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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 2021. The GÉANT NREN Compendium may be found online at: https://compendium.geant.org/.

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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 2022 focused primarily on the period from January to December 2021, 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 40 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 2022. 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.

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.

[1] This is especially true when percentage increases across NRENs are shown (e.g. Figure 2.3: Development of total NREN budgets since 2019; Figure 2.6: Total staff numbers of the NREN sector; Figure 5.1: Increase of traffic into the NRENs from external networks (upper panel) and NREN end users (lower panel) 2020 to 2022; and Figure 5.5: Development of the NRENs' IRU networks 2019–2022). 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.

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 managers 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 2022 and focuses on the time period from January to December 2021; 40 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 2022 results reveal changes and continuing trends in the NREN landscape, although the changes are mostly gradual.

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, and to their primary users. The data from the Compendium survey should help to trace how NRENs meet this challenge.

Budget and 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 2021 and 2022 (by 3.9% and 8.2%, respectively). The reported budgets across Europe now add up to €826 million.

Organisational context of NRENs

NRENs in Europe share the role of providing network services to their national research and education users. However, they differ considerably in their organisational context. About a quarter of Europe's NRENs are government agencies, while another quarter are member-organisations set up by the R&E community. In between those extremes are mixed forms where both user institution and government participate in the NREN's governance to different degrees. The degree to which NRENs are user-organised or government-controlled generally correlates (with some exceptions) with their funding model: government agencies tend to receive all or most of their money from the government while user-organised NRENs are for the most part user-funded institutions; mixed-governance NRENs tend to receive funding from both sources.

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). About two thirds of all NRENs are engaged in European projects. This share has 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 mostly increased over the past years, across all NRENs. However, the COVID-19 crisis interrupted this pattern and a marked decrease in traffic could be observed in 2021, which likely reflected the reduced presence of students and employees at the R&E institutions. This seems to have reversed now, mirroring the fading pandemic, and traffic has grown again. In the case of the GÉANT network it has even topped traffic levels from before COVID.

In line with this, NRENs expect the upward trend to continue into the medium term: for the years 2022–2025, 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 about 70%. Similarly high growth is also expected to come from research institutions, with 74% traffic growth, and universities, estimated to grow by 68%.

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 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. 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 currently most NREN services in the educational sector either facilitate teaching (as online teaching or VLEs) or ease the administrative burden on universities and schools, a system of digital academic credentials is being considered, which would make participating NRENs part of an accreditation system for digital diplomas.

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 provided 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 GNx-n projects, of which the incarnation relevant for this Compendium Report was 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] was to provide the European research sector with an infrastructure that promotes scientific excellence through access to and reuse of research data. It also aimed to make scientific infrastructures Europe-wide more cost-efficient through the promotion of interoperability with other e-infrastructures. GN4-3 and GN4-3N began in 2019 and were funded by the EC's Directorate-General for Communications Networks, Content and Technology [DG Connect]. GN4-3 continued until the end of 2022 and has since been succeeded by GN5-1, while GN4-3N will continue until the end of 2023.[3]

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.

In addition to the pan-European coverage, therefore, GÉANT's global connectivity enables the European R&E community to collaborate with peers and access data sources in more than 65 countries and territories outside Europe, with a total global capacity today of nearly 1.9 Tbps, including 1 Tbps to the USA and Canada, 200G Gbps to Latin America, 230 Gbps to Sub-Saharan Africa, nearly 150 Gbps to North Africa and Western Asia, and 260 Gbps to the Asia-Pacific region. Intercontinental links are provided through a variety of approaches, with some funded by GÉANT members and the GÉANT project, and others in collaboration with or by R&E networking partners. In order to maximise the benefit of all global links, GÉANT works with R&E networks in Europe and across the globe to establish mutually supportive back-up collaborations, thereby ensuring that if one link suffers an outage, traffic is quickly and efficiently switched to other paths. This is done today through the Advanced North Atlantic (ANA), Asia-Europe Ring (AER) and Bridging Europe, Africa and the Americas (BEAA) collaborations.

The development of GÉANT's global reach has been substantially advanced thanks to support received over two decades from the European Commission via the Directorate-General for International Partnerships [DG INTPA]

[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 and SUNET) have formed their own regional ISP, NORDUnet, which takes part in the GNx-n projects.
[3] GN4-3 had a budget of €118,879,719 (with an EC contribution of €77,500,000); GN4-3 ended in December 2022 and has been followed by GN5-1, which started in January 2023. GN4-3N will run until December 2023 and has a budget of €63,125,000 (with an EC contribution of €50,500,000).

and the Directorate-General for European Neighbourhood and Enlargement Negotiations [DG NEAR] through regional development programmes: EUMEDCONNECT (North Africa and the Eastern Mediterranean), ALICE (Latin America), TEIN and Asi@Connect (Asia-Pacific), CAREN (Central Asia). Current projects are AfricaConnect3 [AfricaConnect3] and Asi@Connect [Asi@Connect].

2 NREN Organisations

This section of the Compendium report considers the NRENs as organisations, looking at their funding model and governance structures, funding sources, annual budgets and staffing.[4]

2.1 Funding Model 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 (8 NRENs), Represented via Public Funding Bodies (4 NRENs), Board Representation (10 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 or no 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 2.1 below.

FUNDING MODEL	NO GOVERNMENT REPRESENTA-TION	REPRESENTED BY PUBLIC FUNDING BODY	BOARD REPRESENTA-TION	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, Sikt
Government subsidised	SANET		AMRES, RESTENA	ARNES, CARNET, GRNET, RedIRIS	AzScienceNet, EENet, FCCN, KIFÜ, LAT, MARnet. MREN, RoEduNet, ULAKBIM

Table 2.1: 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.

[4] 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].

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 (14 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 2.2, which plots the two stakeholder types against each other – as a rule of thumb, more user influence means less government influence and vice versa.[5]

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, DelC, 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, Sikt

Table 2.2: User representation vs. government representation in NREN governance structures

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 Chapter 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 2.1).

[5] In Azerbaijan, the National Academy of Sciences is a government structure organised as a membership organisation of scientific institutes. AzScienceNet is part of one of these institutes, the Institute of Information Technology, and acts as a support organisation for the Academy. This institutional setup results in the slightly odd classification as a membership organisation without (formal) presentation of the members.

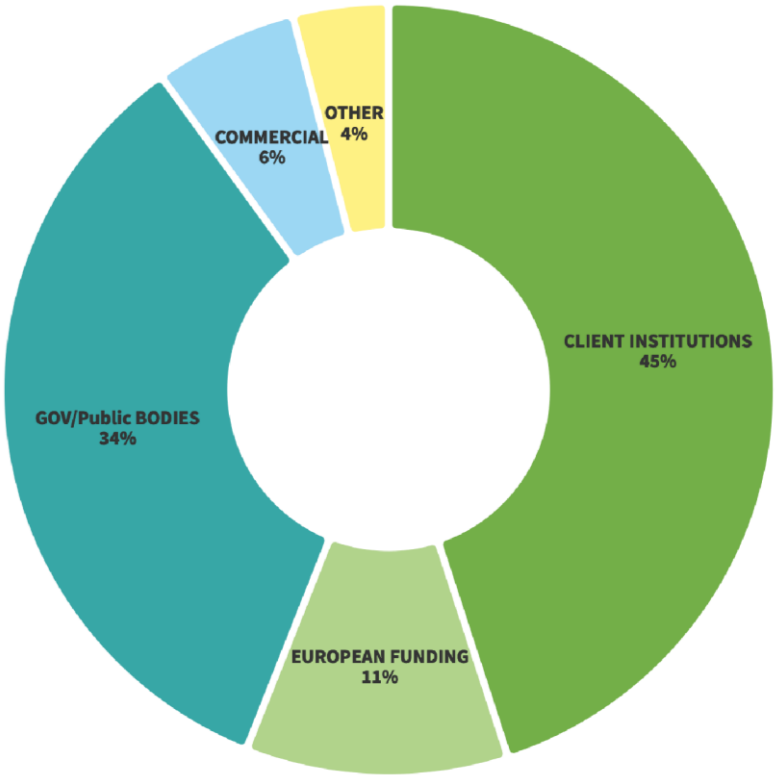


Figure 2.1: Funding sources of NRENs. This figure shows the share of different funding sources for the combined total of European NRENs' budgets. The numbers are based on the survey responses of the NRENs that provided their budget numbers as well as their income sources (37 out of 43). The percentage 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 budget.

Interestingly, there have been some changes compared with 2021: the share contributed by client institutions has increased from 32% to 45% and direct government funding has dropped from 38% to 34%. The funding through European funds has decreased, from 17% to 11%.

While Figure 2.1 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 2.3).

	CLIENT INSTITUTIONS	EUROPEAN FUNDING	GOV/Public BODIES	COMMERCIAL	OTHER
ACOnet	100%				
AMRES			100%		
ARNES		1%	87%	12%	
ASNET-AM	10%	45%	43%		
BASNET	32% (29%)	51% (56%)	17% (15%)		
Belnet	45% (46%)	1% (0%)	49% (49%)	5% (6%)	
CARNET		71% (72%)	27% (26%)	2% (1%)	1% (0%)
CESNET	16% (21%)	30% (3%)	47% (73%)	2% (0%)	6% (1%)
CYNET	70% (65%)	25%	5% (10%)		
DeIC	96% (98%)	3% (1%)	1%		
DFN	97%	1% (1%)	1% (0%)	1% (0%)	0% (1%)
EENet		1%	99%		
FCCN	3% (3%)	21% (25%)	76% (72%)		
Funet	60%		40%		
GARR	90%	2%	8%		
GRENA	45% (40%)	45% (50%)		5%	5%
GRNET S.A.		26% (25%)	74% (70%)		0% (5%)
HEAnet	13% (16%)		78% (72%)	8% (10%)	1% (2%)
IUCC	89% (82%)	3% (12%)	8% (6%)		
Jisc	19% (20%)	0% (1%)	50%	31% (30%)	
KIFÜ	8% (4%)	2% (3%)	90% (93%)		
LAT			100%		
LITNET		40% (50%)	60% (50%)		
MARnet		22% (35%)	25%	53% (40%)	
MREN		20%	70%		5%
RASH	8%	2%	90%		
RedIRIS		39% (41%)	60% (58%)		1%
RENAM	23% (18%)	70% (80%)	3% (2%)		
RESTENA	7%	2%	34% (32%)	40% (37%)	17% (21%)
RoEduNet			100%		
SANET	7%		94%		
SUNET	70%		20%		10%
SURF	76%	2%		22%	
SWITCH	56% (58%)	0% (1%)	0% (1%)	43% (41%)	
ULAKBIM	94% (0%)	3% (0%)	0% (100%)		3% (0%)
URAN	35% (62%)	47% (16%)	0% (1%)	16% (19%)	2% (2%)

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

Table 2.3: 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 2021 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 2.2 summarises how NRENs are distributed over these funding models.

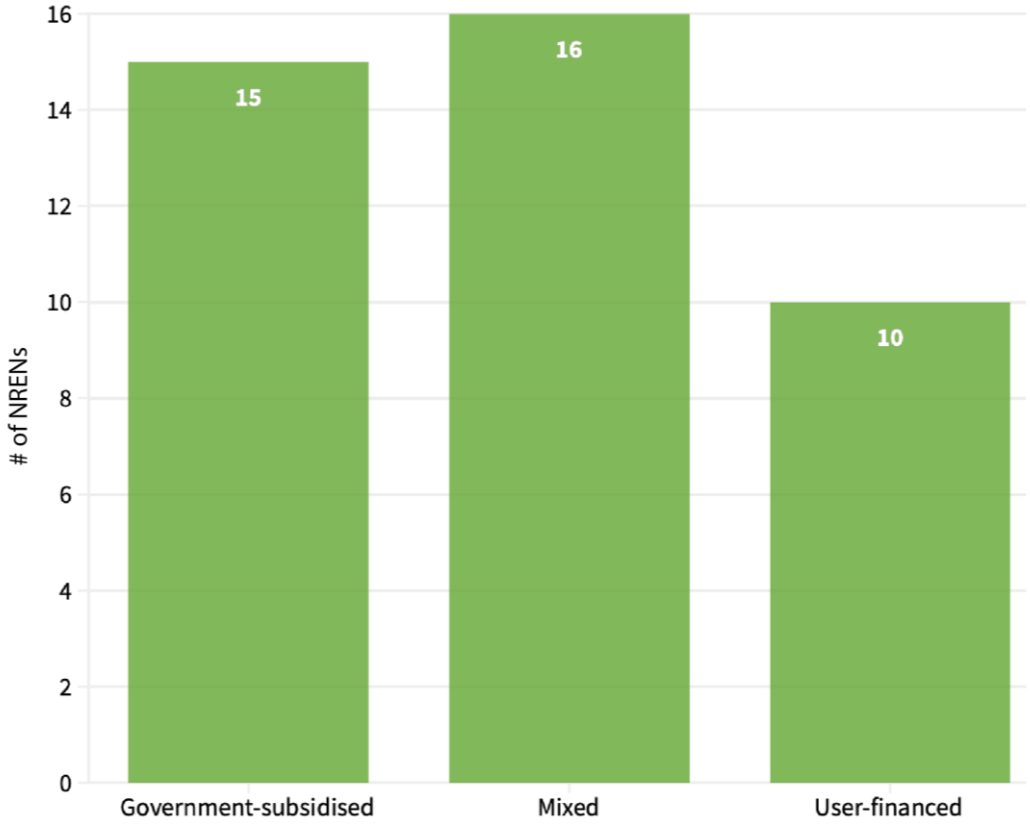


Figure 2.2: NREN Funding models. 15 NRENs can be considered government-subsidised (AMRES, ARNES, CARNET, EENet, FCCN, GRNET, KIFÜ, LAT, MARnet, MREN, RedIRIS, RESTENA, RoEduNet, SANET, ULAKBIM) while 10 NRENs are mostly user-financed (ACOnet, DeIC, DFN, GARR, GRENA, IUCC, RENAM, RHnet, SWITCH, URAN). Mixed funding is used by 16 NRENs (ASNET-AM, AzScienceNet, BASNET, Belnet, BREN, CESNET, CyNet, CSC/Funet, HEAnet, Jisc, LITNET, RASH, RENATER, SUNET, SURF, Sikt). 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.

As not-for-profit organisations, only a minority of NRENs (13 of 43) have a commercial income. A variety of activities are commercialised by NRENs[6] 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[7] or run important national Internet exchanges (IXs).[8]

2.3 Budget

Budgets play a pivotal role in determining an organisation's capacity to provide services, which means NREN budget figures are a significant part of the NREN story. In general, budgets allocated to NREN activities have demonstrated a significant increase over the last half-decade, as illustrated in Figure 2.3 (19 NRENs reported an increase in budget from 2020 to 2021). Of course, this trend does not necessarily hold true for every NREN, as demonstrated by the variation in the budgets according to the 2021 and 2022 surveys of individual NRENs, depicted in Figure 2.4. While the trend of increasing budgets evident in Figure 2.3 is still recognisable, 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.[9] Certain budgetary increases may also be attributed to accounting changes.

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.[10] The roles national NRENs play vary considerably, which is reflected in their budgets.

[6] 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.

[7] ACOnet, ARNES, BASNET, Belnet, CARNET, DFN, EEnet, GARR, GRENA, GRNET, HEAnet, Jisc, KIFÜ, MARNET, MREN, RENAM, RENATER, RESTENA, SANET, Sikt, SURF, SWITCH, URAN register domain names, though many of these NRENs limit this service to their traditional users and do not derive commercial income from it.

[8] Belnet, FCCN, MARnet, MREN, PSNC/PIONIER, RASH, RedIRIS, SURF, SWITCH, RESTENA run internet exchanges, though not all of these are commercialised.

[9] RedIRIS's budget decrease of €5 million reflects the end of some European Regional Development Fund (ERDF) projects.

[10] 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. in Estonia, Norway and the Netherlands). In the Netherlands, the merger of SURFnet (the original NREN) with SURFsara (HPC) and SURFmarket (ICT marketplace) has created SURF, an organisation with a budget of €230 M (SURFnet in 2020 had a budget of €54 M).

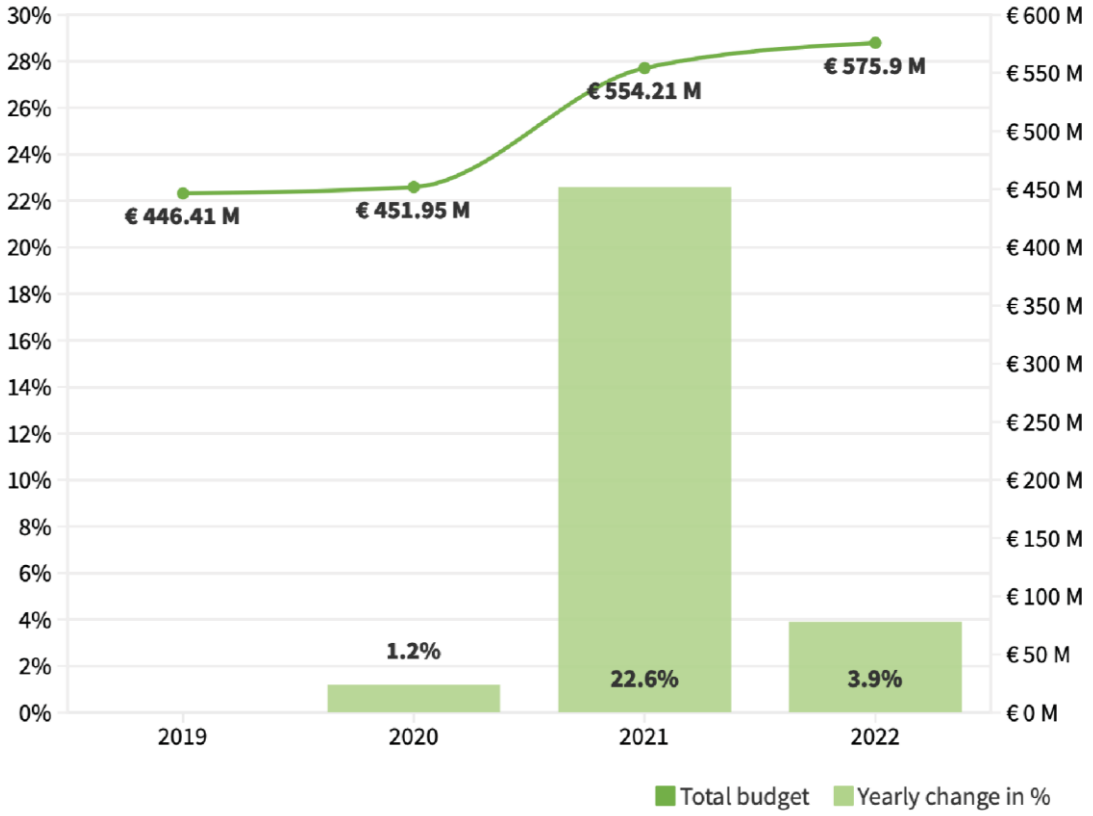


Figure 2.3: Development of total NREN budgets since 2019. The numbers are based on 35 NRENs that reported their budgets continuously throughout this period. This means that some larger NRENs are not included and therefore the actual total budgets will have been higher. (For comparison, the total budget according to the 2022 survey results based on the data for all responding NRENs that year is €826 M). The percentage change is based on the previous year's budget.

