategy on cloud and above-the-net services. The NREN joint offers would also get more engagement with researchers and should eventually add more applications beyond Infrastructure as a Service, which has been in the main focus up to now. In total, the NRENs, together with their IT partners at institutions, can evolve their role from IT resource operators to more full-service solution facilitators and thereby keeping their value visible to their user communities in an increasingly digitalised environment[59].

8.3. Community Feedback

In 2021, two cloud studies were carried out: a survey among NRENs and R&E institutions, and a series of interviews with actors in the cloud space[60]. The aim of the survey was to get

[59] Examples of NRENs that act as cloud competence centres for their users are ACOnet, HEAnet, IUCC, Jisc, Sikt and SURF. In most (but not all) cases, this offer is centred around the IaaS+ Framework.

[60] The survey was the 2021 GÉANT Cloud Survey for NRENs and Research and Education Institutions [Cloud Survey2021] (112 responses, including 17 NRENs and their connected institutions, among which more than half were large universities with more than 500 employees). The interview series took place within the framework of the NREN Cloud Consultations 2021 [NREN_CC2021] (16 one-to-one interviews with NRENs, GÉANT Association and NORDUnet).

an overview of the R&E community's awareness and usage of cloud services and the GÉANT cloud portfolio; the aim of the NREN Cloud Consultations was to help plan the future activities of GÉANT in the cloud space.

8.3.1. 2021 Cloud Survey Results

All NRENs that responded to the survey used infrastructure services and knew of the GÉANT cloud services. Almost all the institutions that had used the 2016 IaaS Framework were very satisfied or somewhat satisfied with the overall Framework Agreement, the suppliers, and the support provided by their NREN. The most popular service provider solutions that NRENs collaborate with are the big global players, Microsoft Azure and AWS, but at the national level, independent providers play an important role as well.

Most of the respondents were also familiar with the 2020 IaaS+ Framework, while those who had not heard of it wished to learn more about it. The reasons why some of the NRENs did not plan to use 2020 IaaS+ Framework services were because they had their own national cloud, which was sufficient for their use, or because the resources available in EOSC were sufficient for them. Most of the institutions that planned to start using the 2020 IaaS+ Framework were interested in attending the cloud trainings, especially on topics such as security, cost control, strategic guidance on cloud migration, and legal clarifications. Institutions first needed to see what they would gain from using the offered services, and how they could implement them. Thus, marketing and service adoption played an important role for the uptake of the Frameworks.

8.3.2. 2021 NREN Consultations Results

The NRENs' interest in Infrastructure as a Service (IaaS) services has increased compared with earlier years. Still, in several European countries some legal obstacles to brokering the services have remained for users due to restrictions imposed by their national legal system. Most of the interviewed NRENs brokered IaaS, through the IaaS Frameworks of 2016 and 2020, but several also operated their own national offerings, based on OpenStack, VMware, and Kubernetes.

The compute services, such as IaaS+, high-performance computing (HPC) infrastructures (OpenStack and Kubernetes clusters), and containers and platforms, are foreseen to be supported in the future by half of the interviewed NRENs. Also, the most popular services for community-based offerings mentioned were the IaaS services for research.

Regarding the NREN future environments and the main changes and impacts on cloud services delivery, three main categories could be highlighted: COVID-19 influence on service delivery, digital transformation in research and higher education, and changes and impact regarding the business models.

Digital transformation in research and higher education has resulted in a need for end-user-friendly services (e.g., infrastructure services for individual researchers), data sovereignty ("how to find the balance between commercial providers from the US and Europe?"), the definition of NRENs' role in digital transformation ("will institutions see IT departments and NRENs as the channel in the process?"), NRENs to provide network connectivity combined with advanced and customised services for research and education ("network and cloud will become one"), and integrating data centres to bring data closer to computer facilitators (museums, libraries, Copernicus).

NRENs face general challenges relating to improving cloud awareness and competence, but other challenges also include NRENs' limited resources compared with those of commercial operators, legal and policy challenges, and technical challenges. Another general challenge is that the NRENs are an inhomogeneous group. Thus "one size" does not fit all. Higher education's need for cloud services is growing (IaaS, LMS); however, it is not systematically communicated as such into the campus-IT/NREN community channels. It is complicated to build cloud expertise and strategic perspective without direct stakeholder demand. Therefore, before cloud adoption can be increased on the national level, the many formal, legal, and organisational challenges facing institutional IT during digital transformation need to be solved. Creating and delivering support on these fronts is outside the NRENs' service portfolio and experience, and would require extra resources to develop.

8.4. Uptake of the GÉANT IaaS Cloud Frameworks

Since 2016, the GÉANT Frameworks for infrastructure clouds (IaaS) have offered centrally procured commercial cloud services with improved conditions for R&E institutions, and have been very successful in fulfilling the demand for such services wherever it was expressed through the NRENs. The 2016 IaaS Framework (2017–2020) saw consistent annual growth throughout its duration (Figure 8.1 below).

The availability of the second-generation IaaS framework (2020 IaaS+, which started in December 2020)[61] coincides with a dramatic increase in uptake, the annual 2021 spend on both Frameworks almost equalling the total of the preceding four years, as shown in Figure 8.1.

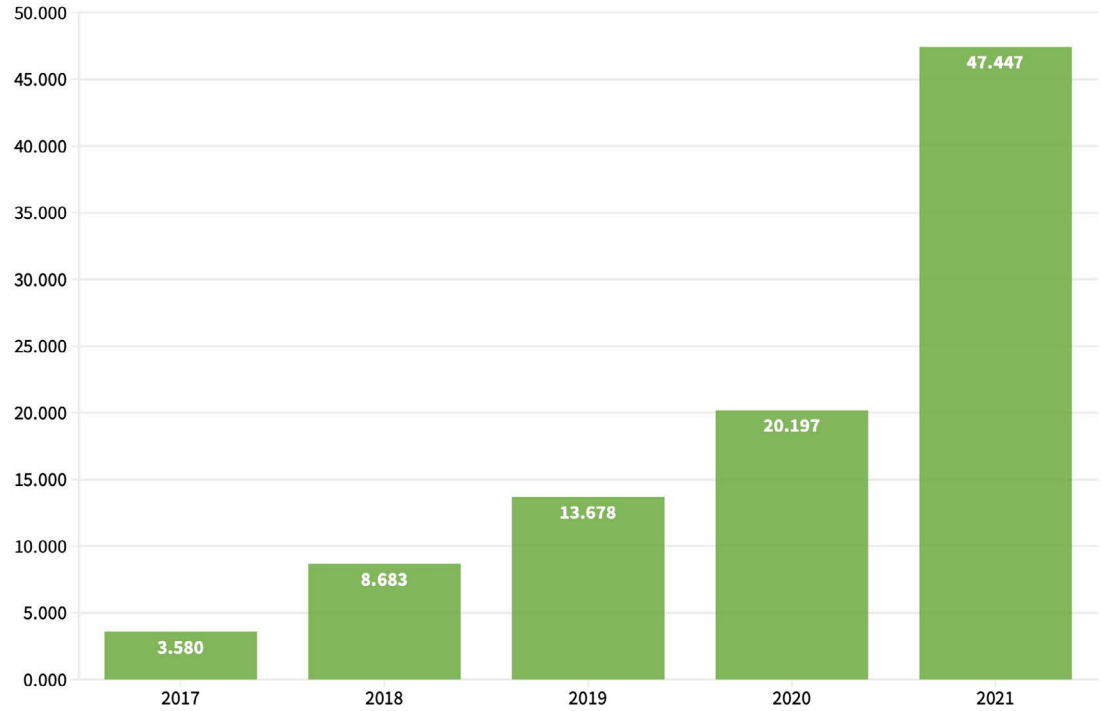

Figure 8.1: Yearly spending (Million €) via the GÉANT cloud Frameworks (IaaS and IaaS+, 2017–2021)

[61] The tender for the 2020 IaaS+ Framework was run by the Open Clouds for Research Environments (OCRE) project, hence it is also known as the OCRE Framework.