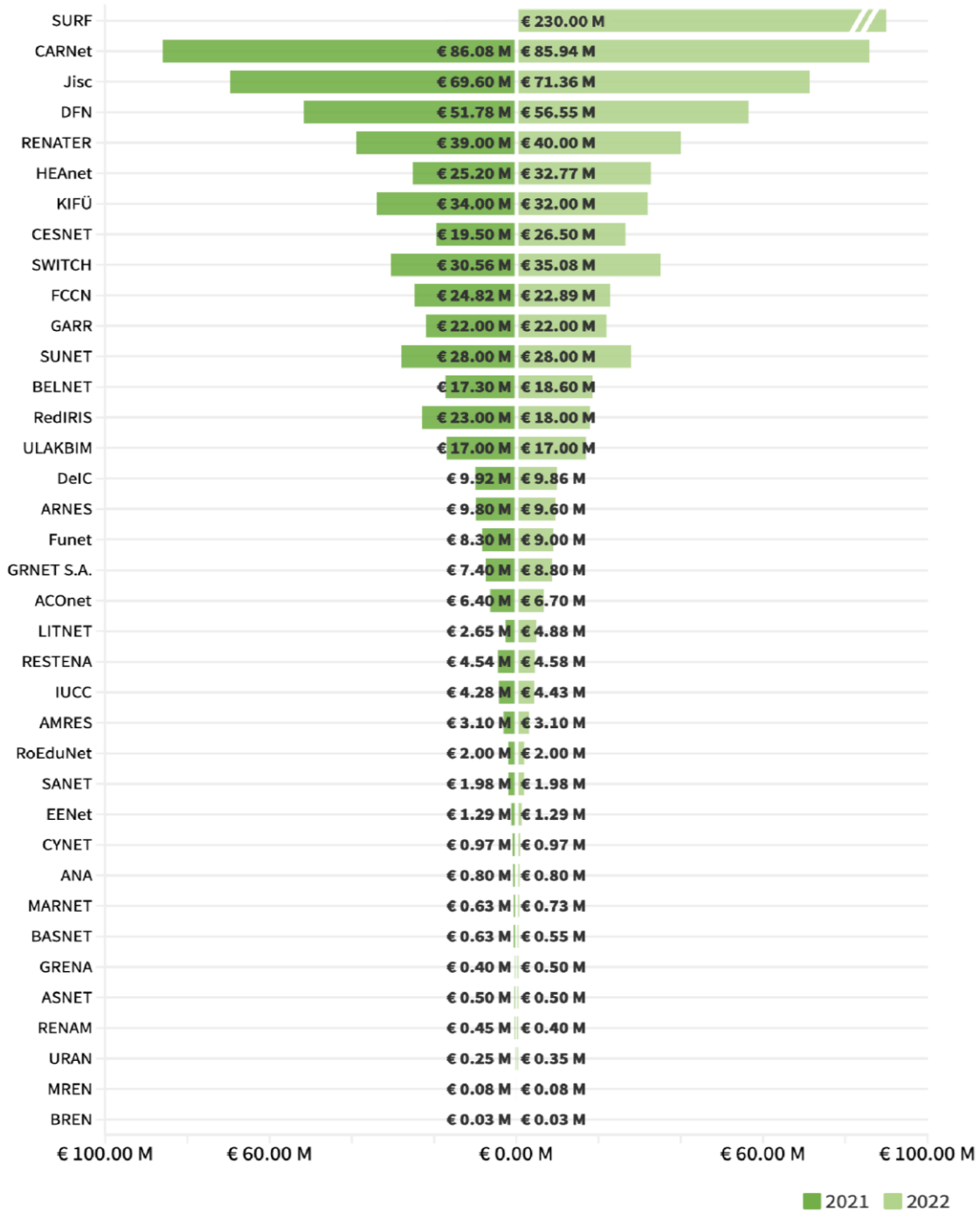


Figure 2.4: Individual NREN budgets in the 2021 and 2022 surveys. The figure includes NRENs that have provided budget numbers for only one of these years, hence the occasional gap. Overall, 16 NRENs reported an increase in budget, 12 no change and 12 a reduced budget.

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 2.4, where NRENs from larger countries tend to have larger budgets – although there are quite a few exceptions.[11] This becomes even clearer in Figure 2.5, which shows NREN budgets normalised to

[11] Note that the top ten budgets feature the NRENs of only four of the 10 largest European countries (ULAKBIM/Turkey, RedIRIS/Spain, RoEduNet/Romania and URAN/Ukraine are not in the top 10). SURF (Netherlands) would likely make it into

Gross Domestic Product (GDP) and population. In this case, the correlation between country size and NREN budget that is still visible in Figure 2.4 disappears. Figure 2.5 orders the NRENs by budget per GDP, which allows budgets to be compared based on the economic strength of countries (as reflected in the GDP). As an example, the UK's Jisc, which has a large budget in absolute numbers, is average by this measure, while Hungary's KIFÜ, with about half of Jisc's budget size, is in second place among all the NRENs.

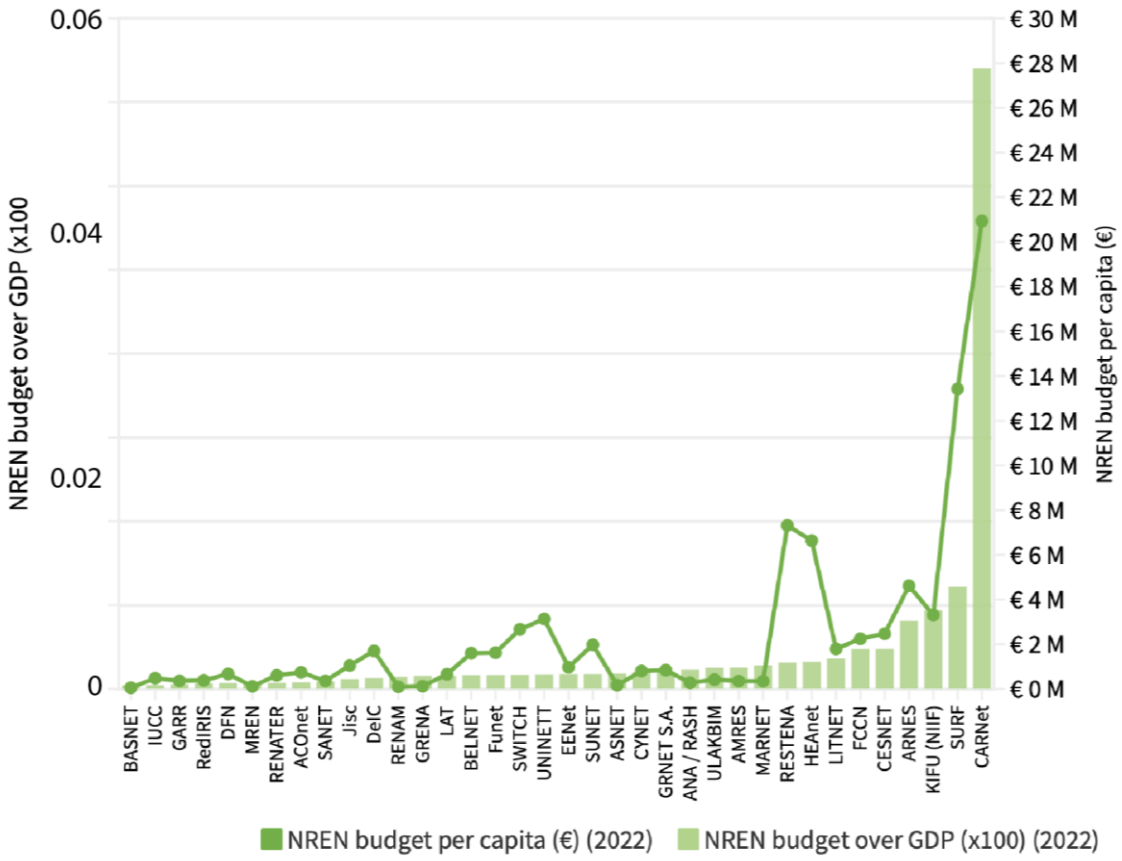


Figure 2.5: NREN budgets normalised to GDP and population. The numbers shown here are simple indices formed by dividing the NRENs' budgets by the GDP (in Billion € x100) and population sizes. Both indices give a measure of national spending on research and education networks, but are looking at different 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.

The data presented in Figure 2.5 [12] is indicative of the significant differences observed between NRENs, attributable to a multitude of factors. Of particular relevance to this report is the observation that the business models of NRENs exhibit considerable variability, with some organisations expanding beyond their core function

the top 10 as its budget is traditionally high (€230 million in 2022) but they have not provided budget numbers for 2021. Similarly, PSNC (Poland) did not disclose their budget but they also would likely rank in the top 10.
NRENs from several significantly smaller countries, such as SWITCH (Switzerland), CARNET (Croatia), HEAnet (Ireland), and KIFÜ (Hungary) make the ranking instead.

[12] 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 wider 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 2.5: NREN budgets normalised to GDP and population).

as an academic Internet Service Provider (ISP). NRENs occupying the top ranks in either index (budget over GDP or budget per capita) tend to offer an extensive range of services beyond connectivity, such as procurement support, computational resources, and educational resources, among others. Furthermore, these organisations frequently extend their services to communities beyond the traditional scope of NRENs, necessitating additional funding (and human resources – as elaborated below).[13]

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 2018 and 2022, 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 2022 Compendium survey reached 2,951.

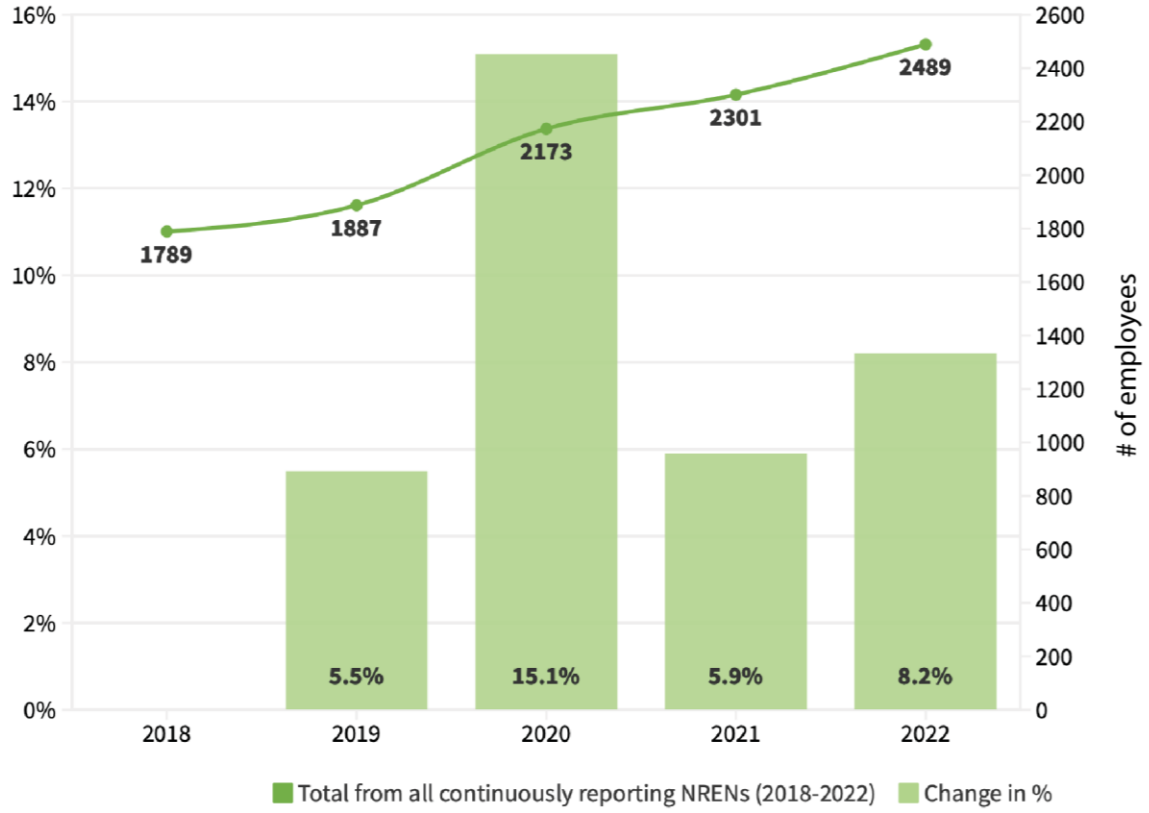


Figure 2.6: Total staff numbers of the NREN sector. The percentage change is based on the earlier year's staff numbers. While the total number of staff reported in 2021 was 2,951, the data series shown in the graph is based on those NRENs that reported their staff numbers continuously throughout this period, which means that some NRENs are not included (see footnote 1).

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 2021 and 2022 is presented in Figure 2.7. While changes in employee numbers are apparent in these data, they are generally not

[13] 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.

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.[14]

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. The overall ratio between the two employment categories has seen little change over the years, starting with about 13% of subcontracted positions in 2017, 12% in 2018, 13% in 2019, 14% in 2020, 15% in 2021and 14% in 2022. The slight variation is most likely just noise in the data generated by the variability in the survey response rate.

[14] Two obvious examples for this are SURF and Sikt, which have grown into huge organisation by NREN standards. In both cases, several IT-related organisations merged to form a larger organisation. In SURF's case these were SURFnet (NREN), SURFsara (HPC), SURFmarket (ICT procurement); in Sikt's case these were Uninett (NREN), NSD (Norwegian Center for Research Data), and Unit (Directorate for ICT and joint services in higher education and research). Such large e-infrastructures provide services well beyond the "traditional" role of NRENs as ISPs, which makes it a bit of a judgement call whether to count all employees as NREN employees. Jisc, another very large organisation, chose to reassess the way they categorise employee roles, resulting in a much lower headcount involved in NREN activities; the massive decrease visible in the figure therefore did not involve mass layoffs. Many NRENs generally are in a challenging situation concerning staff recruitment, as public services have to compete with the commercial sector for qualified staff.

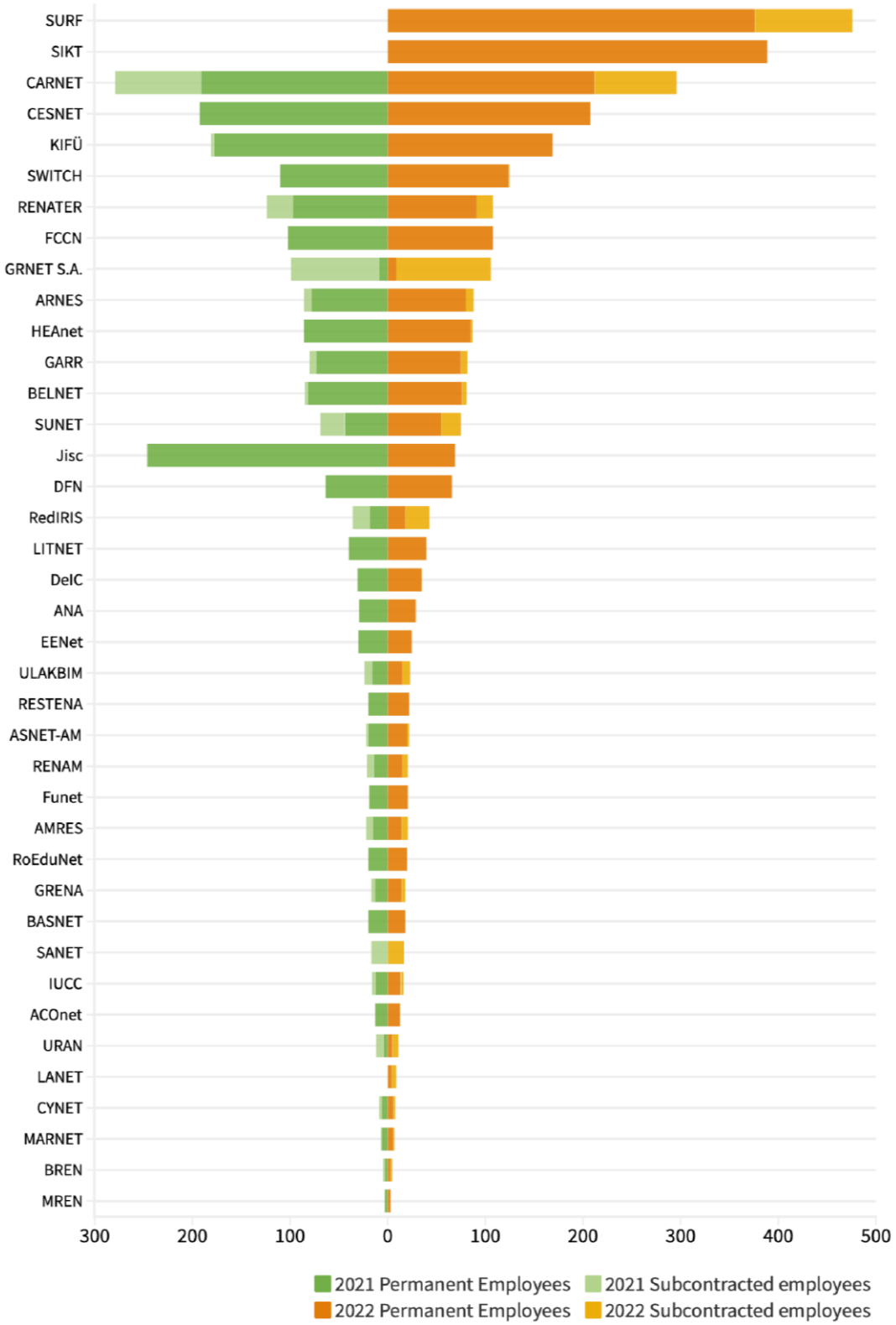


Figure 2.7: Staff numbers of NRENs in the years 2021 and 2022. The figure includes NRENs that have provided staff numbers for only one of these years, hence the occasional gap. The steep drop in the number of employees that is apparent in the UK NREN Jisc resulted from a reassessment of the way they categorise employee roles, leading to a much lower headcount involved in NREN activities.

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.[15] Nevertheless, there is considerable variation between NRENs, which again emphasises how different NRENs are from each other.