The growth in consumption under the new 2020 IaaS+ Framework is significantly driven by growth of usage in new countries that have achieved sizeable national cloud procurement aggregation through the Frameworks, demonstrating the progress that more and more NRENs are making in becoming cloud procurement pathways for their national communities. Several more countries are making significant steps in growth relative to their previously modest or even non-existent levels of purchasing aggregation. Of the 39 NRENs that joined the 2020 IaaS+ Framework procurement, over 50% (23) were recording active consumption in the first year (Figure 8.2). The remainder are mostly in non-EU countries that do not have the same easy access to the Framework-governing EU Procurement Directive.

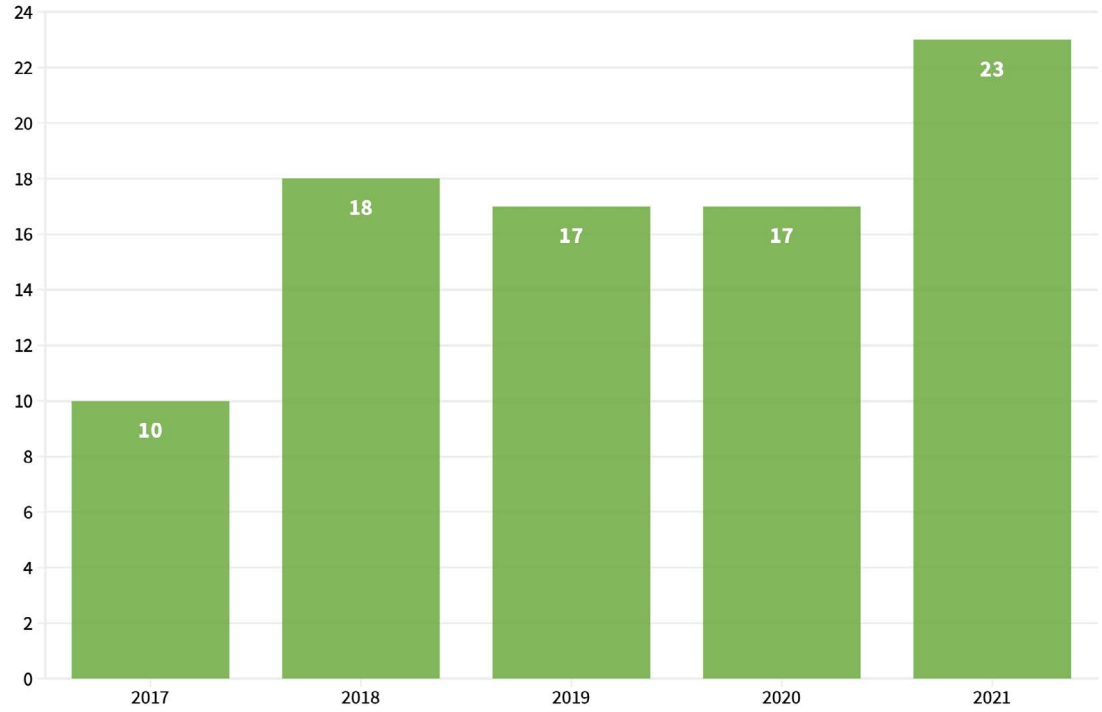

Figure 8.2: Number of countries with active Framework consumption

Those NRENs that are channelling their institutions' cloud purchases through the IaaS+ Framework are delivering significant value to those institutions in the form of effort and time saved on procurement and cost reductions unachievable to any single institution, so saving taxpayer money across Europe and improving research and education outcomes. The value of the Iaas+ Framework and the NRENs' value-add is most visible to those institutions that have developed a cloud-inclusive IT procurement practice and can optimally exploit the Framework benefits.

8.5. Conditions Determining Cloud Services Adoption

Despite the continuing digital transformation of workflows across the world, accelerated even more by the pandemic-driven change in patterns of work and mobility, the European research and education institutions as a whole are not adopting infrastructure cloud services at the same rate as other sectors, with notable exceptions expressing themselves in the very uneven per-country usage of the IaaS+ Framework. There are several driving and delaying factors, many cultural, at play here:

Driving Factors

- **End-user demand.** The capability to quickly and flexibly deliver state-of-the-art digital experiences is becoming a competitive playing field for universities and research institutes looking to recruit top-level talent and to increase the excellence of their graduates and research output. This is a driver particularly towards Platform as a Service (PaaS) for flexible and powerful application/research development with low IT-management overhead, as well as Software as a Service (SaaS) solutions with high end-user experience quality.
- **Value.** A transition from large one-time hardware purchases to ongoing payment for resources as used ("CAPEX to OPEX" shift) allows more flexible cost/value optimisation. This enables trade-offs of the "time is money" kind to be made, using the scalable nature of large-scale cloud platforms, where more processing resources are always available for extra cost.
- **Legislation and regulations.** GDPR issues affect both in-house and externally sourced services, with increasing pressures on in-house-operated services to satisfy, and be certified to, professional IT security standards. This changes the value calculation of on-premises versus cloud, especially when existing local data centres reach end-of-life and the necessary investment decisions for replacement are made.
- **Multi-cloud.** Data and application interoperability and portability between different clouds have come a long way in recent years. De-facto-standard data transfer APIs have emerged, along with platform-abstraction layers such as Kubernetes that allow orchestration and migration of workloads across cloud platforms. The parallel usage of multiple cloud platforms, even within one application, is emerging as the best practice.
- **Scalability/elasticity**. As the gap in capacity between locally operated cloud services and hyperscale platforms widens, operators of local resources increasingly face issues in relation to accommodating applications with high short-term resource requirements, making a suitably large-scale and elastic cloud-hosted application platform more attractive for applications with time-variable resource requirements.

Delaying Factors

- **Lack of clarity in legislation and regulations (GDPR)**
  - A large part of the R&E infrastructure operators community is maintaining the default perception that the data protection legal risks (and effort) are lower for on-premises solutions. With externally sourced services, contracts must be checked and revised, and processes on the supply and demand side have had to be changed. This perceived gap in data protection effort and risk will reduce as requirements around equivalent IT security and certifications are applied more systematically to all data and applications for which institutions are responsible.
  - Schrems II: The CJEU ruling invalidating the US-EU Privacy Shield agreement sparked significant uncertainty about the consequences and risks around the US cloud suppliers' obligation under the US Cloud Act to deliver even EU users' data to US authorities under search warrants. To continue to abide

by GDPR, EU users of US cloud providers need to take additional measures to minimise the data protection exposure of their data. This additional effort should be best practice in any data processing environment, but the associated public uncertainty and doubt over the issue is slowing adoption of all cloud services, even in clearly legal use cases.