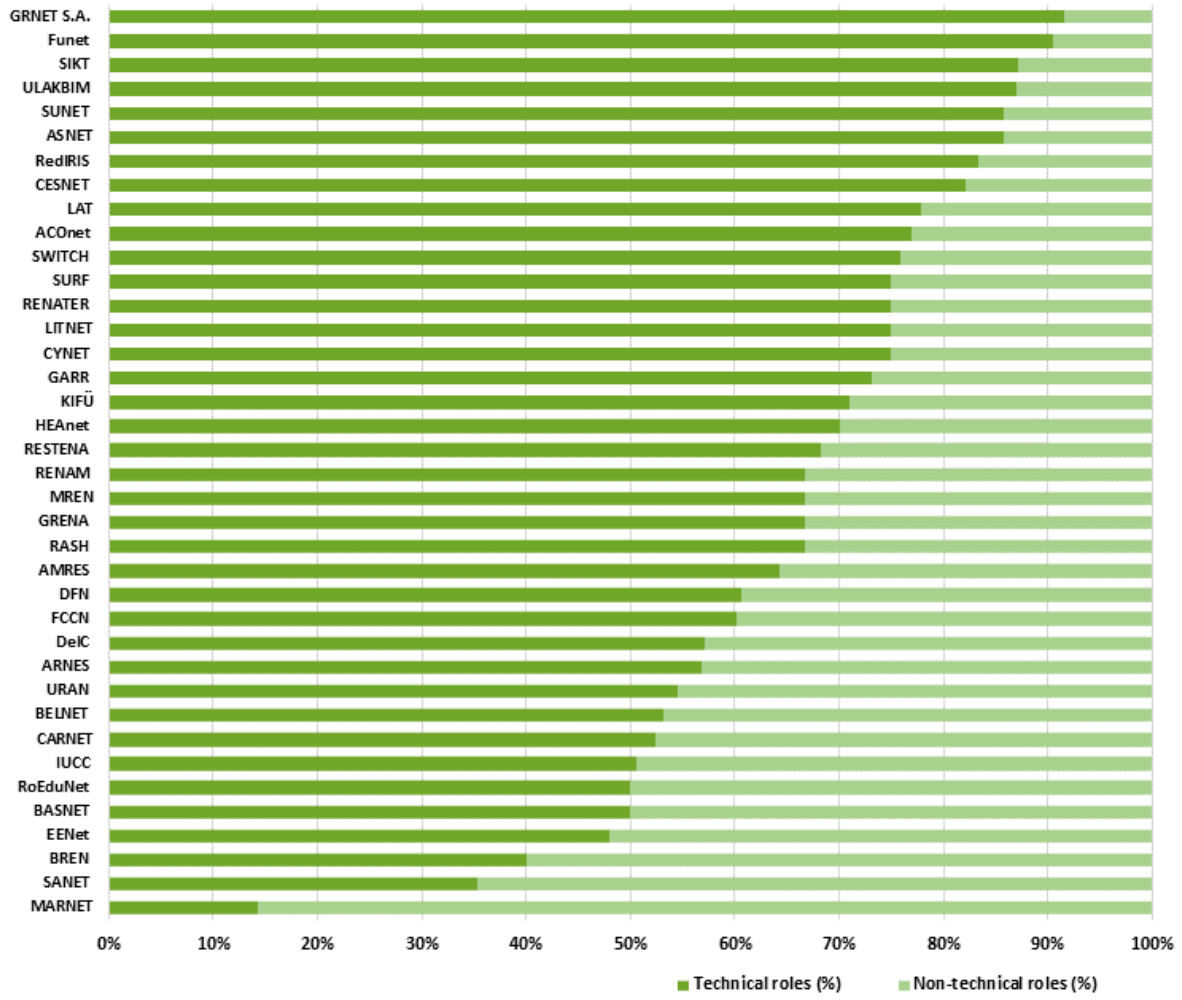


Figure 2.8: Share of technical roles among staff numbers. For the purpose of this figure, non-technical roles are e.g. legal, finance, HR and PR, while technical roles would be network operation, software development or IT security.

2.5 Summary

The NREN sector is experiencing growth in both funding and staffing, indicative of an increasing investment in the public ICT infrastructure of the R&E sector in Europe as a whole. This investment is predominantly derived from public sources, either directly or via contributions from publicly funded customer institutions. While such funding provides relatively stable income during normal times, it also renders the funding strongly reliant on the state of public finances.

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

At the level of individual NRENs, the data presented in this section underscore the diversity of NRENs, wherein both staffing levels and budgets exhibit significant variation, even when corrected for the size of the NREN's home country. This variability reflects the distinct set of responsibilities NRENs are entrusted with. These observations will be further elaborated upon in the following section detailing the NRENs' user base.

3 End Users

NRENs offer their services to a range of different user types. Research and higher education institutions (i.e. universities and research institutes) are the core end users of all NRENs. However, many NRENs provide connectivity and other services to a wider group of constituencies beyond this core "market". Generally, these are public institutions, including primary and secondary schools, libraries or government organisations. Under some 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 among the institutions connected to each NREN, and link capacities provided to different types of connected institutions.[16]

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.

[16] To differentiate between different types of education institutions in a consistent way across different national education systems, this section follows the ISCED 2011 classification system (the UNESCO scheme for International Standard Classification of Education) [ISCED 2011].

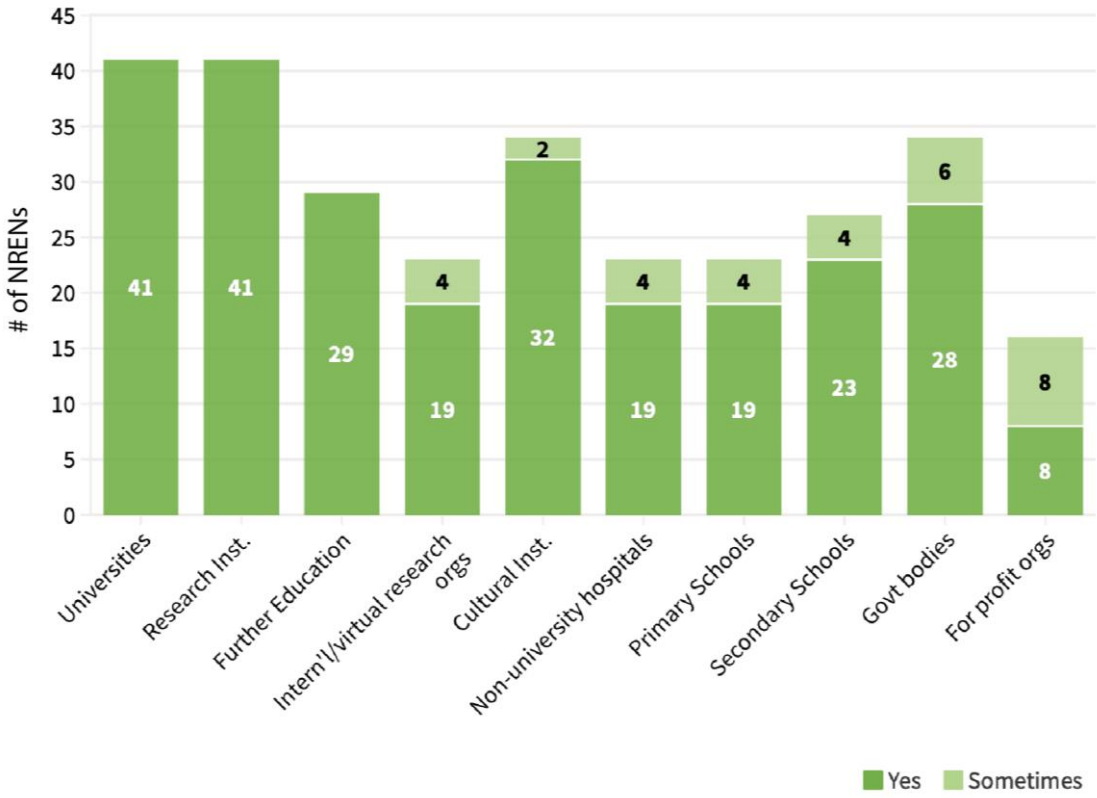


Figure 3.1: The number of NRENs connecting different user types. While higher education and research are clearly the core of NREN activity, most NRENs also serve other user groups in the public space. "Sometimes" refers to special situations: an example would be start-up companies that have grown out of the R&E sector.

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. In 2022, for the first time, all NRENs that responded to the Compendium survey 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 as well.)

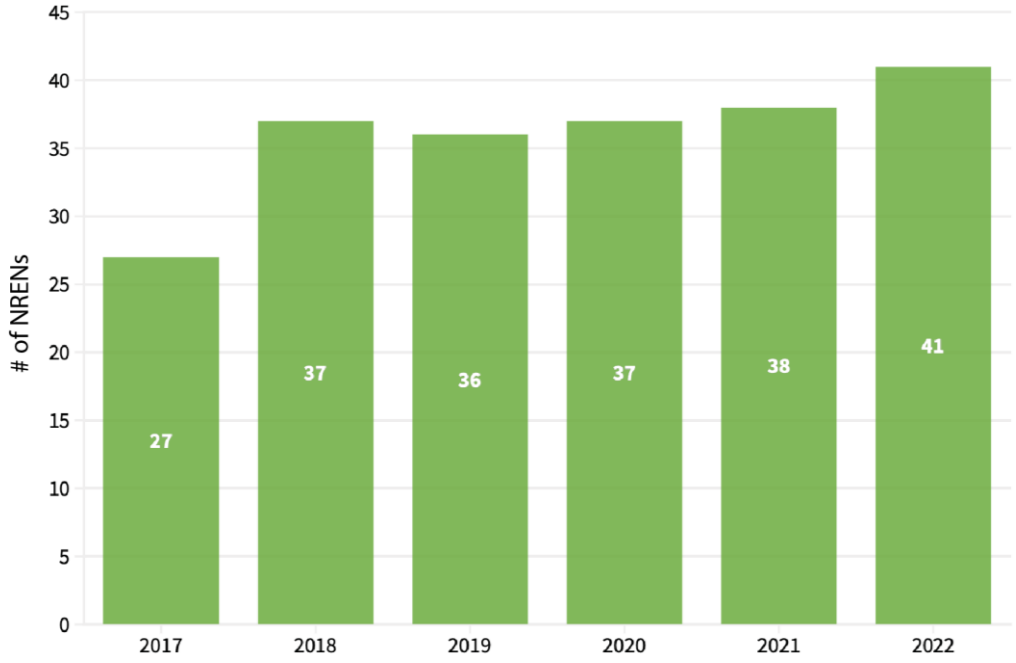


Figure 3.2: Number of NRENs that reported having an acceptable use policy (AUP) in place. The slight drop in the number of AUPs from 2018 to 2019 is due to the varying response rate. Between 2017 and 2022, no NREN has reported having abandoned an existing AUP, and in 2022, all NRENs responding to the survey have an AUP in place.

3.3 Approximate Market Shares for Different Types of Institutions

An NREN's connectivity remit defines which institution types it may connect but not whether a given category of institutions actually makes up a sizeable part of its customer base. To determine this, the Compendium survey asks NRENs to give an estimate of their market share for different user categories.[17] The estimated market shares per institution type, per NREN, are presented in Table 3.1.

The overall market share distribution in 2022 is comparable to that of 2021. 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.[18] Where schools fall into an 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 are a directly state-funded "public infrastructure", which makes them a natural resource to turn to when ISP services are needed for public institutions. This is also reflected in the numbers: of the 16 NRENs that are (mostly) government-funded, 8 provide connectivity to a significant number of schools (market share of 40% or more) while of the 10 NRENs that receive no (direct) government-funding, only one connects schools (see also Section 2 for a discussion of funding models).

[17] No commercial implications are intended by this term; it is used in the Compendium survey as a convenient shorthand.
[18] There are exceptions. URAN only connects about a third of the Ukrainian universities, and only 50% of Israel's universities are making use of IUCC's services.

Overall market shares are not very dynamic, and large jumps are rare; in most cases, noticeable changes take several years and the 2022 results are almost identical to those of 2021.[19]

	Universities	Research Ins.	Further Education	Inter'l research Inst	Libraries	Hospitals	Primary Schools	Secondary Schools	Government	For-Profit Orgs
ACOnet	85				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			34					
BELNET	90	75	1		1	5	5	5	20	
BREN	50	100								
CARNet	100	98	10		1	94	99	99	81	1
CESNET	95	97	7	90	3	25	2	6	11	
CYNET	100	70	40							
DeIC	100	25	33	50	10	60		1	5	1
EENet	89	4	71		8		13	49	10	
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	95	95		10	5	94	97	1	
LITNET	90	100	80		19	10	16	50	10	
MARnet	100									
RedIRIS	90							60		
RENAM	65	70	11		1	3		0.01	5	5
RENATER	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	4	6	8	8		1
SWITCH	100				5					
ULAKBIM	96	10			0.1				2	

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 and therefore are missing from the table. 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.

3.4 Typical and Highest Capacity of Connected Institutions

All users have to be connected to the NREN's backbone. The capacity of these links is an important parameter as it determines the amount of data transfer they can support. The typical link capacity for connected institutions ranges from 1 Mbps up to 100 Gbps (Figure 3.3). Looking at both the typical (Figure 3.3) and the highest capacity links (Figure 3.4) provided to different types of institutions shows a pattern that reflects the needs of the

[19] 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.

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. Both figures juxtapose typical and highest capacity links from 2019 and 2022 and for all user categories. The share of high-capacity links (500–1,500 Mbps and >1,500 Mbps) has increased while the share of low-capacity links (<500 Mbps) has decreased. Clearly, many NRENs have upgraded their offers. Among those are EENet, Funet, RESTENA and ULAKBIM, which now all provide high-capacity links to universities and research institutes by default, which wasn't the case in 2019.

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 overcapacity when they are designed.

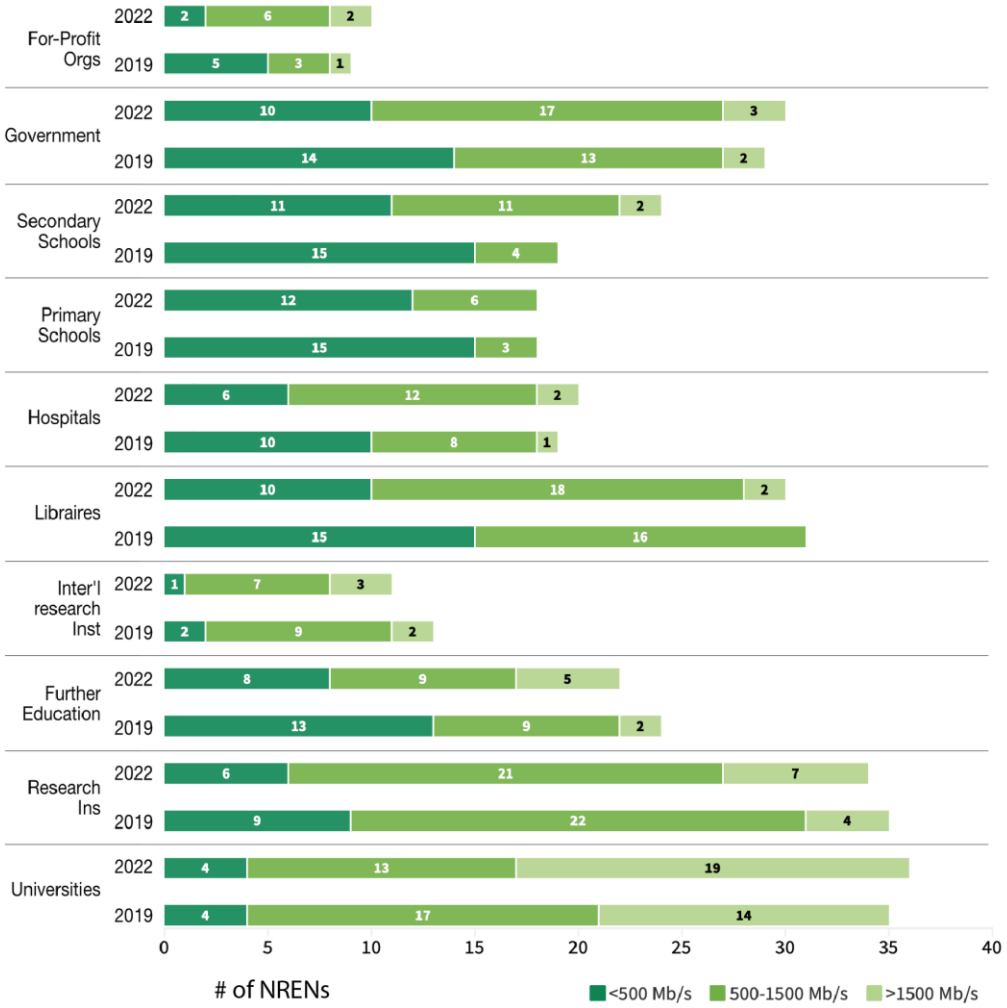


Figure 3.3: Typical link capacities provided by NRENs to different types of connected institutions in 2019 and 2022. For the purpose of this figure, link capacities have been grouped into three capacity categories: less than 500 Mbps, 500–1,500 Mbps, and beyond 1,500 Mbps. The figure also shows that NRENs 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. Comparing 2019 and 2022 results also shows that NRENs have increased the typical capacity of the last mile link across all their user types, i.e. the lower capacity categories counts have decreased while higher capacity categories counts have increased.

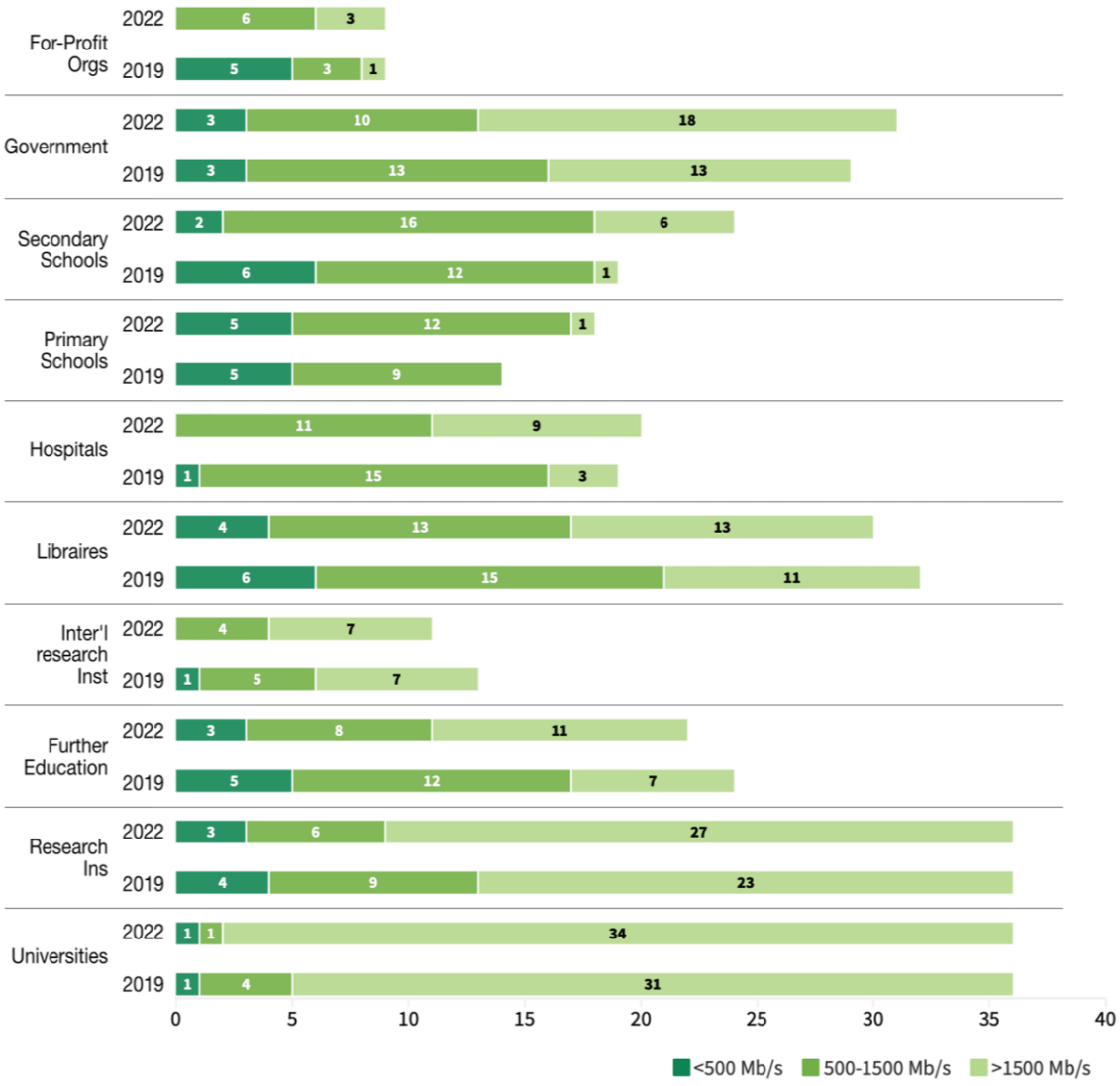


Figure 3.4: Highest link capacities provided by NRENs to different types of connected institutions in 2019 and 2022. For the purpose of this figure, link capacities have been grouped into three capacity categories: less than 500 Mbps, 500–1,500 Mbps, and beyond 1,500 Mbps.

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 (RRENs) 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 (the exception to the rule being 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.	FURTHER EDUCATION	INTERN'L RES. INST.	CULTURAL INSTITUTIONS	HOSPITALS	PRIMARY SCHOOLS	SECONDARY SCHOOLS	GOVERNT	FOR-PROFIT ORGS
NRENS provides access link	27	23	14	8	19	12	5	9	13	4
Access link by regional REN	4	4	2	2	4	3	3	2	3	1
Commercial providers	3	6	8	1	5	4	10	9	7	1
Metropolitan area networks (MAN)	2	1	1	1	2	1	2	2	3	1
Other	2	1	0	2	1	1	2	4	5	3

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. Regarding 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. Note also that some NRENs have not provided this information and are therefore not present in this table (BREN, LANET, RHnet, UoM).

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, CESNET, LITNET, RENAM, RoEduNet, SWITCH, ULAKBIM). Belnet uses a MAN for all institutions within the Brussels area and PSNC PIONIER uses MANs for all of their links.

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
BELNET	498,902	32,491	900	2,788	2,094	19,560		61,896	147,643	
BREN	150,000	5,000								
CARNet	200,000	5,000	1,000	100	300	14,000	400,000	205,000	53,000	100
CESNET	400,000	50,000	5,000	500	4,000	5,500	4,000	23,000		
CYNET	80,000	150	600							
DeIC	150,000	1,200	100,000	100	1,000	80,000		7,000	1,000	
FCCN	448,468						481,890	566,634		
Funet	370,000	26,000			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		12,000	25,000	100,000	100,000	2,000	
HEAnet	250,000						600,000	400,000		
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	
MREN	20,000									
RENAM	74,500	2,900	850					208		
SURF	750,000	120,000	430,000	10,000	18,000	30,000	60,000	60,000		
SWITCH	332,051		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

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.[20]

3.7 Digital Health

The European NRENs are dealing with support to the national and international Digital Health community at various levels, and with different degrees of involvement, thus providing a very heterogeneous landscape within the GÉANT community in relation to engaging with the Health community.

[20] 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).
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.

Health community support ranges from advanced involvement by the NREN, providing tailored storage services, specific cloud computing services, or cloud-based authentication and authorisation infrastructure (AAI) solutions for Health, to a very minimal or completely missing engagement with Health institutions or key Health initiatives and projects. It is therefore challenging to define what common goals, challenges and ambitions could be pursued within the GÉANT NRENs in relation to the support to be provided to the Digital Health community.

Despite this heterogeneity in relation to the Digital Health landscape, there are common interests numerous NRENs share.

The first key common element is the great interest about the forthcoming EU regulations, and, specifically, the European Health Data Space (EHDS).[21] The EU is indeed working towards the definition of interoperable common European Data Spaces, including EHDS1 ("MyHealth@EU"), a continental e-infrastructure for primary health care and for the provisioning of cross-border health services, which should integrate patient medical records, electronic health record (EHR) systems, and ensure healthcare workflows involving physicians and patients will be implemented cross-border within the EU. While this infrastructure will possibly be based on a set of specific providers, essentially all NRENs are interested in learning how to position themselves in relation to this upcoming e-infrastructure and the corresponding national health initiatives.

NRENs are likely to play a more substantial role in the implementation of the EHDS2 ("HealthData@EU") infrastructure, aimed at hosting, storing, and sharing Digital Health data for secondary use (research). Here NRENs are well positioned as in many cases they already interconnect major data centers both nationally and internationally and provide access to HPC centres involved in many Digital Health research projects, including key initiatives such as the Human Brain Project and the Digital Human Twins Project, the forthcoming initiatives within the Destination Human roadmap addressed by the European Commission.

Many NRENs are also closely supporting initiatives related to Health and Life Sciences, such as EOSC-Life and ELIXIR, and their national nodes. In many cases, the support provided to these research infrastructures is very tightly related to cloud computing and cloud storage services provided either directly by the NRENs, or by some of their stakeholder institutions.

AAI is another key area where NRENs are likely to provide crucial support to the eHealth sector. The currently adopted GÉANT community solutions (e.g. eduGAIN, eduTEAMS and the EOSC Core AAI platform) on the one side and the new eIDAS 2.0 Regulation, together with the new EU Digital Identity (EUDI) Wallet initiative on the other, make it likely that NRENs will provide significant support to the Digital Health community.

For this reason, NRENs have expressed the need for the GÉANT community to proactively track key initiatives and projects in this domain.[22]

[21] EHDS will be one of the official Data Spaces supported by EOSC, which will need to be interoperable with EOSC and the common EU Data Spaces framework for data, which will likely be based on the Simpl middleware currently being procured by the EC.

[22] To assess the situation in this domain, the GÉANT Community Programme (CGP) organised two main community events on eHealth: a community baselining event on eHealth in January 2021 and a meeting on eHealth at the TNC21 conference in June 2021. Based on the feedback from these events, the CGP eHealth Task Force (TF-eHealth) was established in July 2021. Since its inception, TF-eHealth has carried out an analysis on eHealth support in the NREN community, organised eHealth-specific security training (including on the European Health Data Space) and provided a list of community services and projects of relevance for the eHealth community.

3.8 Summary

In general, NRENs dominate their core “market” of universities and research institutions while other fields show a more varied picture. Overall, market shares are not very dynamic, 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.

4 Involvement in EC-Funded Projects

Many NRENs participate in a number of projects funded by the European Commission other than the GNx-projects. This section analyses those activities and draws conclusions based on the trends.[23] 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).[24]

The data show that 35 individual NRENs participated in a total of 104 unique projects, which means the number of participating NRENs has remained stable compared with 2021, when the same number of NRENs reported project participation, while the number of projects has increased slightly compared with 2021, when 100 projects were recorded. Many of the projects are related to EOSC and Open Science, underlining the growing importance of above-the-net services to many NREN portfolios.

Figure 4.1 provides an overview of NREN involvement in EC-funded projects other than GN4-3/GN4-3N. The graph shows that many NRENs have multiple commitments to collaborations in international science. However, this also necessitates 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.

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] This section looks at EC project involvement beyond the GN4-3/GN4-3N projects, which include all European NRENs.
[24] Data were cross-checked for 78 projects, 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. Initiatives have not been checked for NREN participation.

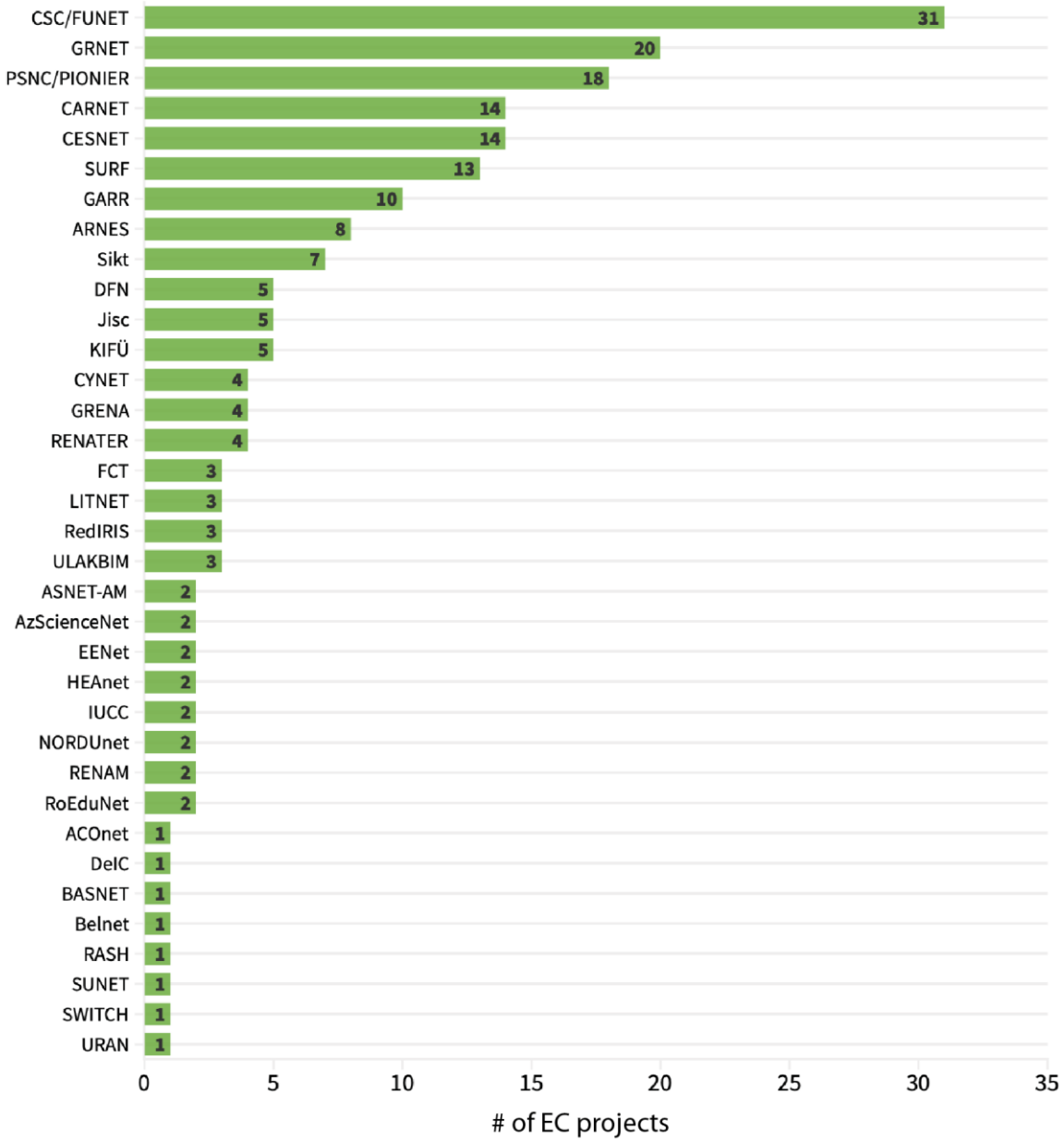


Figure 4.1: NRENs' participation in EC-funded projects other than GN4-3 – total number of projects per NREN

4.1 Overview of Top EC-Funded Projects

This section gives a brief overview of nine 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), while others address the network, regional collaborations or computing.

PROJECT	NO. OF NRENS PARTICIPATING
EaPConnect 2	14
EOSC Future	10
PRACE-6IP	10
NI4OS	7
EGI-ACE	7
EuroCC	6
DICE/EUDAT	4
OCRE	6
EOSC Synergy	3

Table 4.1: Summary of the projects with most NREN participants. PRACE-6IP, 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) Association and Projects

The European Open Science Cloud (EOSC) is an EC-funded initiative to create a pan-European platform that acts as a web of Findable, Accessible, Interoperable and Reusable (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[25]
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 to 30 September 2023.	CESNET, CSC/Funet,[26] DFN, GRNET, HEAnet, Jisc, KIFÜ, NORDUnet, PSNC/PIONIER,[26] SUNET, SURF, Sikt
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

[25] The list of NRENs reflects both publicly available data from the projects'/resources' websites and NRENs' self-reported involvement.

[26] Funet as a network is part of the Finnish Centre for Scientific Computing (CSC), which provides ICT support, computing and information services for academia, research institutes and companies in Finland. The two organisations are closely intertwined. A similar relationship exists between the Polish network, PIONIER, and its mother organisation PSNC (Poznan Supercomputing and Networking Centre).

Project	Project Profile	Contributing NRENs[25]
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, Sikt
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, Sikt
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, Sikt
EOSC-Pillar [EOSC-Pillar]	Bundling initiatives from Austria, Belgium, France, Germany, and Italy	GARR
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
EOSC Synergy [EOSC_Synergy]	Bundling initiatives from Spain, Portugal, UK, Czech Republic, Slovakia, Poland, the Netherlands, and Germany	CESNET, FCCN, Jisc, PSNC/PIONIER, RedIRIS
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.[27] GÉANT was one of the founding members and is represented on the Board of Directors, along with the Finnish NREN

[27] The EOSC Association was founded in Brussels on 29 July 2020 as an international non-profit association (AISBL). It is composed of 144 Members and 94 Observers (figures accurate as of 8 April 2022) representing research-performing

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 26 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[28] 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 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].

EaPConnect2

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.[29] Part of the role of EaPConnect2 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.

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].

[28] 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 Persistent Identifier (PID) Policy and Implementation Task Force, and Raimundas Tuminauskas of PSNC in the Rules of Participation (RoP) Compliance Monitoring Task Force.

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

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.

PRACE-6IP

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 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 (PRACE-6IP), which ran until 31 December 2022.

EuroCC

The EuroCC project aimed to 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 was 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.

ARNES, CSC/Funet, GRNET, KIFÜ, Sikt and SURF were partners in EuroCC.[30]

The EuroCC project was funded 50 per cent through H2020 (EuroHPC Joint Undertaking JU) and 50 per cent through national funding programmes within the partner countries. EuroCC ran 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. 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. As the current provider of connectivity to all current EuroHPC sites, GÉANT and the NRENs are well placed to understand and respond to changing requirements. Five NRENs are involved in the infrastructure advisory group (INFRAG) of EuroHPC (CSC/Funet, PSNC/PIONIER, Sikt, SURF, ULAKBIM); additionally, three NRENs are also now running new EuroHPC sites (GRNET, CSC and KIFÜ). 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.[31] Regular EuroHPC NREN coordination meetings are held between GÉANT and the NREN community to ensure that the community is well placed to meet both the current, and any future needs that the HPC community may have in the areas of secure connectivity, trust and identity or other priority areas.

[30] In addition to the direct involvement of NRENs, organisations that are closely associated with local NRENs were 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.

[31] 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.

4.2 Summary

The diversity of EC-funded projects presented in this section and the large number of NRENs that participate in them demonstrate 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 and the volume of NRENs who are Mandated Organisations for EOSC. 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 GÉANT has been serving this community for over 20 years. Furthermore, as new topics appear on the horizon, such as Quantum Computing, a rising number of NRENs are involved in related EC-funded projects. Impressive also is the NREN involvement in H2020 societal programmes, which deal with health, education and regional development.

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 2022. These continue, and current priorities, such as Quantum, now have their own coordination meetings where joint strategies and community collaboration are 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 directors and Task Force chairs and members.

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 external networks (upper graph) and from NREN end users (lower graph) for 2020 to 2022. While these figures are only representative of a subset of NRENs, the developments visible in the graphs are indicative for all NRENs. The pronounced changes in traffic from 2020 to 2021 likely reflect the effects of the COVID-19 pandemic: while traffic coming from NREN users (mostly from universities and research institutes) increased dramatically, traffic from external networks showed a slight drop. Both effects saw a slight reversal in 2021–2022, though the current traffic patterns still show longer-lasting changes in working and studying behaviour.

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 863,000 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.

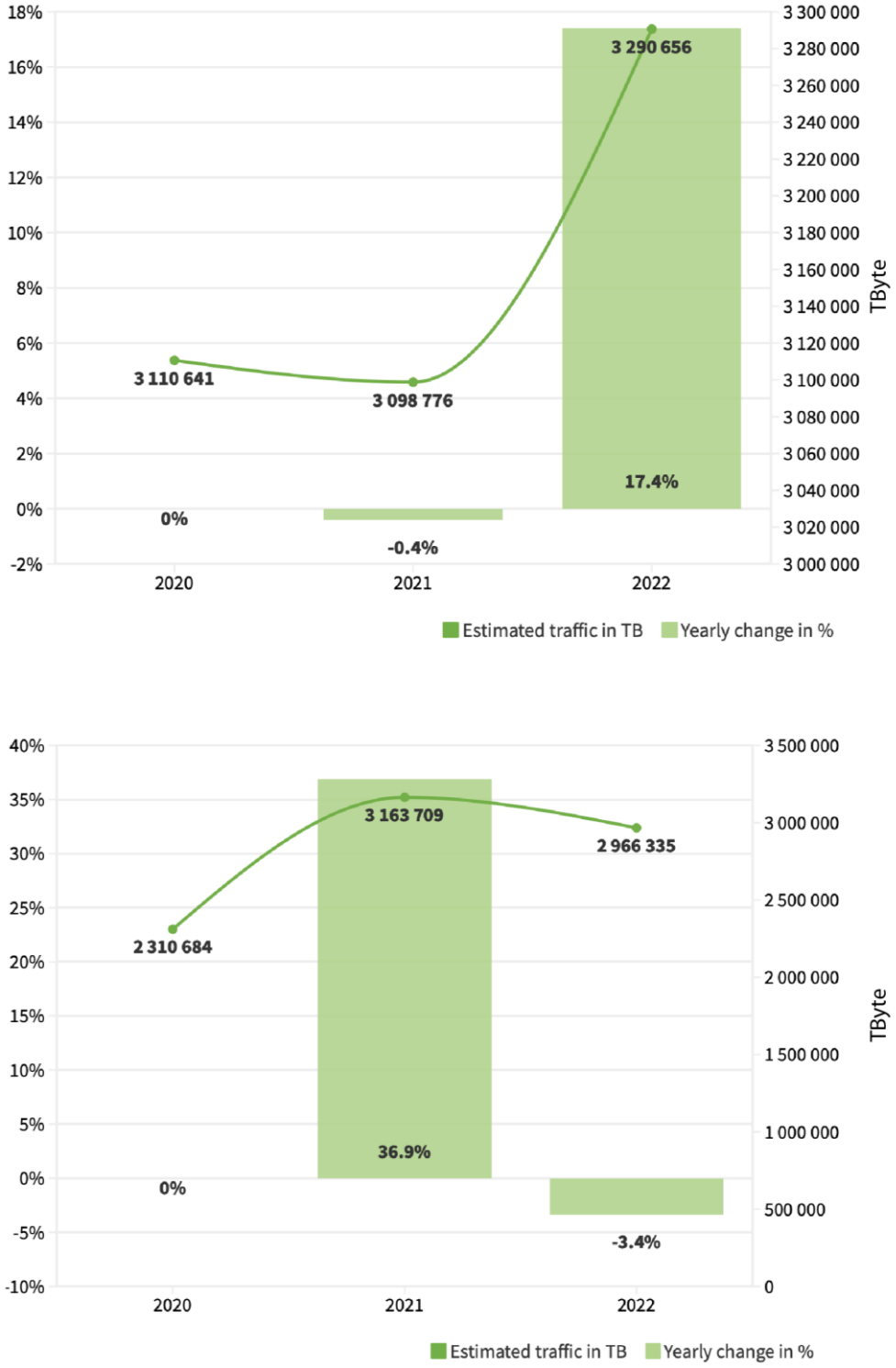


Figure 5.1: Increase of traffic into the NRENs from external networks (upper panel) and NREN end users (lower panel) 2020 to 2022. "External networks" denotes sources that are outside the NREN's domain, such as GÉANT, general/commercial Internet, Internet exchange, peerings, other NRENs. "NREN end users" denotes sources that are part of the remit of an NREN's domain. The figures are based on traffic data from 24 NRENs for which there are continuous traffic records from 2020 to 2022 (AMRES, BASNET, Belnet, CARNet, CESNET, CyNet, DeIC, DFN, FCCN, GARR, GRENA, GRNET, HEAnet, Jisc, LITNET, PIONIER, RASH, RedIRIS, RENAM, RENATER, RESTENA, SURF, SWITCH, ULAKBIM).