- **Uncertainty and risk aversion.** Many institutions are adopting a "me second" approach to cloud adoption – waiting for other institutions to be the leaders. The NREN community will continue to share user experience and coordinate best practice examples to reduce the uncertainty of cloud adoption.
- **Data-sovereignty concerns.** Not all users are comfortable with the idea that their data might be stored outside of their national jurisdiction, which in some countries and for some types of data might even be a legal requirement. These reservations overlap partially with the legal concerns that lead to Schrems II (see above).
- **Low awareness of Framework existence at institutions.** Not all NRENs have the resources to advertise the GÉANT IaaS+ Framework widely to their users and consequently the IaaS+ Framework lacks visibility among the institutions in some countries – as does the NRENs' role in making it available. A related problem is that the potential users of these services within the R&E institutions are frequently not the contact people of the NREN. This is a missed opportunity to connect demand with an optimised supply, resulting often in small ad hoc cloud procurements by user groups, without oversight and at less advantageous conditions.

8.6. Summary

The data and responses for 2021 show clearly that state-of-the-art digital services are in high demand throughout the R&E community, and that the cloud model of service delivery plays a valuable and significant part in the service landscape, meriting the close attention of the NREN community. There is a great opportunity for NRENs to forge a role for themselves in delivering value to their institutions through aggregating demand and centralising effort around cloud procurement. As demonstrated by the 2021 GÉANT Cloud Survey and the 2021 Cloud Consultations, most NRENs recognise and acknowledge this development.

Cloud services developed and operated from within the R&E community have the opportunity to differentiate themselves by being highly integrated with the R&E service ecosystem and to address requirements around sovereignty or niche applications not well served by general-purpose cloud providers. However, to achieve the required service levels, a minimum amount of scale will be necessary in the future and the required operating models to achieve this from within the R&E community are not readily accessible to most community members. Work in the community continues to harmonise community and public cloud approaches into a unified strategy framework in which NRENs can find their optimal role.

The IaaS+ Framework consumption data show a significant increase in the number of NRENs that have taken steps to translate this awareness of their opportunity into procurement aggregation activities, and also demonstrate the value and savings that NRENs can deliver to their communities. Total consumption across all the IaaS+ Frameworks since 2017 is on course to cross the €100 million mark during 2022. Effort and time saved on individual procurements, as well as a significant percentage in discounts on that sum total across Europe, add up to massive savings of tax money that is available to improve research and education outcomes instead.

9. EDUCATION

While NRENs have always provided connectivity and above-the-net services to educational institutions, a number of NRENs are offering services that are specifically designed to serve education. This is a development that reflects the increasing use of ICT tools in the teaching and learning communities. Educational institutions use a wide range of education services, some of which are of strategic importance to them, ranging from learning management platforms to learning analytics and e-assessment systems. As ICT experts, NRENs are well placed to support these needs in various ways.

This section is based on the work of the Task Force on Educational Technologies [TF-EDU]. TF-EDU was founded by GÉANT in early 2020 with the aim to create a platform where NRENs that support educational institutions can share experiences and information, and initiate collaboration activities between interested NRENs. The section summarises recent TF-EDU events, and gives an overview of the activities of NRENs in supporting education, showing how many and which services they offer.

9.1. TF-EDU Events

During the course of 2021, TF-EDU organised 9 virtual events including 3 meetings of the Task Force itself and 6 community sessions to address specific topics deemed of interest for the NREN community.

Discussions in TF-EDU community events concerned a number of different topics and attracted participants from different NRENs. This is summarised in Table 9.1, with further details below.

DISCUSSION EVENTS	NO. OF PARTICIPANTS	
	EUROPEAN NRENS	INTERNATIONAL NRENS
Moodle scaling up collaborative solutions	20	5
Stepping Up and Reaching Out	17	4
Educational services	16	3
The importance of standards with the EdTech ecosystem	12	1
Schrems II	12	1
Managing and running large-scale Moodle system	7	0

Table 9.1: Discussion events organised by TF-EDU and level of NREN participation
The topics discussed during the events covered strategic issues as well as specific technical areas. Not all NRENs provide education services, hence the number of potential participants is lower than the total number of NRENs. Note, however, that the meetings are open to NRENs worldwide, so the participants include international NRENs.

The events on "Educational services" looked at the current picture, meaning the NRENs' offer of services across the spectrum of education stages, from higher education and universities to schools, the maturity of these services and how they have been developed. "Stepping up and Reaching Out" and "The importance of standards with the EdTech ecosystem"

focused more on the NREN strategies, on the future of educational cases for NRENs, the role of NRENs and the next development in educational services. The meetings on "Moodle scaling up collaborative solutions", "Managing and running large-scale Moodle system" and "Schrems II" addressed specific technical areas such as student mobility, eduID, student administration systems and data protection regulations.

The number of participating NRENs varied, reflecting the fact that only a subset of NRENs provide education services. These events were open to an international audience and some international NRENs participated.

9.2. Education Services

Apart from organising events, one of the main TF-EDU activities is scanning the landscape of educational offers of NRENs and providing aggregated information on those offers back to the GÉANT community.

This section gives an overview of the activities of NRENs in supporting education, detailing how many and which services they offer, and also gives a brief overview of the services. It is mainly based on the surveys among NRENs that TF-EDU carried out in 2019, 2020, 2021 and 2022 about their activities in education.

9.2.1. Categories of Education Services

The surveys defined a number of service types (see Figure 9.1) and asked the NRENs whether their service offering included any of these education-related services[62].

Explanations of the less self-explanatory services are as follows:

- An open badge/micro credential is a validated indicator of an accomplishment or skill that can be earned in a learning environment. Usually these are like mini degrees or certifications (hence "micro"). This enters the realm of NREN competence when it takes the form of a digital certificate.
- Learning analytics refers to collecting, analysing and reporting data from learning environments in order to improve the learning process of students. This information can then be made available to students, teachers or training management.
- Student management systems are software systems for the administration, documentation, tracking, reporting and delivery of educational courses and student performances.
- Trust and identity (T&I) for education refers to T&I applications that are specific for educational purposes, e.g. an educational ID (eduID) that works like an electronic student ID.
- Support for offshore students (not shown in Figure 9.1) was added in the 2021 survey as a new question.
- Anti-plagiarism was merged into the Digital assessment question, which is the reason for not having data available for 2021.

[62] In total, the surveys received 46 responses: 34 NRENs from EU countries, 4 NRENs from the Eastern Partnership countries (EaPConnect) and 8 NRENs from outside Europe.

Figure 9.1: Categories of education services NRENs offer

9.2.2. NRENs' Education Portfolio

This section gives an overview of the current state of the educational activities among NRENs, laying out how common it is for NRENs to offer education-related services and what kind of services these are.

Figure 9.2 presents a summary of how many European NRENs offer any education service in their portfolio and how this has developed over the last 4 years, indicating a slight upward trend. The number of such services offered varies considerably between NRENs, as is shown in Figure 9.3.

A look at the details (shown in Figure 9.3 and Table 9.2: NREN portfolios of education services) reveals that in the 2022 survey 30 European NRENs offer trust and identity services, while 27 NRENs offer videoconferencing for education. Given that T&I is one of the core competences of NRENs, this is not surprising. Similarly, videoconferencing is a service that has been offered for a long time by many NRENs and that can therefore be repurposed for the specific needs of the education sector, making this a relatively easy service to establish.