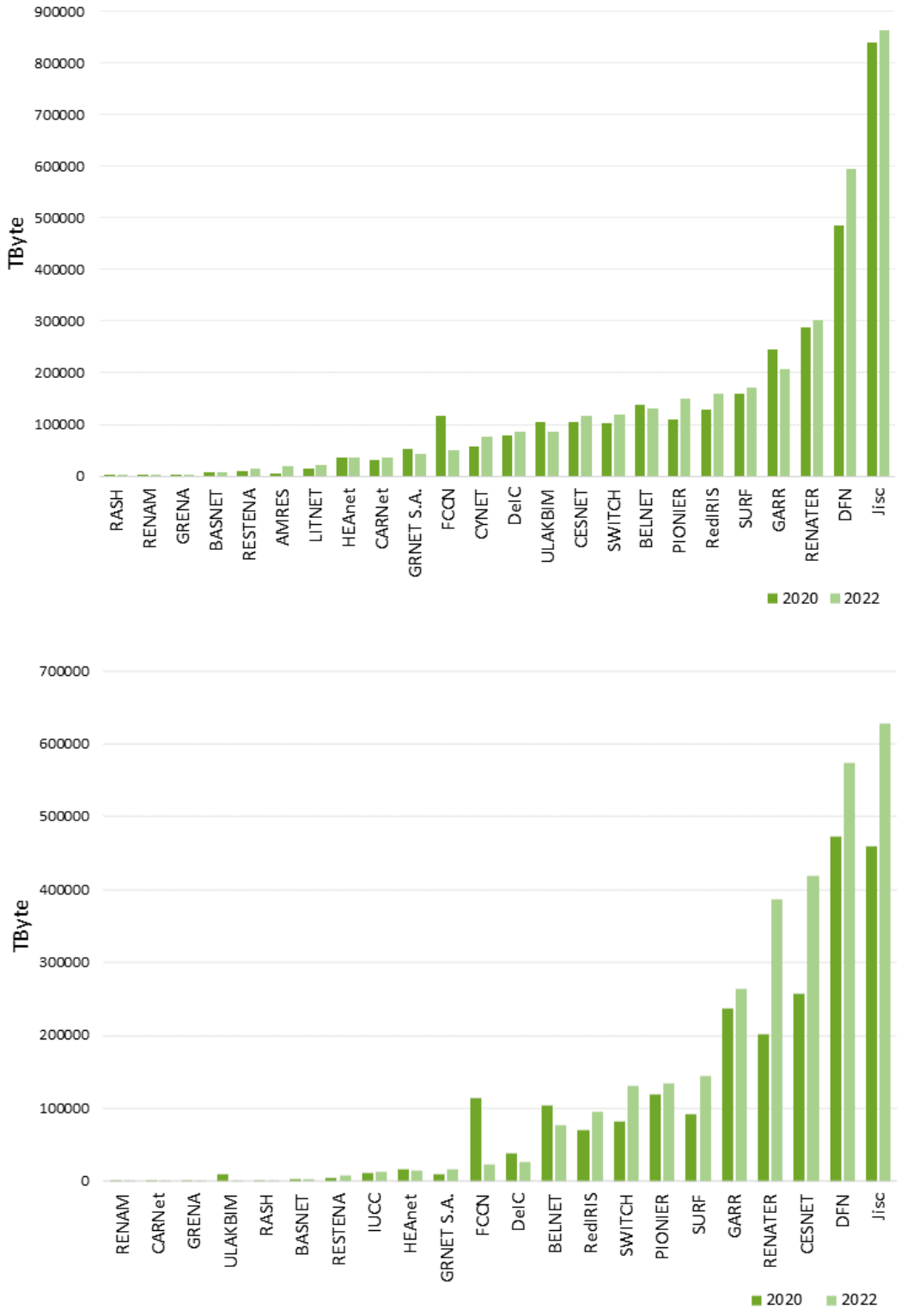


Figure 5.2: Traffic per NREN from external networks (upper panel) and NREN end users (lower panel) 2020 and 2020. The figure shows all NRENs that reported their traffic volumes in both the 2020 and 2022 surveys; to make the figure easier to read, 2021 data were omitted. As in the previous figure, "External network" denotes sources that are outside the NREN's domain, such as GÉANT, general/commercial Internet, Internet exchange, peerings, other NRENs. "NREN end users" 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.[32]

NRENs expect traffic to grow in the medium term: all 32 NRENs that provided estimates expect traffic growth over the three years 2023 to 2025, 10 of them by more than 50%, across all organisations within their remit. The highest growth is expected to come from the core users of all NRENs, universities and research institutes, with 68% and 74%, respectively. Schools (which are divided into primary and secondary schools) follow closely, with an anticipated growth of 64% and 72%, respectively (see Figure 5.3).[33]

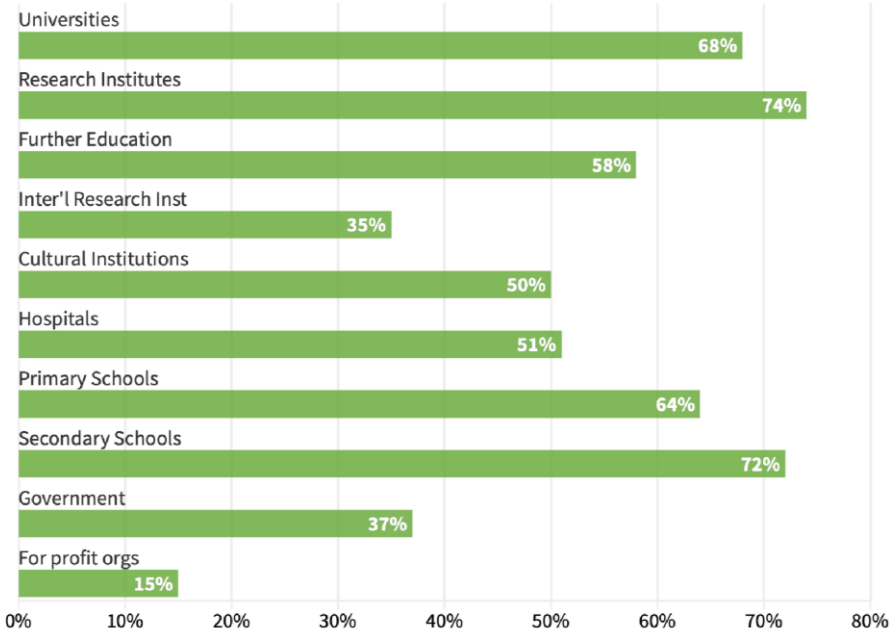


Figure 5.3: NRENs' forecast traffic growth for the years 2023 to 2025, by institution type (based on 32 responses).

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.

[32] 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.

[33] It is possible to do a back-of-the envelope check of how accurate these estimates have been in the past: based on the yearly traffic estimates (shown in Figure 5.1 and Figure 5.2), the increase in overall traffic (the data do not differentiate between user types) was 78% in 2018–2021 and 47% in 2019–2022. The corresponding estimates (averaged over all user types) were 54% and 53%, respectively. While estimate and reality aligned reasonably well for 2019–2022, the period 2018–2021 shows a large gap between estimate and actual data. This reflects the effect of the COVID-19 epidemic, an event that no one could have foreseen.

Table 5.1 below gives an overview of the expected growth in traffic over the three-year period 2023 to 2025, by NREN, and by institution type.

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

LESS = 40	OVER 40-100	OVER 100

Table 5.1: Forecast traffic growth by NREN and institution type for the years 2023 to 2025

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 60% in some places (e.g. India, France) 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.

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 rapid increase in commercial IPv6 Internet traffic, which now matches NREN IPv6 traffic which is also about 35% of the overall traffic, as the commercial ISPs and content providers have adopted IPv6 and have closed the gap to the R&E networks. However, while IPv6 is widely available in R&E backbones, this is not necessarily the case with campuses and networks that connect to the backbone, so 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, and October 2022 showed another increase to 253 Gbps. For the 12-month period from April 2022 to March 2023, 35% of all traffic in the GÉANT network was IPv6, a level very close to the worldwide average.

Figure 5.4 shows the IPv6 traffic average into GÉANT from its partners for October 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 Tier1 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.

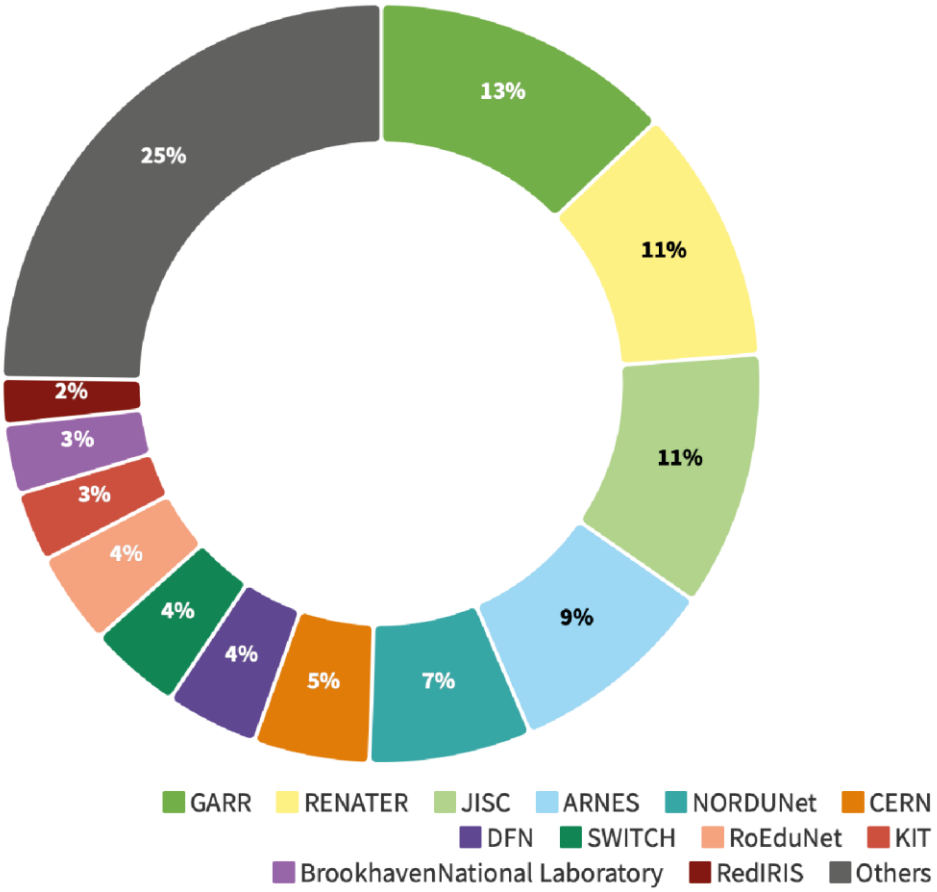


Figure 5.4: Top 12 GÉANT IPv6 traffic sources in October 2022. The total IPv6 traffic for this month was 253 Gbps [Source: GÉANT Kentik tool].

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,[34] 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 2022, the NRENs reported a total of over 150,000 km of dark fibre. Figure

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 11 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.

[34] 33 NRENs affirmed their use of IRUs in the Compendium survey, while 6 NRENs stated that they did not use IRUs (BASNET, BREN, CARNET, CyNet, MARnet, ULAKBIM).

5.6 below shows the number of kilometres of fibre each NREN reported in its own network.[35] This NREN-operated fibre interconnects with GÉANT's 11,000 km of intercity dark fibre, forming a strong community infrastructure (see Section 5.9 GÉANT Network Updates).

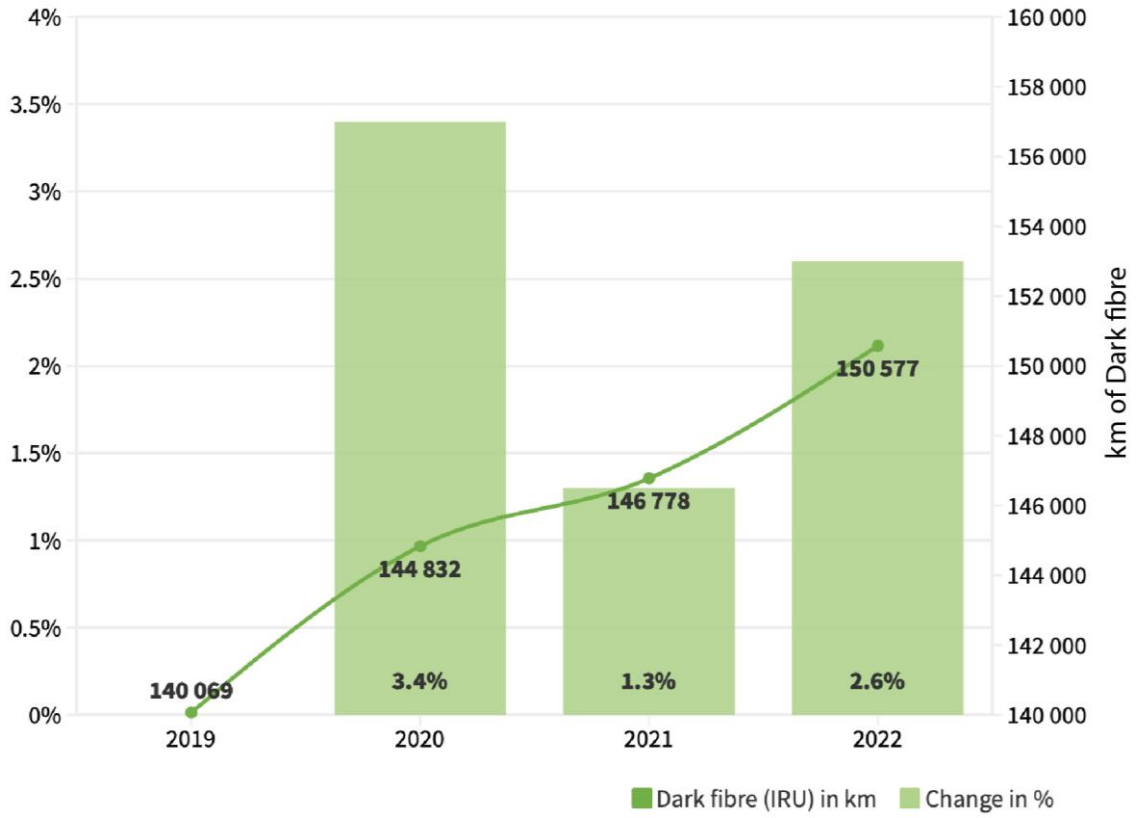


Figure 5.5: Development of the NRENs' IRU networks 2019–2022. To make numbers comparable across the years, the figure shows only the IRUs of NRENs that have provided IRU data in all Compendium surveys from 2019 to 2022. Note the total length of the fibre network is even greater, as only IRUs are counted here, but some connectivity is provided by rented fibres – some NRENs even completely rely on rented connectivity over IRUs (BASNET, BREN, CARNET, CyNet, MARnet, ULAKBIM).

[35] In past reports, Sikt (formerly Uninett) listed 12,600 km of dark fibre. Recently Sikt reclassified 11,100 of those, leaving them with 1,500 km. To make the numbers comparable across years, this has been applied to older numbers in Figure 5.5 and Figure 5.6.

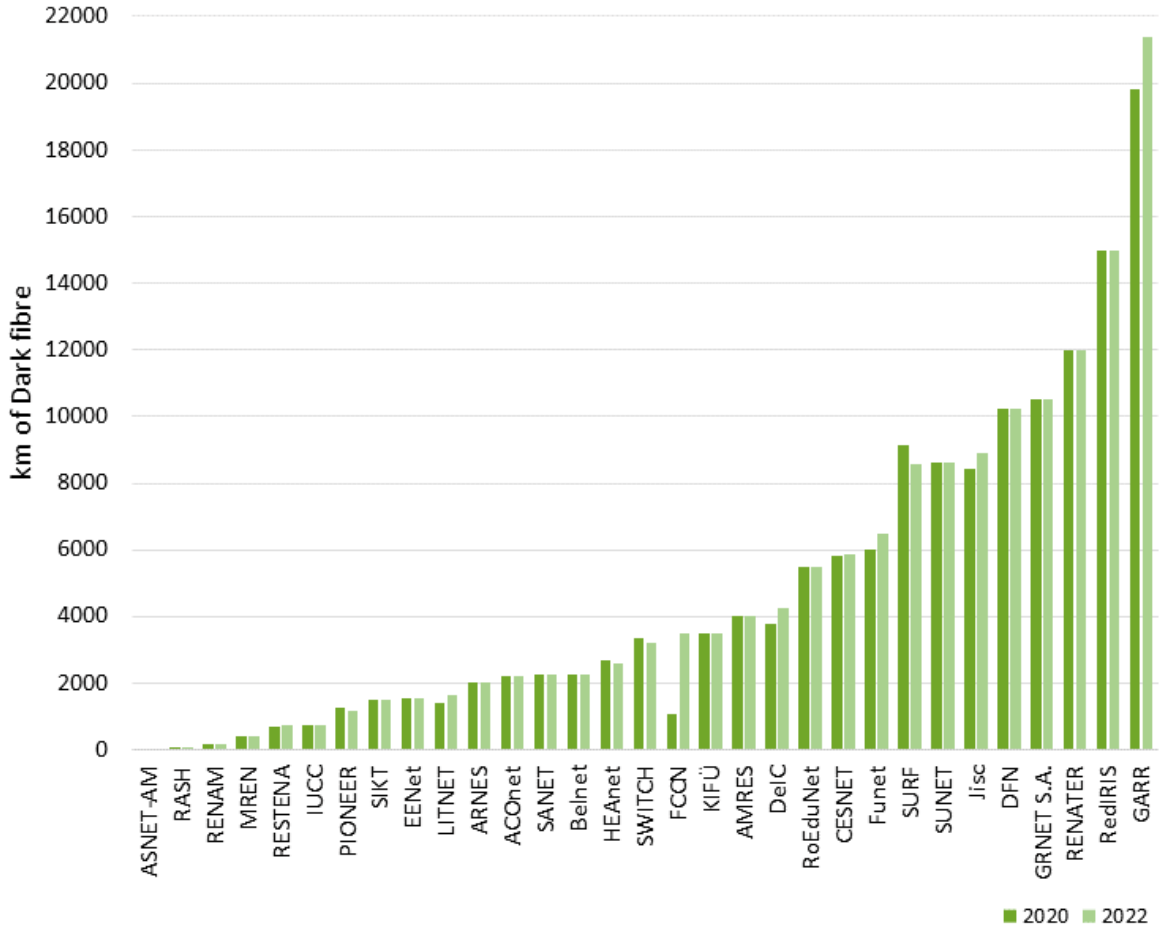


Figure 5.6: Number of kilometres of IRU network per NREN 2020 and 2022. For visual clarity, 2021 was omitted from the graph. Even so, it is clear that overall, only small changes have taken place. The figure shows numbers for all NRENs that reported on their IRU network in the 2022 Compendium survey, i.e. NRENs that reported in previous years but did not do so in 2022 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.[36]

According to the survey results, 17 NRENs are currently making use of alien waves within their network.[37] Integrating alien fibre in an NREN's own network is not the only way to make use of this technology – 10 NRENs

[36] The same technology allows the sharing of infrastructure between NRENs and GÉANT that is discussed in Section 5.9 GÉANT Network Updates. This also means that the sharing of fibres between NREN networks and the GÉANT network is limited to those networks where this technology is available.

[37] ACOnet, ARNES, CESNET, DeIC, FCCN, Funet, GARR, GRNET S.A., HEAnet, LITNET, PIONIER, RENATER, RESTENA, SUNET, SURF, SWITCH, Sikt.

use alien wave services provided by third parties and 6 more are planning to do so.[38] While still representing only a minority of NRENs, both numbers have increased over the years, reflecting the increased use of alien wave technology: in 2019, only 13 NRENs had alien waves in their network (and 5 used third-party services).