The next two most popular education services offered by European NRENs are Digital Learning Environments (offered by 23 European NRENs) and e-Content (offered by 22 NRENs).

The next groups offered are online or blended education (17), learning analytics (16) and open badges / digital credentialing (14). Twelve NRENs offer student management systems and digital assessment. A more rarely offered service is the support for offshore students (although a respectable number of 9 NRENs offer it).

Comparing across the years, there has been an increase in the numbers of education-related services offered by NRENs, not only in absolute numbers, but also in maturity of the services. For example, in 2021, videoconferencing was reported by 21 NRENs, which has increased to 27 in 2022, while the learning analytics offer has increased from 14 to 16.

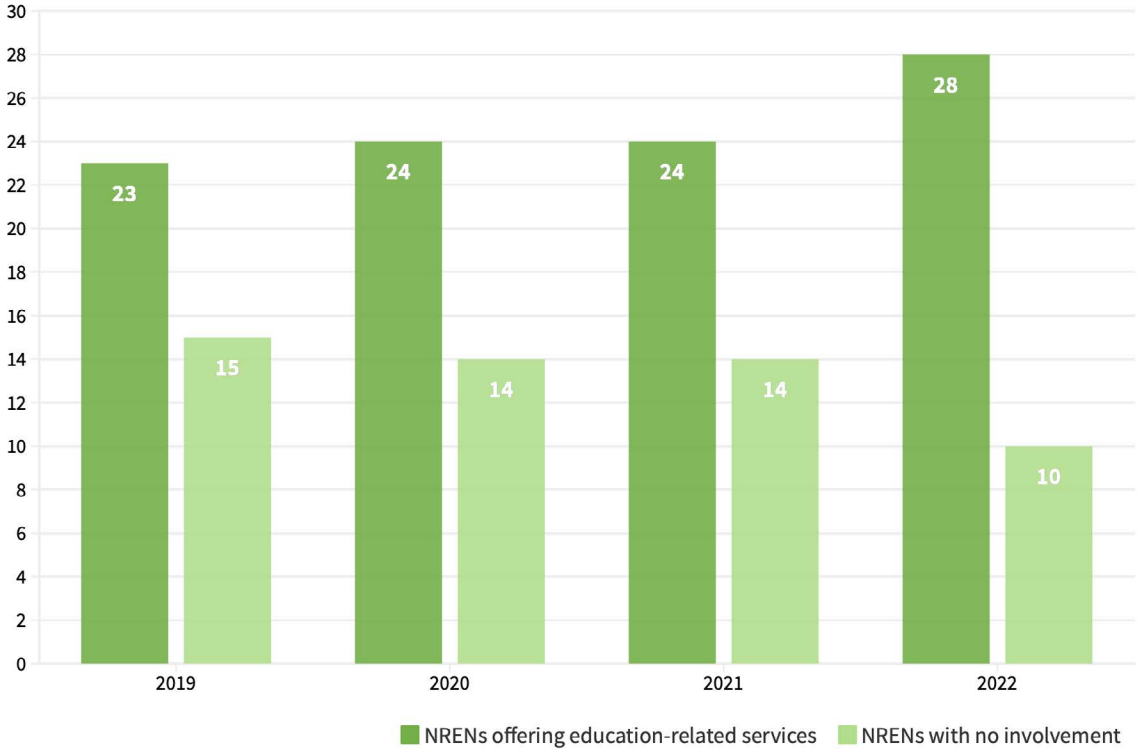

Figure 9.2: Number of NRENs offering education-related services
The majority of NRENs offer services that specifically target education, and the figure even shows a slight increase over the years. Note that the extent of the commitment differs, as becomes clear in Figure 9.3 and Table 9.2. Only NRENs for which consistent information was available are counted in this figure.

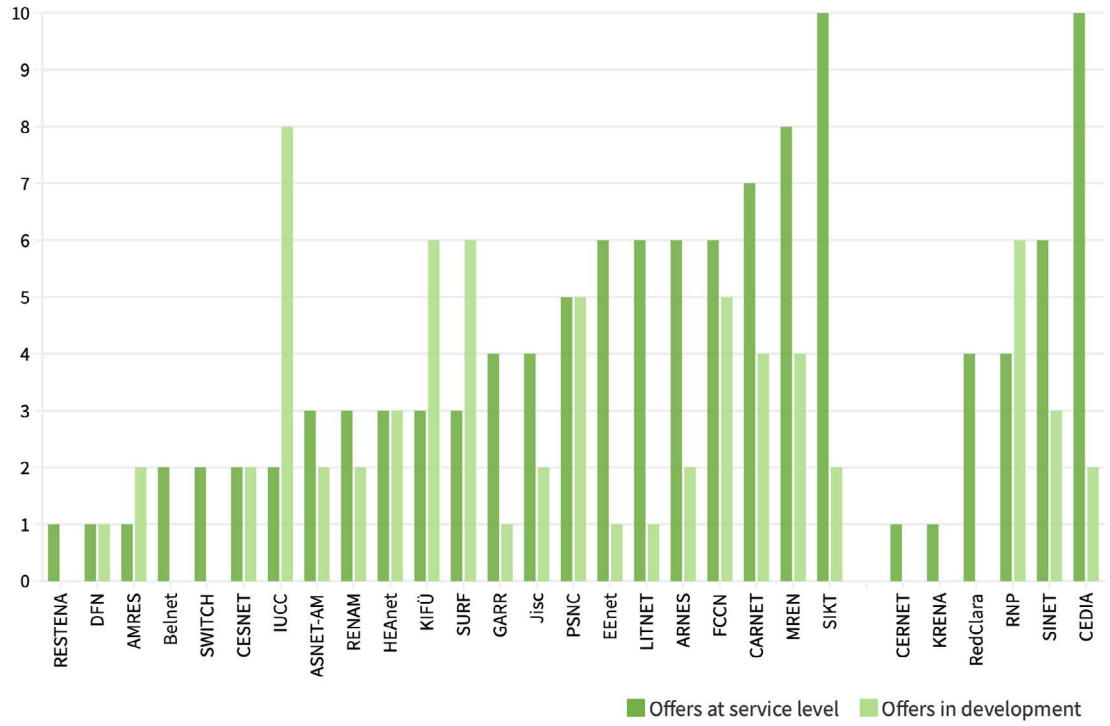

Figure 9.3: Number of education services provided and in development, by NREN
According to the 2022 TF-EDU survey. The figure shows all European NRENs that provided information as well as some international NRENs that participated in the survey (on the right: CERNET- China, KRENA - Kyrgystan, RedCLARA - Latin America, RNP -Brazil, SINET - Japan, CEDIA - Ecuador), which allows a glimpse beyond the confines of the European NREN community. Clearly, the portfolio size of education services differs considerably between NRENs. The TF-EDU surveys asked about the maturity level of the services on offer. In this figure, these data have been condensed into services on offer (mature service-level services) and offers in development (services in initiative or project phase).

The numbers make it clear that this is a well-established area of activity for many NRENs. This is further enforced by the large number of NRENs that are developing new services for the sector, as shown in Figure 9.3, which might become part of the NRENs' service portfolio in the near future.

	Digital learning Invironments	Prioviding e-Content	Online or Blended Education	Digital assessment	Open badges, digital credentialing	Learning analytics	Student manage-ment system	T&I for education	Educational data mining and analytics	Videconferencing for education	Support for Offshore students	In-house built tools for digital learning
AMRES	x							x		x		
ARNES	x	x	x	x	x	x		x		x		
ASNET-AM	x	x	x					x		x		
BELNET								x		x		
CARNET	x	x	x	x	x	x	x	x	x	x		x
CESNET	x	x						x		x		
CSC/Funet	x	x	x	x		x	x	x	x	x	x	
DFN								x		x		
EENet	x	x		x			x	x		x		x
FCCN	x	x	x	x	x	x	x	x	x	x		x
GARR	x	x	x					x		x		
HEAnet						x	x	x	x	x	x	
IUCC	x	x	x	x	x	x		x	x	x		x
Jisc		x			x	x		x	x		x	
KIFÜ	x	x	x		x	x	x	x	x	x		
MREN	x	x	x	x	x	x	x	x	x	x	x	x
PSNC	x	x	x	x	x	x	x	x		x		x
RedIRIS	x	x	x		x	x		x	x	x	x	x
RENAM	x	x						x		x	x	
RENATER	x							x				
RESTENA								x				
SANET	x	x	x				x	x		x		
SIKT	x	x	x	x	x	x	x	x	x	x	x	x
SURF	x	x	x	x	x	x	x	x	x			
SWITCH								x		x		
CERNET								x		x		
KRENA		x	x							x		
RedCLARA	x							x		x		x
RNP	x	x	x	x	x	x		x	x	x		x
NIIP	x	x			x	x		x	x	x	x	x
CEDIA	x	x	x	x	x	x	x	x	x	x	x	x

Table 9.2: NREN portfolios of education services

The table aims to give an overall impression of areas of activity and therefore lists services in production as well as those in development. The most common services are T&I, videoconferencing and digital learning environments. As in Figure 9.3, the participation of some international NRENs in the survey created the opportunity to compare the activities of European NRENs to those of international NRENs and the table shows the education service portfolio of those in addition to the European NRENs (lower end of the table; CERNET- China, KRENA - Kyrgystan, RedCLARA - Latin America, RNP -Brazil, SINET - Japan, CEDIA - Ecuador).

9.3. Reflections on Past and Future Horizons

The TF-EDU survey also revealed some of the underlying drivers and constraints for the NRENs active in the field of education services[63]. In 2021, the disruption caused by emergency online teaching in the wake of the COVID-19 outbreak was still ongoing, though less than in 2020. The increase in the demand for education services continued throughout 2021 and while some NRENs were able to consolidate their emergency services, others struggled with the financial burden and the increased workload. For some NRENs, that meant serious internal restructuring and the necessity to develop new strategies. Almost all NRENs had to expand their capacities to accommodate the challenges of the COVID-19 pandemic, though in some cases this meant that some services had to be reduced to be able to focus the limited resources.

2021 brought some hopes for an increase in financial and especially human resources. NRENs reported continued work on videoconferencing services, lecture recording services, video repositories and similar "bread-and-butter" services. Beyond these, many NRENs put considerable work into maturing their online and hybrid learning tools, and a lot of thought and planning went into the development of services such as digital credentials, student identities and digital assessment.

The horizon for many NRENs seems to be mid-term at most, a consequence of the uncertainties of the current economic situation in most countries, so current strategic planning rarely extends beyond two or three years. The strategic focus naturally varies among NRENs – areas mentioned were engagement in learning analytics, lifelong learning, assessment for learning, increasing the exploration of virtual and augmented reality, WebRTC, interactive video, digital certificates, open badges, and establishing a sustainable and highly scalable communication platform that will address the coming demand for online learning.

9.4. Summary

Supporting the digital transformation needs of the education sector is a growing field. Digital tools have become even more important for the education sector with the recent COVID-19 crisis, and now the majority of NRENs are becoming tasked with expanding their support for the education sector, tapping into their expertise in digital services and rethinking them as a part of their education portfolio.

It is now clear that more NRENs are entering the sector, which for many was triggered by the emergency online teaching in 2020 and 2021. The NRENs have since regrouped, restructured and reorganised to be able to respond to the high demand of the education institutions. However, for many NRENs it is not clear whether this will be a sustainable part of their activity, as the availability of human and financial resources is uncertain.

[63] This section is based on several open questions in the TF-EDU surveys. The questions were the following:

1. Reflecting on 2021: What happened to your organisation in 2021?
2. Reflecting on 2021: How did your organisation respond?
3. Planning for 2022: What will you take forward into 2022?
4. Horizon planning: What will you take forward longer term? What timescales/horizons are you working to (immediate, medium term or ten years)?

10. OUTLOOK

The Compendium's ambition is to provide an overview of and insights into the multi-faceted NREN community. It aims to simultaneously depict the diversity of the NRENs as well as illustrate that, despite their variations and particularities, the European NRENs are built around delivery of the same core, interlinked services.

As the NRENs' business is providing infrastructure, many changes are slow. Nonetheless, changes do happen, and to track and present them the right parameters need to be assessed. Therefore, a project such as the Compendium needs to expand its scope when necessary, to document developments that shape and alter the ways NRENs are serving their user base. A good example is the role of NRENs in education: while NRENs have always served the education sector, more recently many NRENs have now moved to offer services that target its needs specifically – and this development has been further accelerated under the influence of the COVID-19 pandemic. Another example is cloud services, where the landscape has changed considerably over the years and with it the role NRENs play in the delivery of these services. Both developments are reflected in the Compendium, which documents these activities.

While the Compendium is in substantial part based on its eponymous annual Compendium survey, it has always drawn from other data sources, which have become more important over the years. The sections on the above-mentioned cloud services and education, and also the section on T&I, are good examples as they are mostly or entirely based on surveys and/or studies that are completely separate from and independent of the Compendium survey. This means that the Compendium provides a platform where results from subject-specific studies from within the NREN community are presented in a summarised form. In this way, information from disparate teams/workgroups can be consolidated and made available in one place.

For NRENs, the Compendium has often been a source of data they could use for various purposes such as lobbying or benchmarking. While the report format has advantages for such purposes as it provides ready-made figures and analysis, it cannot possibly present all aspects of the data in the survey. The team behind the Compendium is therefore working to make the data from the Compendium survey available online. A particular focus here will be on the service portfolio of NRENs, which is of general interest within the community, but it has always proved difficult to document and records of it are often patchy. Efforts are ongoing to improve this state of affairs and the next edition of the Compendium will likely be able to point to an online presence of the underlying data for further research.

APPENDIX A
CONTACT LIST

Table A.1 below lists the NRENs that responded to the 2021 Compendium survey, and contains links to their respective websites. See also [ASSOCIATION].