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, Sikt).
- NRENs' AW services also have the advantage that they can double as part of the pan-European R&E network: 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 5.9 GÉANT Network Updates below.

5.6 Network Monitoring

A crucial aspect for NRENs is to understand what type of traffic flows via their network. Network monitoring aims to target network performance (speed, efficiency), integrity (failing hardware, bad configurations) and security (vulnerabilities, malware, malicious activity). In the longer term it is also important for capacity planning purposes. While every NREN monitors its network, not all are using the same methods. The general flow of information can be monitored using metadata, but for a more in-depth analysis, the data themselves need to be analysed, which only a minority of NRENs do: among the 37 NRENs that responded to this question, only 10 monitored their networks, using either SPAN ports (5) or TAPs (6) or, in one case, both.

Network data are, of course, not only useful for the NREN but also for the network users, so most NRENs provide tools to their users that allow them to monitor their use of the network (Figure 5.7).

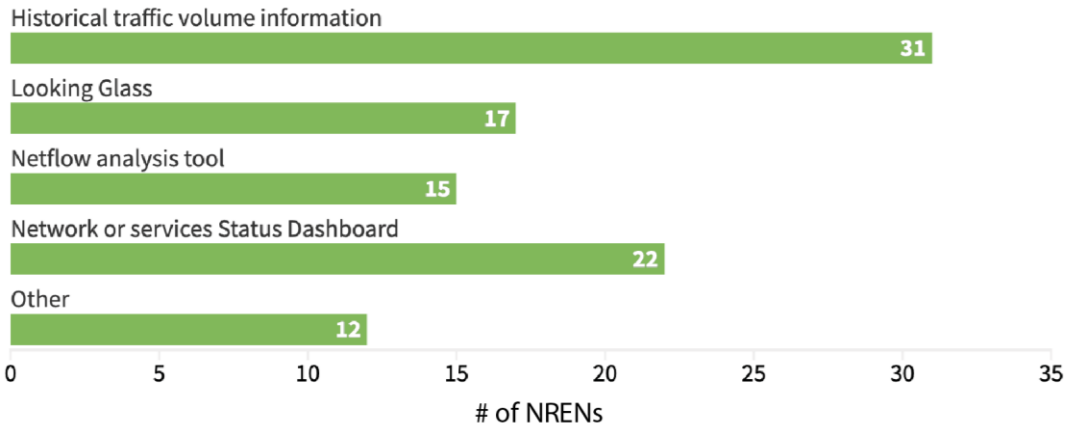


Figure 5.7: Overview of the most common tools that NRENs provide to their users to monitor their network use. A total of 35 NRENs provided a response and many NRENs put several different tools at the disposal of their users.

[38] NRENs that use third-party services are: ARNES, CESNET, DeIC, Funet, LITNET, PIONIER, RESTENA, SURF, SWITCH, ULAKBIM, while Belnet, BREN, EENet, GRNET, KIFÜ, RENAM are planning to do so.

5.7 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, factors such as the funding that is available. An overview of the typical backbone capacity of individual NRENs is shown in Figure 5.8.

NRENs that serve a large research and education sector are increasingly using 100G technology to light their fibre. Eighteen NRENs have reported having typical backbone capacities of 100G or more. Overall, the average capacity of backbones has increased over the years (as can also be seen in Figure 5.8). This is also reflected in the median capacity across NRENs, which has increased noticeably over the last 3 years, having now reached 80 Gbyte/s (with 40 Gbyte/s in 2020 and 60 Gbyte/s in 2021, after hovering around 20 Gbyte/s for several years before that). 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.

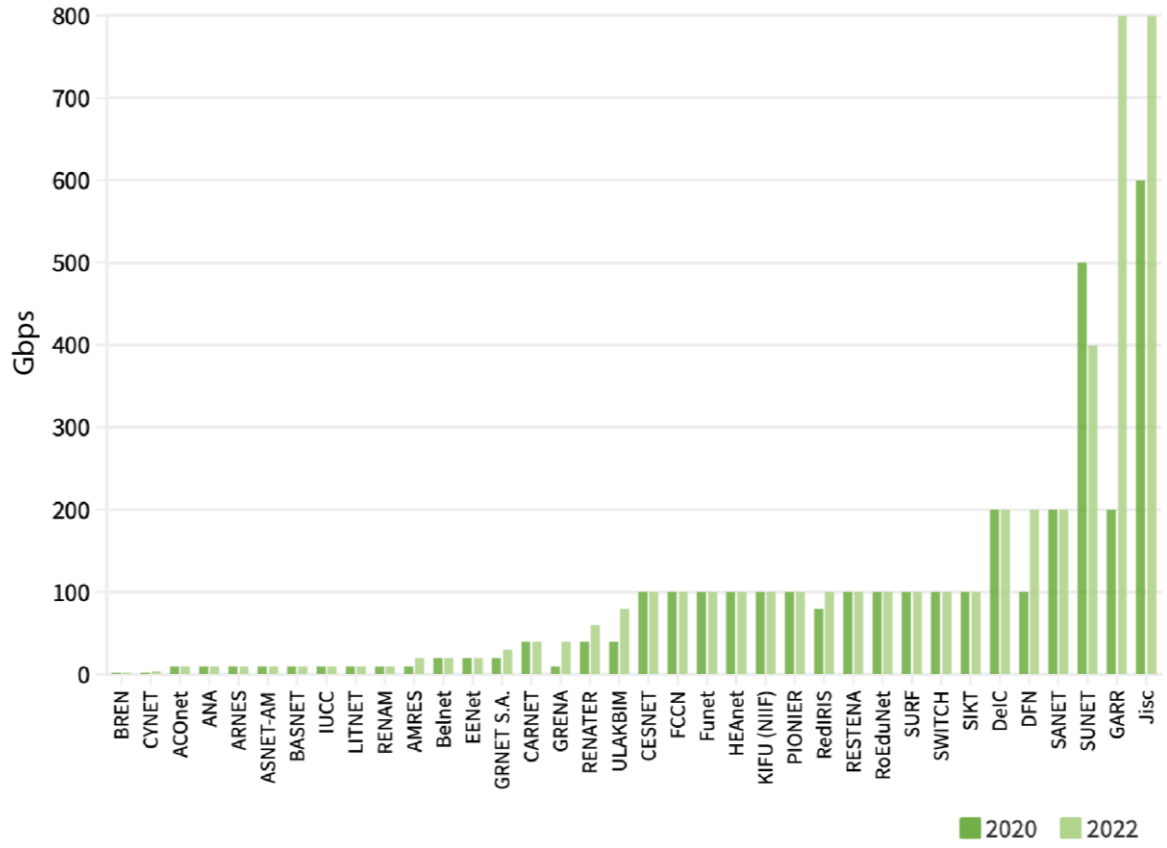


Figure 5.8: NRENs' typical core usable backbone IP trunk in Gbps 2020 and 2022. The figure shows all NRENs that provided data on their trunk capacity in the 2020 and 2020 surveys; NRENs that reported in previous years but did not do so in 2022 are missing. For visual clarity, the 2021 data were omitted from the graph. It is clear that most NRENs' backbone capacity has not changed. However, there are some notable increases: GRNET, ULKBIM, DFN, GARR and Jisc have significantly increased their capacity, and smaller increases have been implemented by AMRES and RedIRIS.

5.8 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.[39]

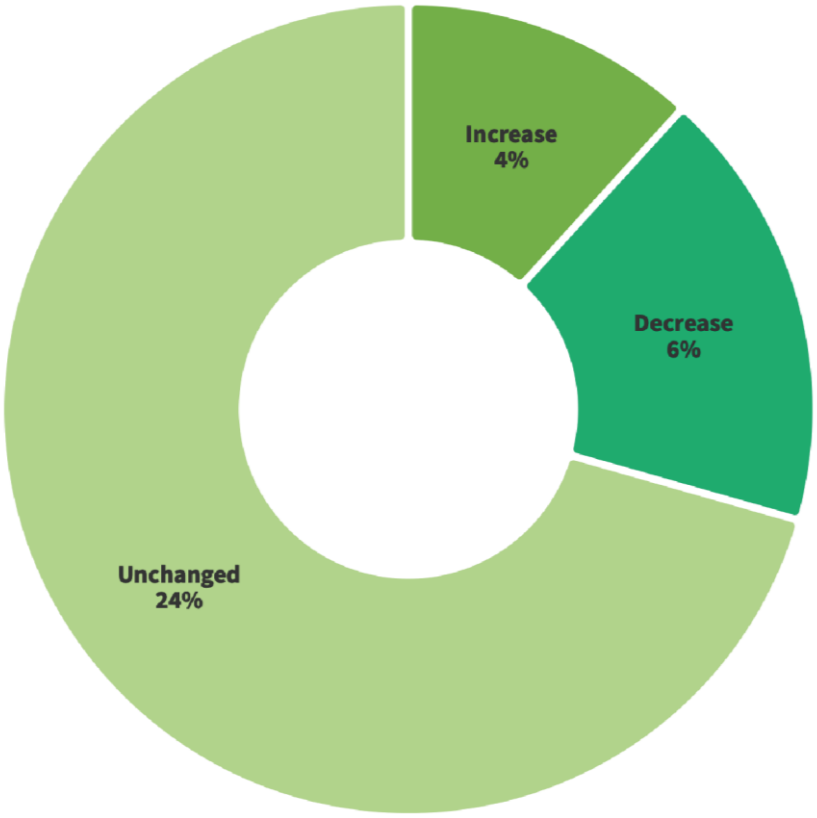


Figure 5.9: Non-R&E network peering development of NRENs 2021 to 2022

In the 2022 survey, of the 34 NRENs responding to this question, 4 reported an increase in the number of non-R&E peering networks, 6 reported a drop, while the remaining 21 NRENs did not see a change in the number of peering agreements (see Figure 5.9). The number of peering agreements per NREN is shown in Figure 5.10.

[39] 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.

In terms of absolute numbers, the number of peering agreements across all NRENs has decreased slightly over the last two years after years of continuous increases: in 2020 a high-water mark of 3,417 was reached and since then the number of peering agreements has dropped to 2,926 in 2022 (with 2,976 in 2021). The policy of individual NRENs towards peering agreements varies widely but most NRENs have only a moderate number of them (single digit or low double-digit numbers), while some NRENs maintain large numbers. As a consequence, 80% of the peering agreements are held by just 7 NRENS (ACOnet, Belnet, DFN, GARR, SUNET, SURF, SWITCH). An overview of the changes from 2019 to 2021 is shown in Figure 5.10.

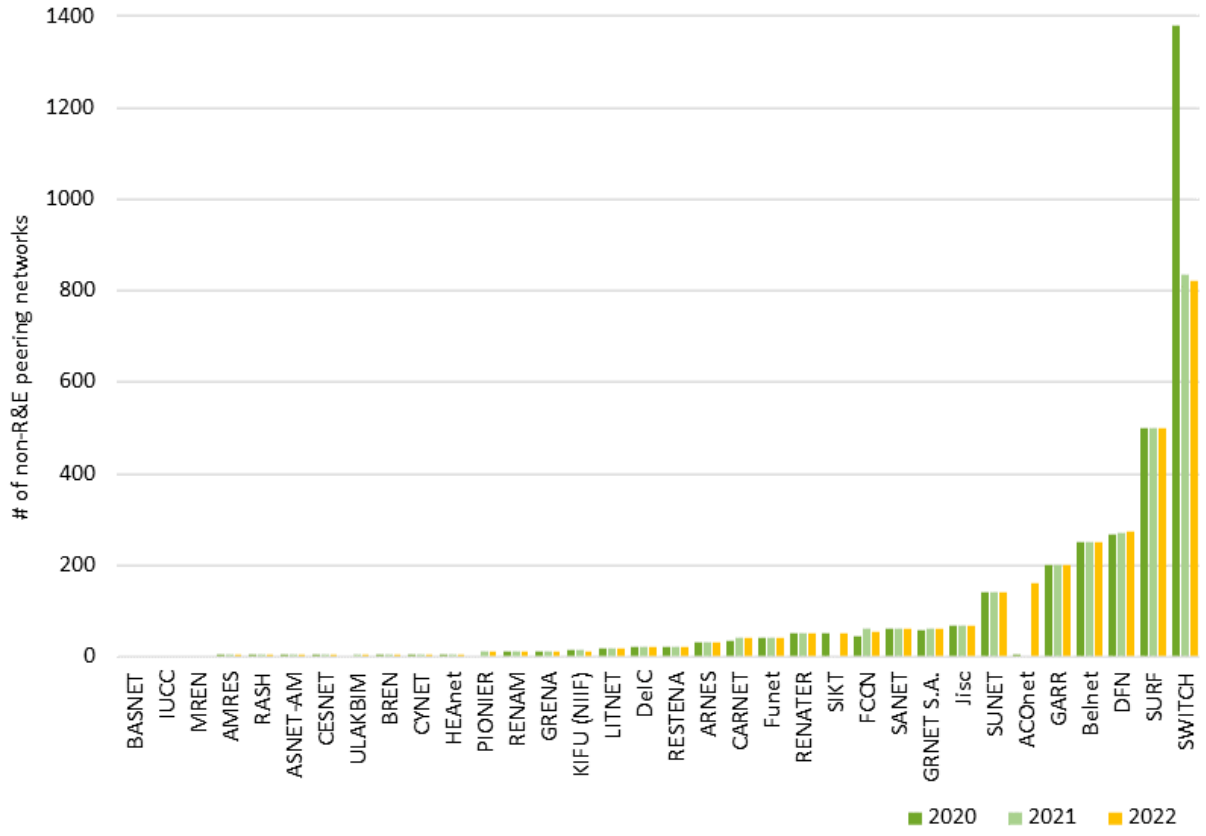


Figure 5.10: Number of non-R&E peering networks 2020 to 2022. The figure shows numbers for all NRENs that reported on their peering agreements in all years shown in the figure. NRENs that did not report in one of these three years are missing in the graph. The figure shows quite clearly that only a minority of NRENs maintain a large number of peering agreements.

5.9 GÉANT Network Updates

The GÉANT network interconnects 43[40] research and education networks in Europe (a topology map is shown in Figure 5.11). 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.

[40] 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.

As planned for the end of GN4-3N, the network will have 33 IP/MPLS routing sites and an additional 15 DWDM add/drop only sites. All routing sites are also DWDM add/drop sites which connect to NRENS and/or international partners.

5.9.1 Current GÉANT Network and Statistics

5.9.1.1 Current GÉANT Network Structure

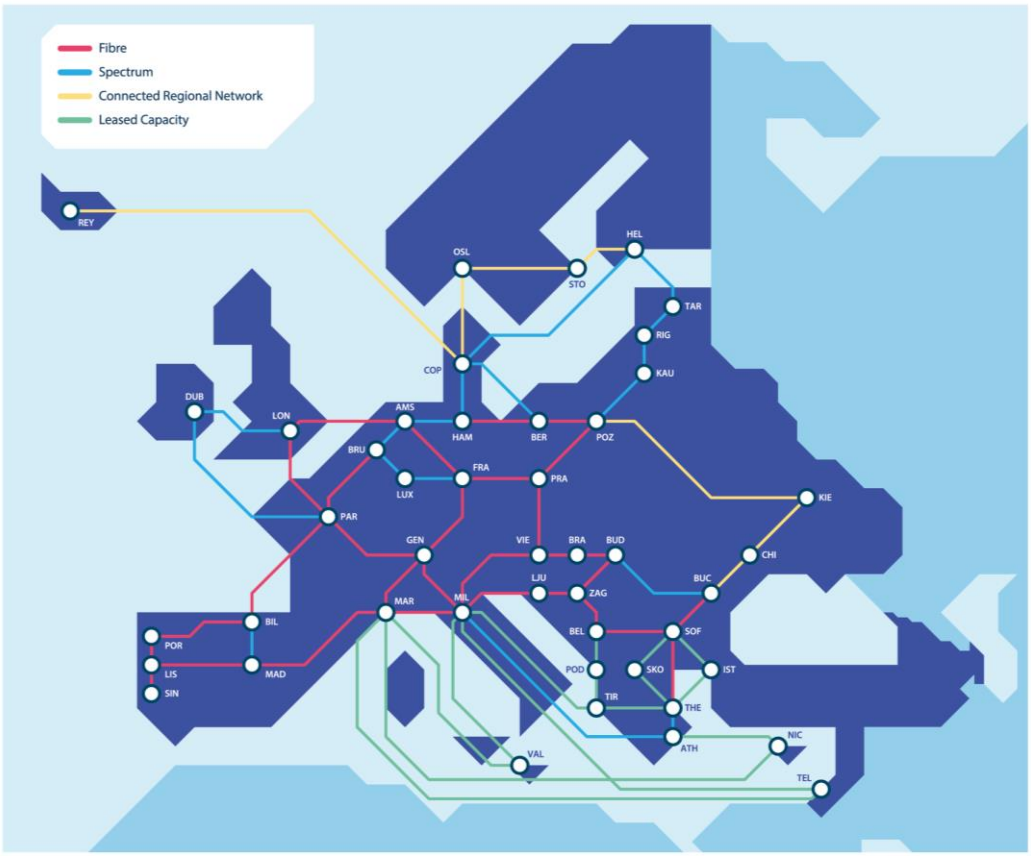


Figure 5.11: GÉANT pan-European network topology map (GN4-3N design)

The GÉANT network is divided into three parts, as shown in Figure 5.12: the Infinera DWDM open line system, the (currently) Infinera DWDM transponders layer and Juniper-based Internet protocol / multiprotocol label switching (IP/MPLS) network [Infinera; Juniper].[41]

The open line system runs on top of dark fibre and spectrum links (for spectrum, see also the textbox below) and provides management of the optical, DWDM signals generated by the transponders layer, that is, amplification, multiplexing and power balancing. The “open” nature of the line system means that this layer can accept signals generated by different sources without restriction to a specific vendor or a specific technology.

Spectrum services for NRENs or R&E partners are delivered directly by this layer.

The next layer up the stack is the transponders layer, constructed utilising Infinera Data Centre Interconnect (DCI) transponders. This layer is responsible for activating point-to-point capacity over the line system routes.

[41] It is important to note that GÉANT is currently retendering for the supplier of the IP/MPLS kit in 2023, with significant changes to this layer expected in 2023–2024.

Transponders terminate short reach Ethernet signals of 10, 100 and 400 Gbps capacity, and generate high-capacity DWDM signals for transmission over the DWDM line system. The transponder layer is responsible for providing high-capacity links to the upper layer and the IP/MPLS layer. These high-capacity point-to-point connections are used for carrying the trunks between the IP/MPLS routers of GÉANT.

"Lambda" services, or point-to-point high-capacity guaranteed Ethernet services to NRENs or R&E partners are delivered directly by this layer.

The final layer of the stack is the IP/MPLS layer, which is today managed by Juniper MX series routers. This layer is responsible for transmission of IP packets and Ethernet frames between connectors across the GÉANT network.

All connectivity services not delivered by the other layers are delivered by the IP/MPLS layer.