ACOnet Vienna University Computer Centre	Austria	www.aco.net
AMRES/UoB Akademska mreža Republike Srbije / Univerzitet u Beogradu	Serbia	www.amres.ac.rs
ANA/RASH Academic Network of Albania / Rrjeti Akademik Shqiptar	Albania	www.rash.al/home-en
ARNES Academic and Research Network of Slovenia	Slovenia	www.arnes.si
ASNET-AM Institute for Informatics and Automation Problems	Armenia	www.asnet.am
AzScienceNet Institute of Information Technology of the Azerbaijan National Academy of Sciences	Azerbaijan	www.science.gov.az
BASNET UIIP NASB	Belarus	www.uiip.bas-net.by
Belnet	Belgium	www.belnet.be
BREN Bulgarian Research and Education Network	Bulgaria	www.bren.bg
CARNet Hrvatska akademska I istrazivacka mreza	Croatia	www.carnet.hr
CESNET CESNET, zajmove sdruzeni pravnickych osob	Czech Republic	www.ces.net

CyNet ΚΥΠΡΙΑΚΟ ΕΡΕΥΝΗΤΙΚΟ ΚΑΙ ΑΚΑΔΗΜΑΪΚΟ ΔΙΚΤΥΟ (KYPRIAKO EREVNITIKO KAI AKADIMAIKO DIKTYO)	Cyprus	www.cynet.ac.cy
DeIC Danish e-infrastructure Cooperation	Denmark	www.deic.dk/en/front
DFN Verein zur Förderung eines Deutschen Forschungsnetzes e.V.	Germany	www.dfn.de
EENet EENet of HITSA (Information Technology Foundation for Education)	Estonia	www.eenet.ee
FCT | FCCN Fundação para a Ciência e a Tecnologia Computação Cientifica Nacional	Portugal	www.fct.pt
GARR Consortium GARR	Italy	www.garr.it
GRENA Georgian Research and Educational Networking Association	Georgia	www.grena.ge
GRNET Greek Research and Technology Network	Greece	www.grnet.gr
HEAnet HEAnet Limited	Ireland	www.heanet.ie
LANET Ministry of Education and Science	Latvia	www.lumii.lv
IUCC Inter University Computation Centre	Israel	www.iucc.ac.il
Jisc Jisc Collections and Janet Limited	UK	www.ja.net
LITNET Kauno Technologijos Universitetas	Lithuania	www.litnet.lt

MARnet Macedonian Academic and Research Network	Former Yugoslav Republic of Macedonia	www.marnet.mk
MREN Javna Ustanova Univerziteta Crne Gore Podgorica	Montenegro	www.mren.ac.me
KIFÜ (formerly NIIFI) Kormányzati Informatikai Fejlesztési ÜgynökségNemzeti	Hungary	www.kifu.gov.hu/kifu
NORDUnet (Representative Member)	Denmark, Finland, Sweden, Norway, Iceland	www.nordu.net
PSNC Poznan Supercomputing and Networking	Poland	www.man.poznan.pl
RedIRIS/RED.ES Entidad pública empresarial RED.ES	Spain	www.rediris.es
RENAM Research and Educational Networking Association of Moldova	Moldova	www.renam.md
RENATER Groupement d'Intérêt Public Réseau National de Télécommunications pour la Technologie, l'Enseignement et la Recherche	France	www.renater.fr
RESTENA Réseau Téléinformatique de l'Education Nationale et de la Recherche	Luxembourg	www.restena.lu
RHnet Rannsókna og háskólanet Íslands hf.	Iceland	www.rhnet.is/english
RoEduNet Agentia de Administrare a Retelei Natinale de Informatica Pentru Educatie si Cercetare	Romania	www.nren.ro
SANET Slovak Academic Network Association	Slovakia	www.sanet.sk

SARNET Academic and Research Network of the Republic of Srpska	Bosnia and Herzegovina	www.jusarnet.net
SikIt Sikt – Norwegian Agency for Shared Services in Education and Research	Norway	www.sikt.no
SURF SURF b.v.	Netherlands	www.surf.nl
SWITCH	Switzerland	www.switch.ch
ULAKBIM Turkiye Bilimsel Ve Teknolojik Arastirma Kurumu	Turkey	www.ulakbim.gov.tr
Uninett Uninett AS	Norway	www.uninett.no/en
UoM L-Università ta' Malta	Malta	www.um.edu.mt/itservices/research
URAN Association of Users of Ukrainian Research and Academic Network	Ukraine	www.uran.net.ua

Table A.1: List of 2020 Compendium survey respondents

APPENDIX B
COMPENDIUM AUTHORS

Sara Barba, Administrative Associate (CARNET), works in the Education Support Department (E-Learning Support Service). Her experience includes work on the e-Schools programme; cooperation and coordination regarding activities on contracts for the procurement of services for the organisation and implementation of live and virtual workshops, and work on the development of a set of digital contents intended for independent and shorter learning (micro-learning) of adult learners.

Sebastiano Buscaglione, Senior Network Architect (GÉANT), has several years of experience working in large-scale service provider networks. Before joining DANTE (now GÉANT) in 2012, he worked as part of the AT&T Global Operations department supporting global enterprise VPN services. His main interests are extraction and analysis of network data and its use in driving optimisation in network architectures. Sebastiano's career path includes networking at the CISCO Networking Academy within London Metropolitan University, and industry certifications, such as CCNP and MEF-CECP.

Vincenzo Capone, Head of Research Engagement and Support (GÉANT), is responsible for user support for network solutions provided to pan-European and international scientific groups and collaborations, and in Science and Research engagement activities, with a background in computer science and networking. Previous positions include the Department of Physics at the University of Naples, where Vincenzo was the Network Architect and manager in charge of the computing resources for physics experiments, and Technical Associate to the ATLAS experiment collaboration at CERN.

Tim Chown, Network Development Manager (Jisc), is responsible for developing and promoting new network-oriented services at Jisc. Currently, he is a Work Package Leader on the GÉANT GN4-3 project, which provides connectivity between European national research and education networks (NRENs), and evaluates new technologies and develops new services to run over that network, everything from perfSONAR network monitoring to quantum key distribution (QKD). Tim has been involved in network operations and research since before Jisc's predecessor Janet came into existence, both as a systems manager and then a lecturer in computer science at the University of Southampton, where he is still a visiting fellow. Tim has a long-term interest in IPv6, through the IETF as well as being co-chair of the UK IPv6 Council, and he was one of the original members of the design team that produced eduroam.

Licia Florio, Senior Trust and Identity Manger (GÉANT), is responsible for the T&I services funded in the GN4-3 project. Licia has been working with the research and education community for nearly two decades and has held a variety of roles linked by one central theme: driving innovation and developing new services and initiatives to enable federated access in the NREN as well as research community. She has also heavily engaged in enabling federated access for student mobility. Prior to leading the Trust and Identity Work Package in the GN4-3 project she coordinated the AARC project.

Tom Fryer, Head of International Relations (GÉANT), joined GÉANT as a member of the International Relations Team in 2008. He leads the team that supports GÉANT's relationships with R&E networking partners in other world regions and that manages EU-funded regional development projects. Tom supports dialogue with global R&E network partners in Latin America, Canada and the US and leads GÉANT's involvement in the BELLA programme, in which he is a member of the BELLA Steering Committee and is project manager for the EC funding contracts for BELLA. Tom has a degree in modern languages and linguistics from the University of Essex.

Gyöngyi Horváth, Community Support Officer (GÉANT), was born in Hungary and graduated from the University of Miskolc in 2002, with a master's degree in sociology. Working with the community for over a decade and being responsible for organising the community's annual conference, TNC, she gained a view on many future initiatives. GÉANT recognised the importance for the NREN community of addressing the needs of students and educators by supporting the educational institutions. For this, a new role of Community Support Officer was created in 2018. With it lies the responsibility of working with the NREN community to support their efforts in enhancing their activities for education, developing and implementing a strategy for the GÉANT Association in the area of education and management of engagement in educational areas. She is working with the NREN community to support their efforts in further developing their educational activities and services.

Sarah Jones, EOSC Engagement Manager (GÉANT), works with NRENs on supporting Open Science and is a member of the EOSC Executive Board. She. Sarah has worked in the field of Open Science and Research Data Management for the past decade. Previously she worked as Associate Director at the Digital Curation Centre, and in July 2020 began at GÉANT as EOSC Engagement Manager. She has been involved in several European Commission-funded projects such as EUDAT, OpenAIRE and FAIRsFAIR, worked on Expert Groups for FAIR data and a Transport Research Cloud, and was an independent expert on the EOSC Executive Board.

Sylvia Kuijpers, Community Manager for Research (SURF), is involved in research engagement for the Dutch research community in collaboration with SURF and the SURF organisations SURFsara and the Netherlands eScience Centre. Previously she has worked at Utrecht University as a PhD candidate on cancer research.

Dragana Kupres, Project Manager (CARNET), is a strategic and project manager with almost two decades of experience in the area of e-learning / technology-enhanced education. Her experience includes the international collaboration on the popular E-Learning Academy (2004–06), establishing the Office for EU Projects at CARNET (2011), designing the national e-Schools programme in Croatia (2015–22) and winning the €40 million contract for its pilot phase.

Garvan McFeeley, Brokerage Service Manager (HEAnet), has over 25 years' experience in ICT across a range of sectors including education, telecommunications, manufacturing and financial services. He holds a BSc in Computer Applications from Dublin City University and an MSc from Trinity College Dublin in Management of Information Systems.

Alf Moens, Senior Information Security Officer (GÉANT), has been the Chair of the Special Interest Group on Information Security Management (SIG-ISM) since 2015 and plays a prominent role in GN4-3 where he is Work Package Leader of Work Package 8 Security. Before joining GÉANT, Alf was Corporate Security Officer for SURF, the Netherlands NREN.

Maria Ristkok, Work Package Leader for the GN4-3 project cloud activity (WP4) (EENet), has approximately 20 years of experience in the European networking community, having had different roles, both technical and non-technical, also in the GÉANT project teams (Clouds, Intelligence Gathering, Communication, Campus Best Practice) and Task Forces. She has been the chair and co-chair of the GÉANT Task Force on Marketing Communication and Public Relations and a member of SIG-Marcomms Steering Committee. Maria has a MA in social sciences with a focus on communication management. Maria's great grandfather was announced the holy hieromartyr (saint) of the Greek Orthodox Church in 2012, establishing a spiritual cloud connection as well.

Jennifer Ross, Partner Relations Officer (GÉANT), has experience in public relations and stakeholder management within the public and non-profit sector. Since joining GÉANT in mid-2020 she has been involved in coordinating the production, release and promotion of the Compendium Report 2019 and 2021.

Jakob Tendel, Cloud Services Manager and primary research liaison (DFN), supports GÉANT in its European procurement efforts for cloud services. Jakob is responsible for coordinating the activities of DFN and German user organisations in cloud services adoption and activities in international big data science projects. He holds a PhD in meteorology (having studied clouds quite literally) from the Hannover Leibniz University and joined DFN in 2013.

Daniel Wüstenberg, Community Research Officer (GÉANT), is responsible for collecting, collating and analysing information from and about the NREN community to provide GÉANT and the NRENs with business intelligence. He runs the yearly NREN Compendium survey as one of his main responsibilities. He has several years' experience in market research in different settings and joined GÉANT in 2018.

APPENDIX C
COMPENDIUM ADVISORY BOARD

he Compendium Advisory Board has been recruited from the NREN community to help the Compendium team to steer the development of the Compendium according to the needs of the community. Its current members are:

Nataša Glavor, Assistant Director of the Croation National CERT (CARNET), works on data, analytics, data lakes and databases, and learning analytics systems in the data management team at CARNET. During her career at CARNET, she fulfilled a number of roles, starting in the computer security incident handling team where she became Assistant Director for Computer Security in 2004 and helped to develop the CARNET security programme and introduced security testing as part of the service development process at CARNET. Later, she became involved in service development within CARNET, the management of the .hr domain registry and the security of services. She also participated in various projects, the GÉANT project and the development of learning analytics systems among them. She chaired the programme committee of the CARNET User Conference and was a member of the working group formed to draft information security laws, as well as the UN Internet Governance Forum, the UN Secretary-General's advisory body on Internet governance issues., In July 2021, she was appointed Assistant Director for the National CERT.

János Mohácsi, Head of Research and Development (KIFÜ), is responsible for coordinating national and European e-infrastructure development within the Agency. Since 1996, he has led or participated in more than 20 European and Hungarian projects related to research and e-infrastructures, cloud and information systems, computer, network development and applications, and the formal description of network protocols and solutions. He has been and still is involved in major projects such as Sulinet+, GÉANT, SEEREN,, VI-SEEM and HBONE+. The latter resulted in a European quality research e-infrastructure in Hungary. In these projects, he has gained extensive knowledge in the development of national and European research e-infrastructure. He is a member of the GÉANT Programme Planning Committee (GPPC), and Vice President of the European Open Science Cloud (EOSC) Steering Committee and the Hungarian IPv6 Forum.

Hank Nussbacher, Director of Network & Computing Infrastructure (IUCC), has been working for IUCC since 1986 and has been involved with GÉANT since 2000. Hank has worked as a consultant to numerous companies including Cisco, AT&T, IBM, Checkpoint, Orange and many others, and is a co-author on a patent for selective diversion which is used by all DDoS mitigation companies. He is also the co-author of two IETF RFCs and has presented lectures at numerous RIPE, NANOG, FIRST and Terena conferences. In 1996 and 1997 he was a representative on the International Ad Hoc Committee (IAHC) to determine the future structure of the generic top-level domain system, which served as the basis for the establishment of ICANN, the Internet Corporation for Assigned Names and Numbers.

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[CEF]	www.ec.europa.eu/info/funding-tenders/find-funding/eu-funding-programmes/connecting-europe-facility_en
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[D4.1]	GN4-3 Deliverable D4.1: "Community Clouds Delivery Plan Services Selection, Business Models and Proposed Development Roadmap":
[D4.3]	GN4-3 Deliverable D4.3: "Review of Community Clouds Delivery":
[D7.1]	GN4-3 Deliverable D7.1 GÉANT Network Evolution Plan www.intranet.geant.org/gn4/3/Work-Packages/WP7/Deliverables%20Documents/G%C3%89ANT%20Network%20Evolution%20Plan/D7-1_G%C3%89ANT-Network-Evolution-Plan.pdf [access restricted to project participants]
[D8.1]	GN4-3 Deliverable D8.1 Summary of Security Training and Awareness Campaign Materials: An Investigation and Gap Analysis of Current Security Training and Awareness Resources www.geant.org/wp-content/uploads/2021/11/D8.1-Summary-of-Security-Training-and-Awareness-Campaign-Materials.pdf
[D8.2]	GN4-3 Deliverable D8.2 Security Baseline for NRENs www.geant.org/Projects/GEANT_Project_GN4-3/GN43_deliverables/D8-2_Security-Baseline-for-NRENs.pdf
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[InAcademia]	www.inacademia.org
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[ISCED 2011]	www.uis.unesco.org/Education/Documents/isced-2011-en.pdf
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GLOSSARY

AAI
Authentication and Authorisation Infrastructure

AARC
Authentication and Authorisation for Research and Collaboration

ACL
Access Control List

AI
Artificial Intelligence

AISBL
Association Internationale Sans But Lucratif / International Non-Profit Association