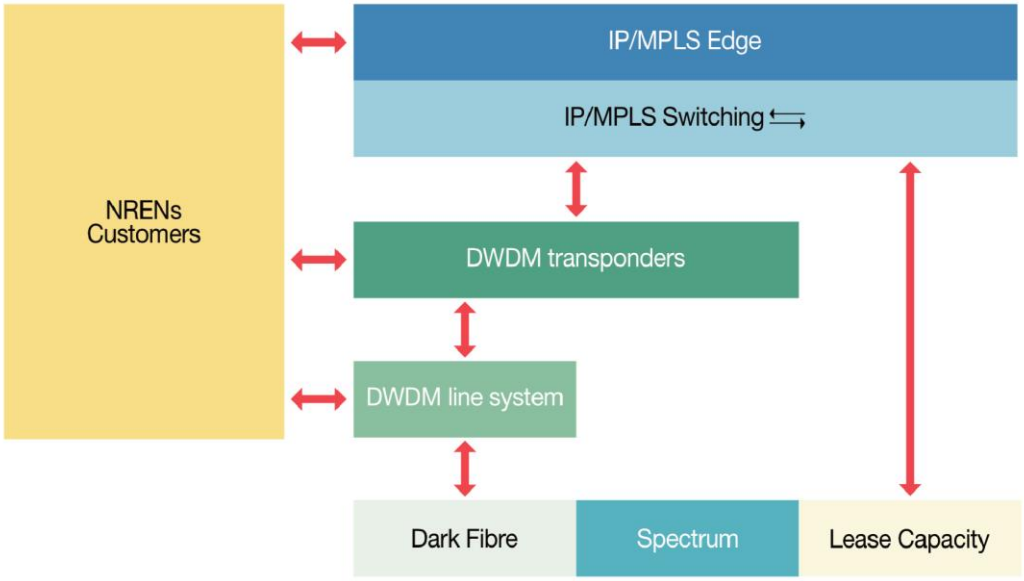


Figure 5.12: The current layered structure of the GÉANT network. The IP/MPLS routing part of the network, provided by Juniper MXs, is shown in blue, while the optical transport network (OTN) / DWDM part, provided by Infinera, is shown in green. The arrows represent demarcation points between building blocks.

5.9.1.2 GÉANT Network Statistics

In 2022 the GÉANT network received 3.01 Exabytes of traffic, representing an increase of 17% from the previous year's figure. Figure 5.13 shows the year-on-year traffic growth from 2015 to 2022. 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,[42] has remained relatively strong. The increase of LHCONE traffic during the same time period is shown in Figure 5.14.

[42] 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.

However, traffic has grown again in 2021 and 2022, with the overall yearly traffic levels in 2022 reaching the same level as in 2019 and Q4 2022 showing the highest traffic volume of any quarter yet (Figure 5.13 and Figure 5.15). It is important to note that IP/MPLS traffic alone is now at a significantly higher level than it was in 2019, while traffic through Lambda services has been declining since 2018. This trend is important as it shows that the network is actually growing more strongly and is expected to continue with this upward trend.

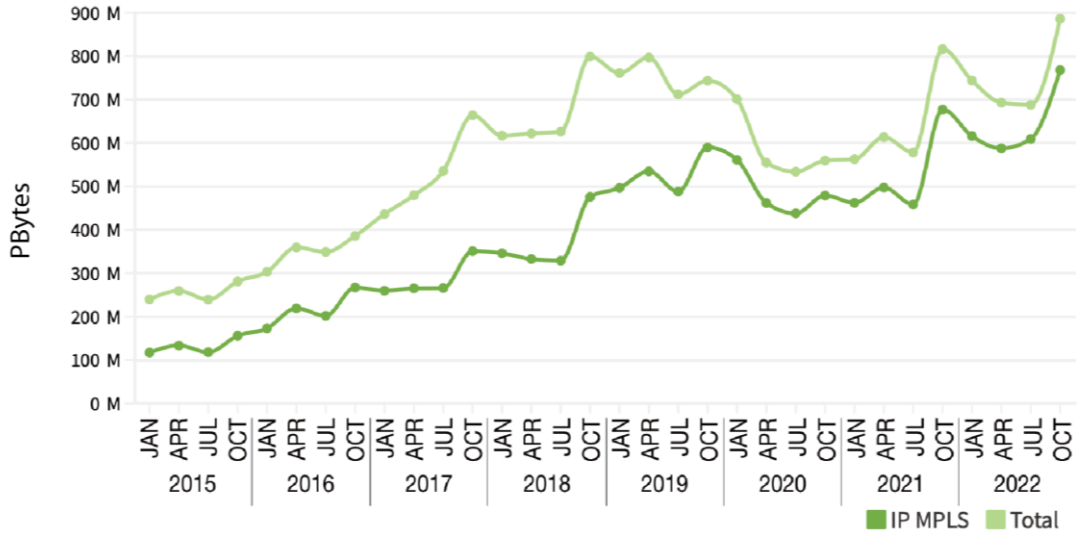


Figure 5.13: Quarterly view of data received by GÉANT (in PetaBytes). The data were aggregated by quarter, starting from Q1 2015 up to Q4 2022. The difference between IP/MPLS and Total is the traffic carried by 10G and 100G Lambda services.

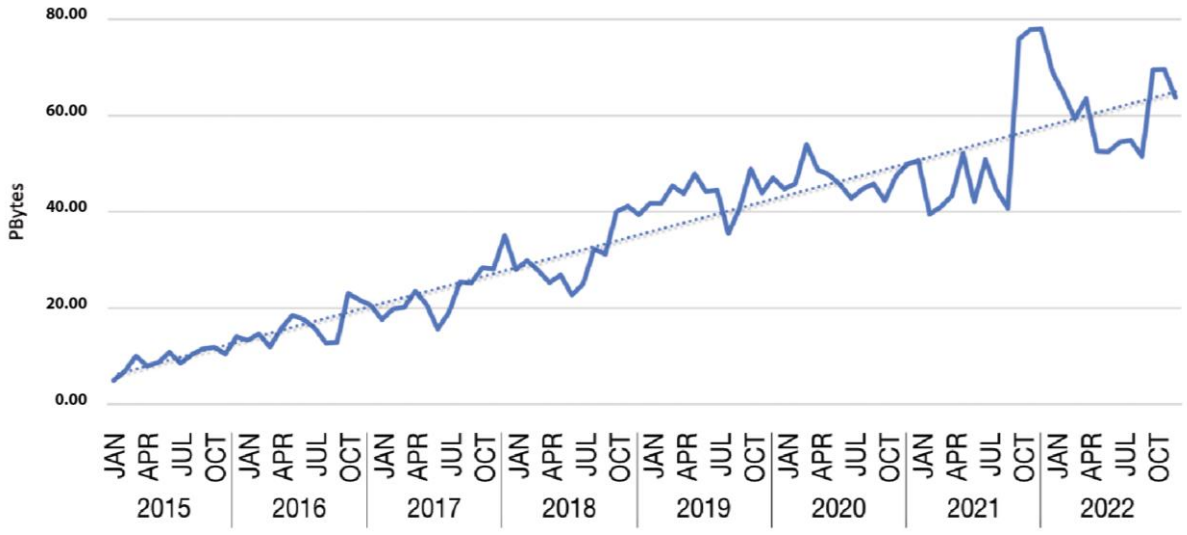


Figure 5.14: LHCONE Traffic in PetaBytes. The figure shows monthly LHCONE traffic from January 2015 to December 2022. The impact of the COVID-19 pandemic on the traffic in this part of the network has been relatively limited, with volumes mostly slightly below trendline. This can be compared with the graph in Figure 5.13, where the impact of COVID-19 on the overall GÉANT traffic is shown.

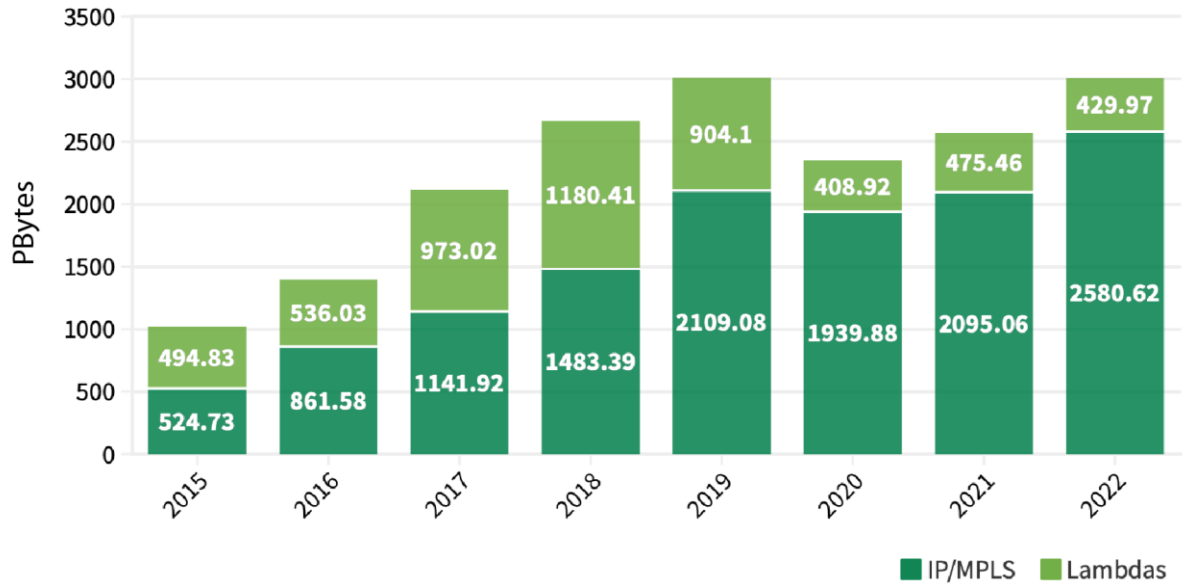


Figure 5.15: Overall yearly traffic volumes in PetaBytes. The figure shows the yearly volume of traffic received by GÉANT in PetaBytes, distinguishing between IP/MPLS traffic and Lambda point-to-point traffic.

5.9.2 Evolution of the GÉANT Network

5.9.2.1 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 5.16 below presents an overview of the progress of GN4-3N as of January 2023, showing the completion status of the routes that were part of the original reference topology for GN4-3N.

GN4-3N

Together with GN5-1, GN4-3N is the most recent iteration of a series of projects (GN1, GN2, GN3, GN3plus, GN4-1, GN4-2 and GN4-3) 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.

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 5.16 for details).

It is important to note that a considerable number (about 25% in terms of overall length) of connections planned to be part of the new network will be provided by NRENs, sharing existing infrastructure with GÉANT. This will

ensure that infrastructure duplication is minimised and GN4-3N funding can be directed towards places where it is most needed.[43] Full details can be found in the latest revision of the GÉANT Network Evolution Plan [D7.5].

In 2021 a revised reference topology for the GÉANT network was approved. This new reference topology saw the addition of 6 new phases as well as improvements to some of the original phases (namely, Phase 8 – Ireland and UK) (see Figure 5.16).

By the end of 2022, the majority of the new planned routes have been implemented with only some left for delivery and only 2 phases left for tendering results in 2023 (Israel and Cyprus, Phase 11, and Scandinavian resiliency, Phase 14).

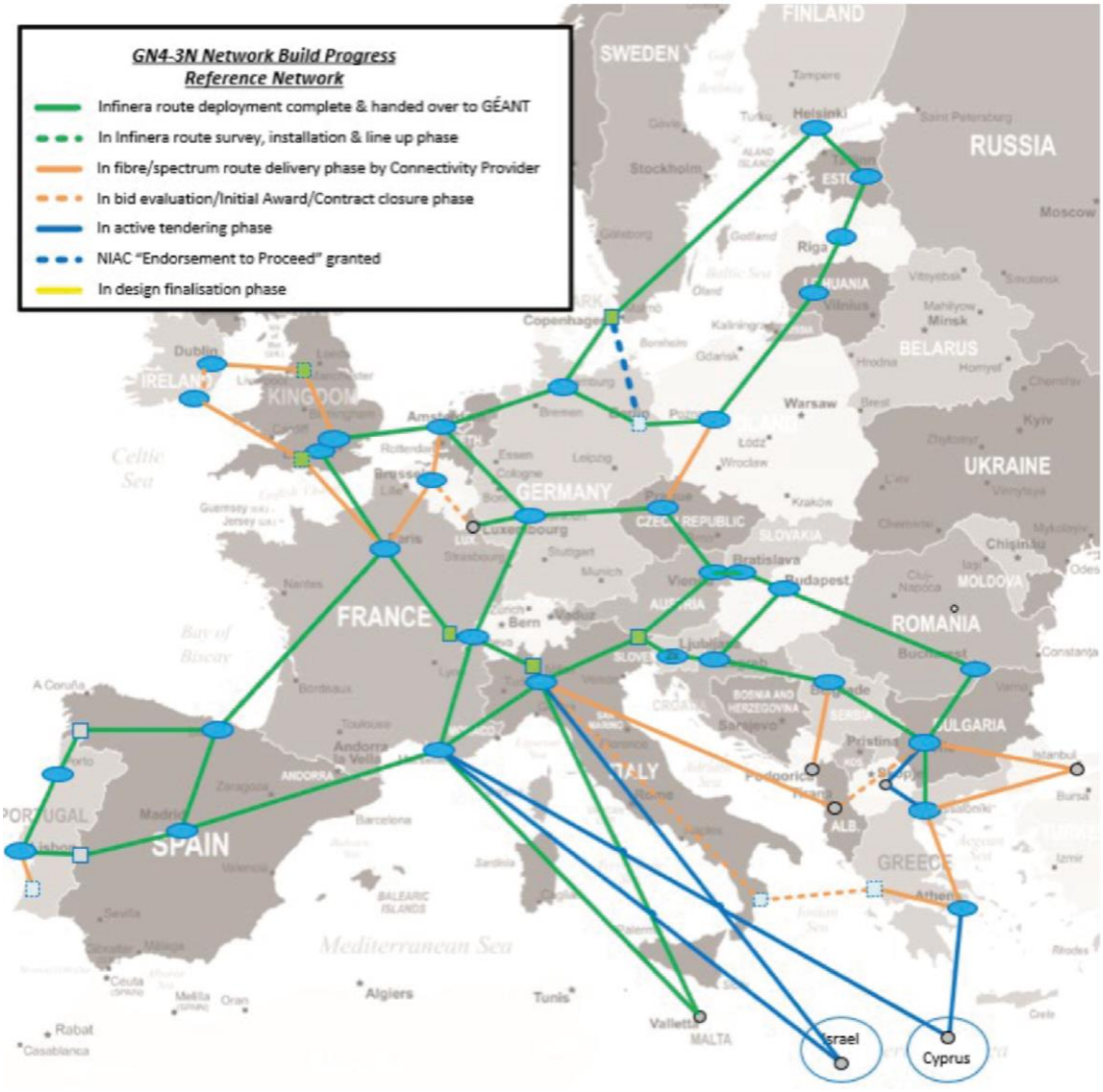


Figure 5.16: A view of the revised reference topology for GN4-3N. The map was revised in 2021, and some of the previously classed improvement projects are now part of the main scope of the project. The map shows only the GÉANT backbone; it does not include infrastructure run by NORDUnet, EaP countries, other projects. The project is divided into Phases, shown by the various colours in this map.

[43] 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.

5.9.2.2 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 5.17) will also enable GÉANT to share spectrum with NRENs. An activity in GN4-3 is working to define the parameters of this new service.

Spectrum

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.

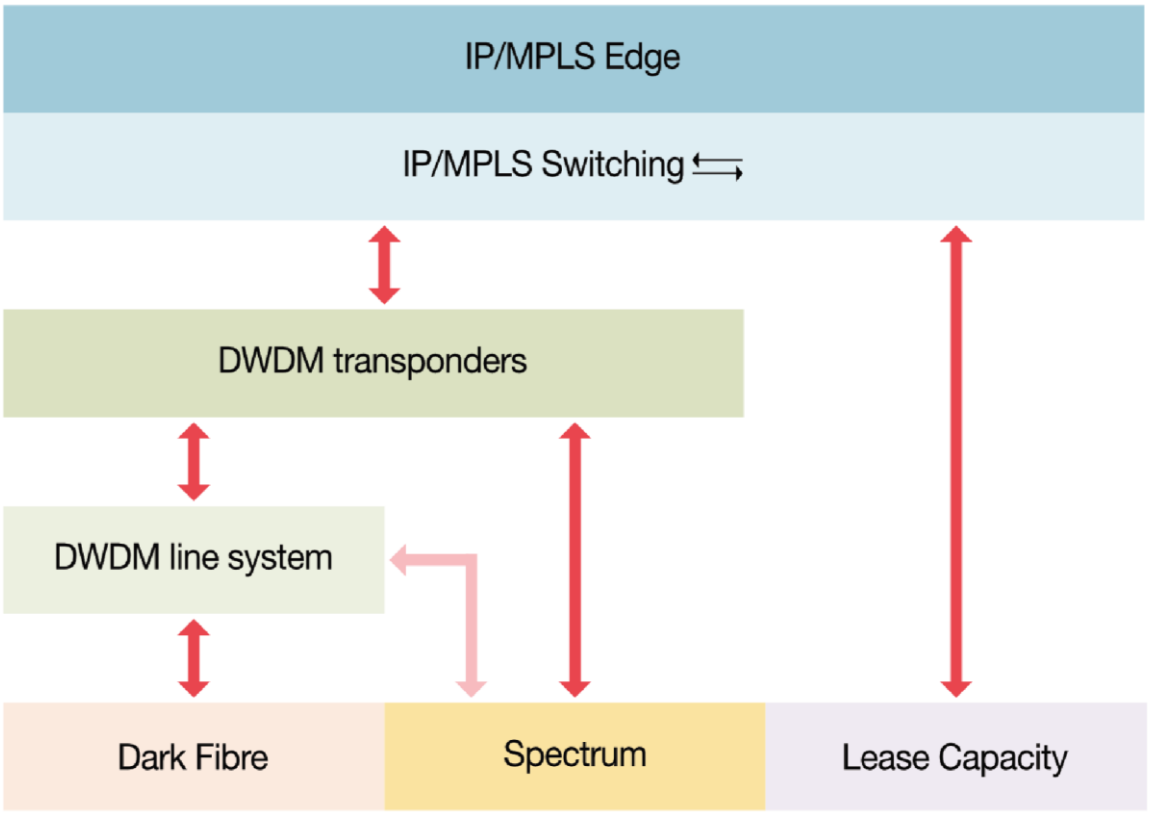


Figure 5.17: Layers of the network as they will be after the transition to a partly disaggregated DWDM system. The three layers are transport, transmission (in green) and packet (in blue). The transmission portion of the network will be composed of only two blocks (OTN switching having been removed), 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.

5.9.2.3 Packet Layer

In 2022 GÉANT initiated the process of tendering for a new IP/MPLS layer to replace the Juniper MX-based one deployed in 2012.

The two-stage open tender procedure will lead to the establishment of a framework allowing the acquisition of new, modern IP/MPLS kit and related services to support the migration and equipment lifecycle.

As part of the new network deployment, GÉANT will upgrade trunk capacities for all links between transit IP/MPLS nodes to 400 Gbps from the current 100 Gbps. Lower costs and a high count of high-speed interfaces will allow GÉANT to leverage the fibre investment of GN4-3N by providing very high data rates to all transit points in the network.

This design will support upcoming interconnecting high-capacity intercontinental links to the edges of Europe, improving the quality of transit services for all NRENs, in particular those not in the central European area.

The tender is expected to provide results by Q2 2023, with a migration starting in Q3/4 2023 and lasting about two years.

Together with the change to the IP/MPLS hardware, GÉANT is also significantly investing in automation to ensure that the configuration of the upcoming IP/MPLS devices is handled by automated processes rather than through manual configuration. This will reduce the risk of human errors, speed up service deployment and ensure regular updates and consistency of configurations.

5.10 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 that there is headroom for traffic growth. Also, R&E networks, such as 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.