API
Application Programming Interface

APNIC
Asia Pacific Network Information Centre

AUP
Acceptable Use Policy

AW
Alien Wave

AWS
Amazon Web Services

BELLA
Building the Europe Link with Latin America

BPA
Blueprint Architecture

CA
Certification Authority

CAPEX
Capital Expenditure

CCNP
Cisco Certified Network Professional

CEF
Connecting Europe Facility

CERN
European Organisation for Nuclear Research

CISO
Chief Information Security Officer

CJEU
Court of Justice of the European Union

CLAW
Crisis Management Workshop for the NREN Community

CLONETS
Clock Network Services

CoCo
Code of Conduct

CORDIS
Community Research and Development Information Service

CSIRT
Computer Security Incident Response Team

CTO
Chief Technology Officer

CUC
CARNET Users Conference

DCI
Data Centre Interconnect

DDoS
Distributed Denial of Service

DG Connect
Directorate-General for Communications Networks, Content and Technology

DG DEVCO
EC Directorate-General for International Cooperation and Development

DG NEAR
EC Directorate-General for European Neighbourhood and Enlargement Negotiations

DICE
Data Infrastructure Capacity for EOSC

DTN
Data Transmission Network

DWDM
Dense Wavelength Division Multiplexing

EaPConnect
Eastern Partnership Connect

EB
Exabyte (1018 bytes of data)

EC
European Commission

EDPB
European Data Protection Board

EDSSI
European Digital Student Service Infrastructure

eduID
Educational ID

eduroam
education roaming. The secure, world-wide roaming access service developed for the international research and education community.

EuroHPC JU
European High Performance Computing Joint Undertaking

EGI-ACE
Advanced Computing for EOSC, coordinated by the EGI Foundation

eID
Electronic Identification

EO
Earth Observation

EOSC
European Open Science Cloud

ERDF
European Regional Development Fund

ESFRI
European Strategy Forum on Research Infrastructures

ESI
European Student Identifier

EuroCC
EuroHPC Competence Centres

FAIR
Findable, Accessible, Interoperable and Reusable

FE
Further Education

FoD
Firewall on Demand

FPA
Framework Partnership Agreement

FTE
Full-time equivalent

Gbps
Gigabits per second

GDP
Gross Domestic Product

GDPR
General Data Protection Regulation

GN4-3
GÉANT Network 4 Phase 3 project, part-funded from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 856726

H2020
Horizon 2020

HPC
High-Performance Computing

HPC-GIG
High-Performance Computing Governance Intelligence Gathering

HPDA
High-Performance Data Analytics

IaaS
Infrastructure as a Service

ICT
Information and Communications Technology

IdP
Identity Provider

IDS
Intrusion Detection System

IETF
Internet Engineering Task Force

IMF
International Monetary Fund

INFRAEOSC
Enabling an operational, open and FAIR EOSC ecosystem

INFRAG
Infrastructure Advisory Group

IP
Internet Protocol

IPS
Intrusion Prevention System

IPv4
Version 4 of the Internet Protocol (StB IETF), a connectionless protocol used on packet-switched networks. Employs 32-bit IP-addresses.

IPv6
Version 6 of the Internet Protocol (StB IETF), The successor to IPv4, employing a 128 bit IP-address. In addition to a larger addressing space, IPv6 deals with addresses in a hierarchal manner and improves route aggregation.

IRU
Indefeasible Rights of Use

ISCED
International Standard Classification of Education
The classification is:
- Level 8: Doctoral or equivalent level
- Level 7: Master's or equivalent level
- Level 6: Bachelor's or equivalent level
- Level 5: Short-cycle tertiary education
- Level 4: Post-secondary non-tertiary education. This can include, for example, short vocational training programmes.
- Level 3: Upper secondary education
- Level 2: Lower secondary education
- Level 1: Primary or basic education
- Level 0: Early childhood or pre-primary education

The different institutions types are classified as follows:
- Universities and other (ISCED 6–8)
- Further education (ISCED 4–5)
- Secondary schools (ISCED 2–3)
- Primary schools (ISCED 1)
- Research institutes

Libraries, museums, archives, cultural institutions
Non-university public hospitals
Government departments (national, regional, local)
International (virtual) research organisations
For-profit organisations

ISO
International Organisation for Standardisation

ISP
Internet Service Provider

IX
Internet Exchange

IXP
Internet Exchange Point

LHC
Large Hadron Collider

LHCONE
Large Hadron Collider Open Network Environment

LHCOPN
Large Hadron Collider Optical Private Network

LMS
Learning Management System

MEF
(formerly) Metro Ethernet Forum

MEF-CECP
MEF Carrier Ethernet Certification Program

MFA
Multi-Factor Authentication

MIUN
Mid Sweden University

MPLS
Multiprotocol Label Switching

MyAID IAM
MyAcademicID Identity and Access Platform

NI4OS
National Initiatives for Open Science

NREN
National Research and Education Network

OCRE
Open Clouds for Research Environments project. OCRE aims to accelerate cloud adoption in the European research community by providing a framework for providers and users of cloud services and Earth Observation (EO).

OEO
Optical to Electrical to Optical

OLS
Open Line System

OPEX
Operating Expenditure

OTN
Optical Transport Network

PaaS
Platform as a Service

PaNOSC
Photon and Neutron Open Science Cloud

PB
Petabyte (1015 bytes of data)

PID
Persistent Identifier

PRACE
Partnership for Advanced Computing in Europe. The mission of PRACE (Partnership for Advanced Computing in Europe) is to enable high impact scientific discovery and engineering research and development across all disciplines to enhance European competitiveness for the benefit of society.

QKD
Quantum Key Distribution

R&E
Research and Education

R&S
Research and Scholarship

REN
Research and Education Network

RFC
Request for Comments. A formal document drafted by the IETF that describes the specifications for a particular technology. When an RFC is ratified, it becomes a formal standards document.

RO
Roaming Operator

SaaS
Software as a Service

SIEM
Security Information and Event Management

SIG
Special Interest Group

SIG-ISM
Special Interest Group on Information Security Management

SIM
Security Information Management

Sirtfi
Security Incident Response Trust Framework for Federated Identity

SOC
Security Operations Centre

SP
Service Provider

T
Task

T&I
Trust and Identity

TB
Terabyte (1012 bytes of data)

TCS
Trusted Certificate Service

TERENA
Trans-European Research and Education Networking Association

TF
Task Force

TF-CSIRT
Task Force on Computer Security Incident Response Teams

TF-EDU
Task Force on Educational Technologies

TI
Trusted Introducer

TLD
Top-Level Domain

TNC
The Networking Conference (formerly TERENA Networking Conference)

TRANSITS
State-of-the art, high-quality training, coordinated by GÉANT, for Computer Security and Incident Response Team (CSIRT) personnel, as well as individuals with an interest in establishing a CSIRT

UN
United Nations

VPN
Virtual Private Network

WebRTC
Web Real-Time Communications

WG
Working Group

WLCG
Worldwide Large Hadron Collider Computing Grid

WP
Work Package

WP3
GN4-3 Work Package 3 User and Stakeholder Engagement

WP3 T3
WP3 Task 3 Stakeholder Insights

WP4
GN4-3 Work Package 4 Online Services Development and Delivery

WP7
GN4-3 WP7 Network Core Infrastructure and Core Service Evolution and Operations

WP8
GN4-3 Work Package 8 Security