6 Security

Cyber security is a growing issue in any ICT environment and the R&E sector is no exception. That the R&E sector is a target for cyber criminals has been demonstrated in the past by a number of (successful) major cyber-security attacks on R&E institutions, both universities and research organisations.[44] As the central providers and enablers of ICT services for the research and education sector, NRENs are in a central position regarding security.

The exact role of an NREN in cyber security 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 services to government bodies (e.g. Belnet). Another factor that can 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 larger organisations, usually universities (e.g. ACOnet, UoM – see also the discussion about funding and governance in Section 2.1).

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 GNx-n project, the available skill set, and the risk of becoming the target of attacks.

This challenge is compounded by an increasingly heterogeneous infrastructure in the R&E sector. R&E institutions use numerous network-related resources at the same time, such as different cloud suppliers, data lakes, app stores, computer centres etc. This trend has been present for some time and the NREN community has tackled this challenge by investing in a number of standardisation projects such as the policy kits developed in the AARC projects [AARC] and by supporting the development of standards such as Sirtfi (see also Section 7 Trust and Identity) and the *Security Baseline for NRENs* document [D8.2].

In addition to the security aspects that are intrinsic to their role as ISPs, NRENs also face a changing regulatory landscape, as bodies such as the EU react to the changing cyber security situation by creating regulations. Examples include the General Data Protection Regulation (GDPR) or the Network and Information Security Directive (NIS2), the directive on Critical Entities Resilience (CER) and the Cyber Resilience Act (CRA). NRENs will also need to comply with changes to the funding structure of procurement grants.

The data presented in this section illustrate the current efforts of the NRENs in the two broad areas of organisational security and security services. The data originate from the NREN Compendium survey, where

[44] A number of large NRENs observe and are involved with cyber-attacks on a daily basis, ranging from "run-of-the-mill" Distributed Denial of Service (DDoS) attacks to full-scale DDoS attacks crippling complete universities. To give some examples: there have been ransom attacks on the Dutch research funding organisation NWO (February '21) and Maastricht University (December '19), hacktivist attacks on Italian universities (February '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 (September '20), Rijeka/Croatia (November '20), Sunderland/UK (October '21), Hamburg/Germany (December '22). It should also be noted that not all incidents become public, as the information policies around security issues vary.

NRENs provide data about their service portfolio, from GÉANT's Partner Relations team, and from the Trusted Introducer (TI) programme.[45]

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].[46] Organisational security looks at the processes within an organisation and how they take security issues into account. This would include defined security incident responses but also formal policies concerning security-relevant areas.

[45] 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.

[46] 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.

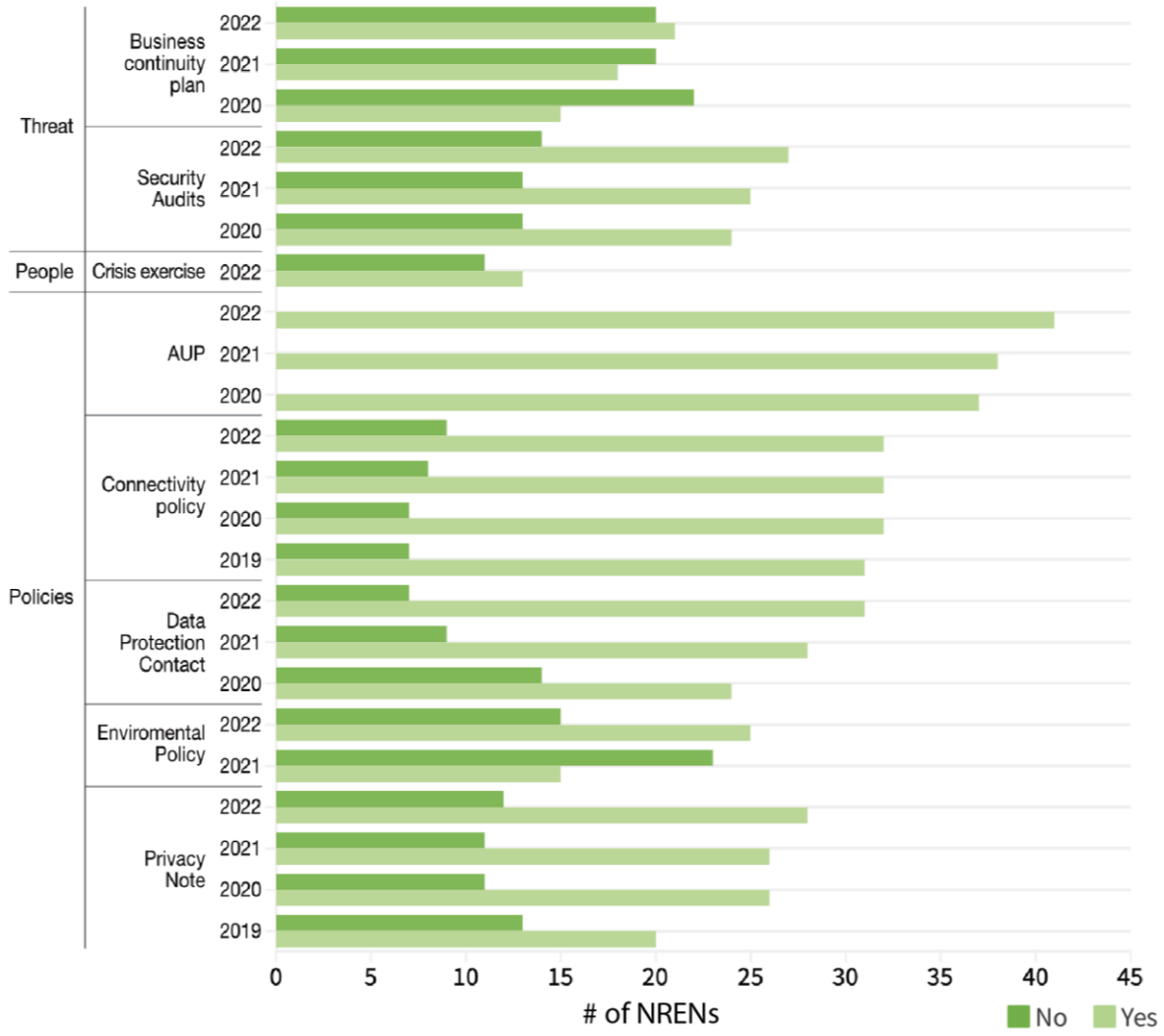


Figure 6.1: Development of the adoption of organisational security features by security area. Not all data are available for all years. The number of surveyed NRENs was 43 for all years. Numbers missing from that count are due to non-responding NRENs.

Policy

An Acceptable Use Policy (AUP) and a Connectivity Policy are important security-related policies. As they are fundamental for an ISP, these are among the NRENs' oldest policies; all NRENs that responded to the survey have an AUP in place and have had for some years (see also Section 3.2 NRENs' Acceptable Use Policy). Dedicated connectivity policies are not quite as widespread, possibly reflecting that some NRENs are part of larger organisations that set such policies instead or reflecting a more operational approach to security.

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 2022, about 60% of the NRENs stated having a privacy notice and 12 explicitly stated a lack thereof. 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

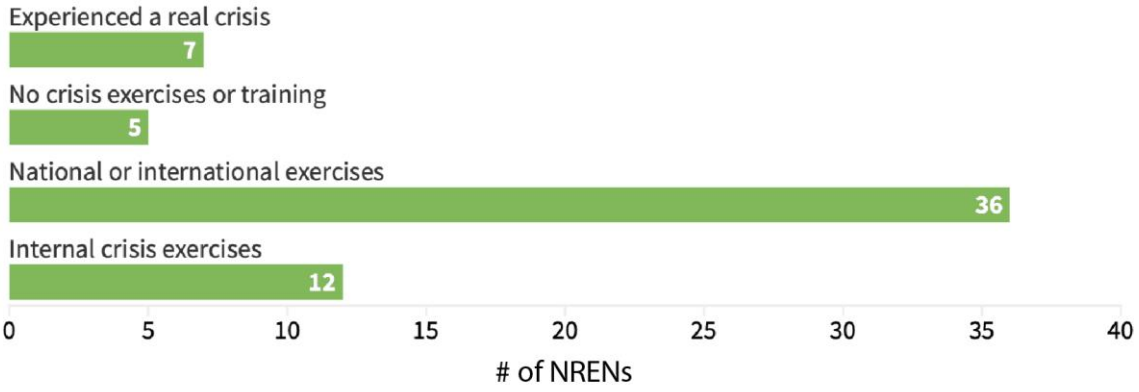
mentioned above, a Privacy Notice is required by law in most jurisdictions, so the numbers can be expected to change in the coming years as NRENs will catch up with regulations).

People

An important factor with regard to improving IT security is the expertise within an organisation and large knowledge gaps in this field are common. Most organisations have a higher demand for security specialists than are available on the job market and therefore struggle to find the experts to fill vacancies – and this situation will not change in the near future. Training offers are an important way to mitigate this situation.[47]

Some training opportunities are provided by GÉANT, which offers some security training (e.g. TRANSITS, CLAW)[48] which some members are using, but many other training options are available. In addition, the majority of NRENs prepare their staff specifically for the case of a security crisis, for example by participating in workshops such as CLAW or carrying out crisis exercises within their organisation (see Figure 6.2).

[47] Unfortunately, there are no numbers available that would document how NRENs make use of training opportunities.
[48] 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.



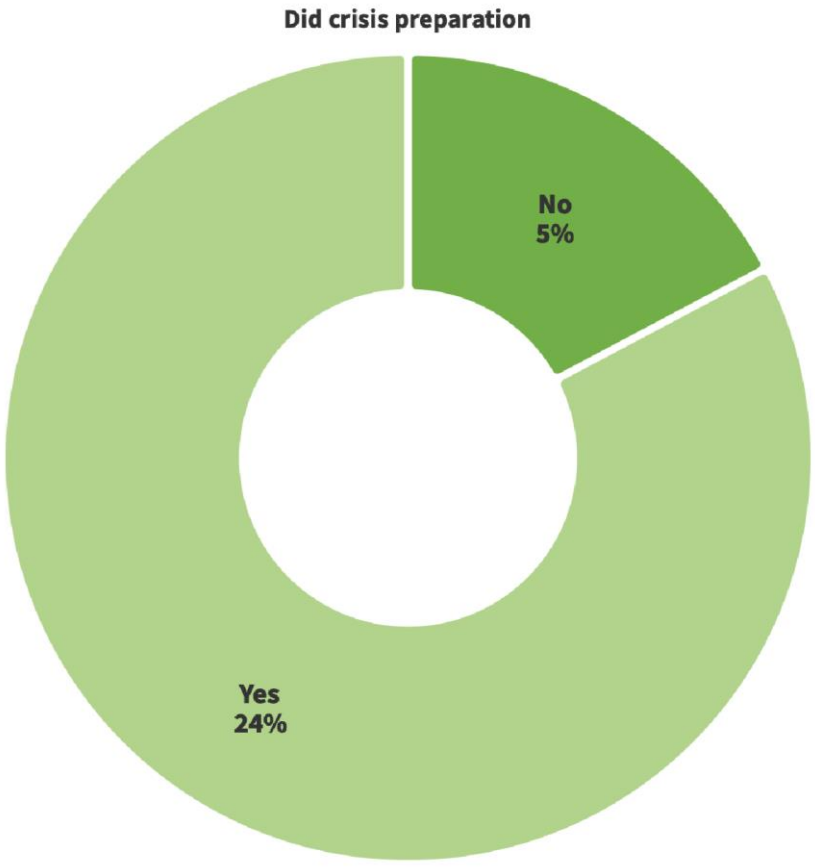


Figure 6.2: NREN crisis preparation. The bar graph summarises what kind of crisis preparation NRENs did. As a number of NRENs took several different measures, numbers in the graph add up to more than 29. One of the NRENs that experienced a real crisis had not done any crisis preparation. The circular chart summarises how many NRENs have carried out crisis preparations (29 NRENs responded to this question).

Threats

As threats are proliferating, NRENs are working to counter them in various ways.

On the network level, a growing number of NRENs operate Security Operations Centre (SOC) or Security Information and/or Event Management (SIEM) functions or are preparing to do so. In 2022, 24 NRENs reported using SOC / SIEM.

On an organisational level, many NRENs perform security audits of their organisation or their services – this, of course, is good practice but is increasingly forced by the presence of legal frameworks, as briefly discussed above. Twenty-seven out of 41 NRENs have some kind of security audit of their organisation; roughly half of them (13) make use of international security certification standards such as ISO 27001.[49]

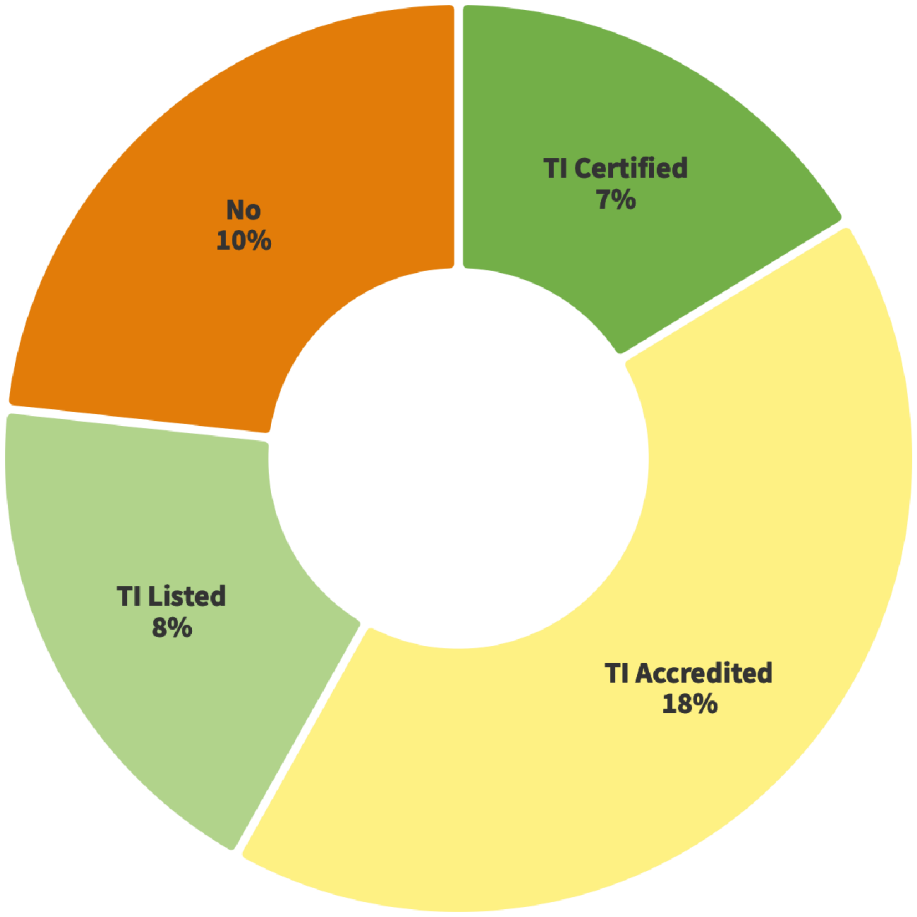


Figure 6.3: Numbers of NRENs with CSIRTs and their level of TI participation. 33 out of 43 NRENs have a CSIRT that is participating in the Trusted Introducer (TI) programme. In December 2022, 7 CSIRTs were certified or candidates for (re-)certification, 18 were accredited or candidates for accreditation, and 8 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 grown by two compared with 2021.

Business continuity plans are another way to prepare for threats and currently 21 NRENs have one of these in place – but 20 NRENs have not. While there is progress in this area (in 2021, only 18 NRENS had a business

[49] 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 14 NRENs reported having an ISO 27001 certification or are working on it.

continuity plan in place), there is clearly work still to be done. 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.[50]

Finally, most NRENs (35 out of 43) also have a Computer Security Incident Response Team (CSIRT) (see Figure 6.3). The number of certified teams (10) has not grown in 2022. Those NRENs that do not have a CSIRT usually have this function covered by closely associated organisations.

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. Forty 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 anti-virus suites, anti-spam and firewalls.[51] However, this is a very wide field, which also includes more sophisticated measures such as integrity checkers or network segmentation. Figure 6.4 presents an overview of how many NRENs use which types of security tool.

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

[51] 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).

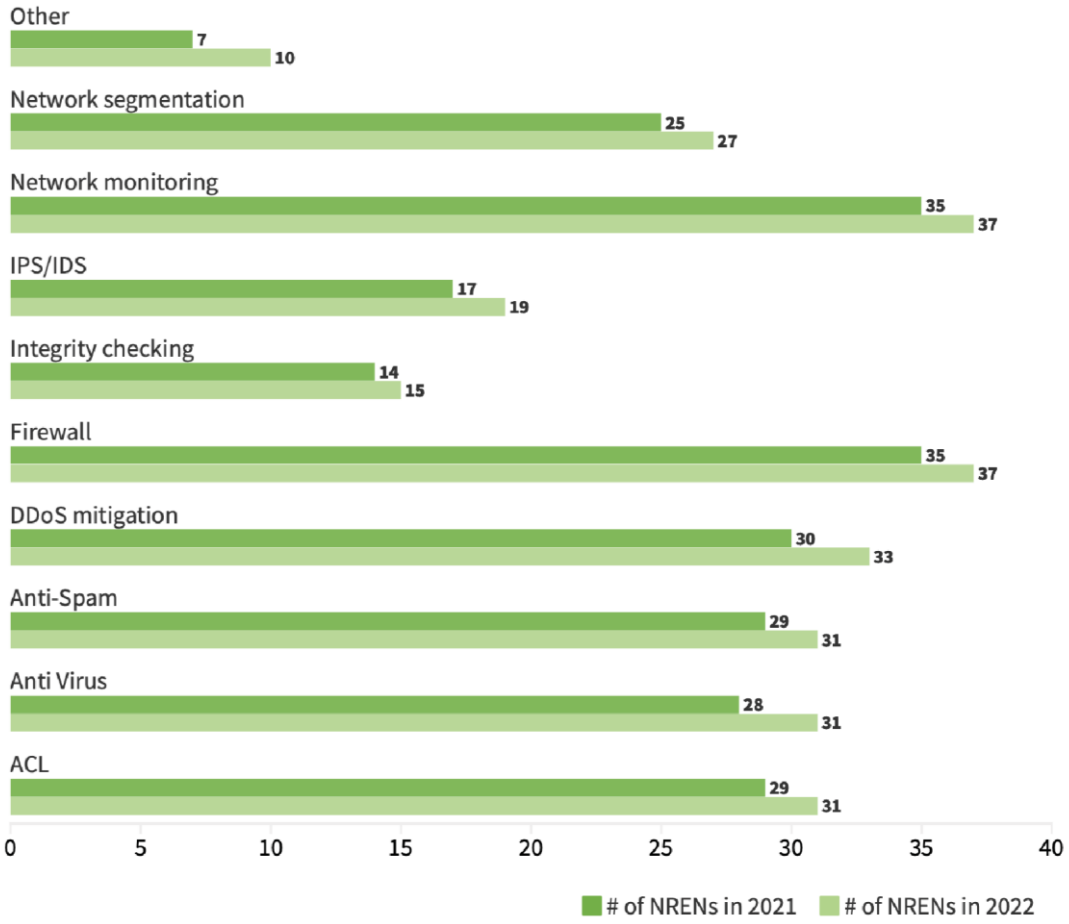


Figure 6.4: Cyber-security tools used by NRENs. The bars indicate how many NRENs are using this particular type of security tool.

6.2 Security Services

As service provider and ICT experts, NRENs are also well placed to provide cyber-security services to their customers. Therefore, many NRENs also offer services to support their users' ICT security. This can mean technical services but also providing advice to users – an overview can be found in Figure 6.5.

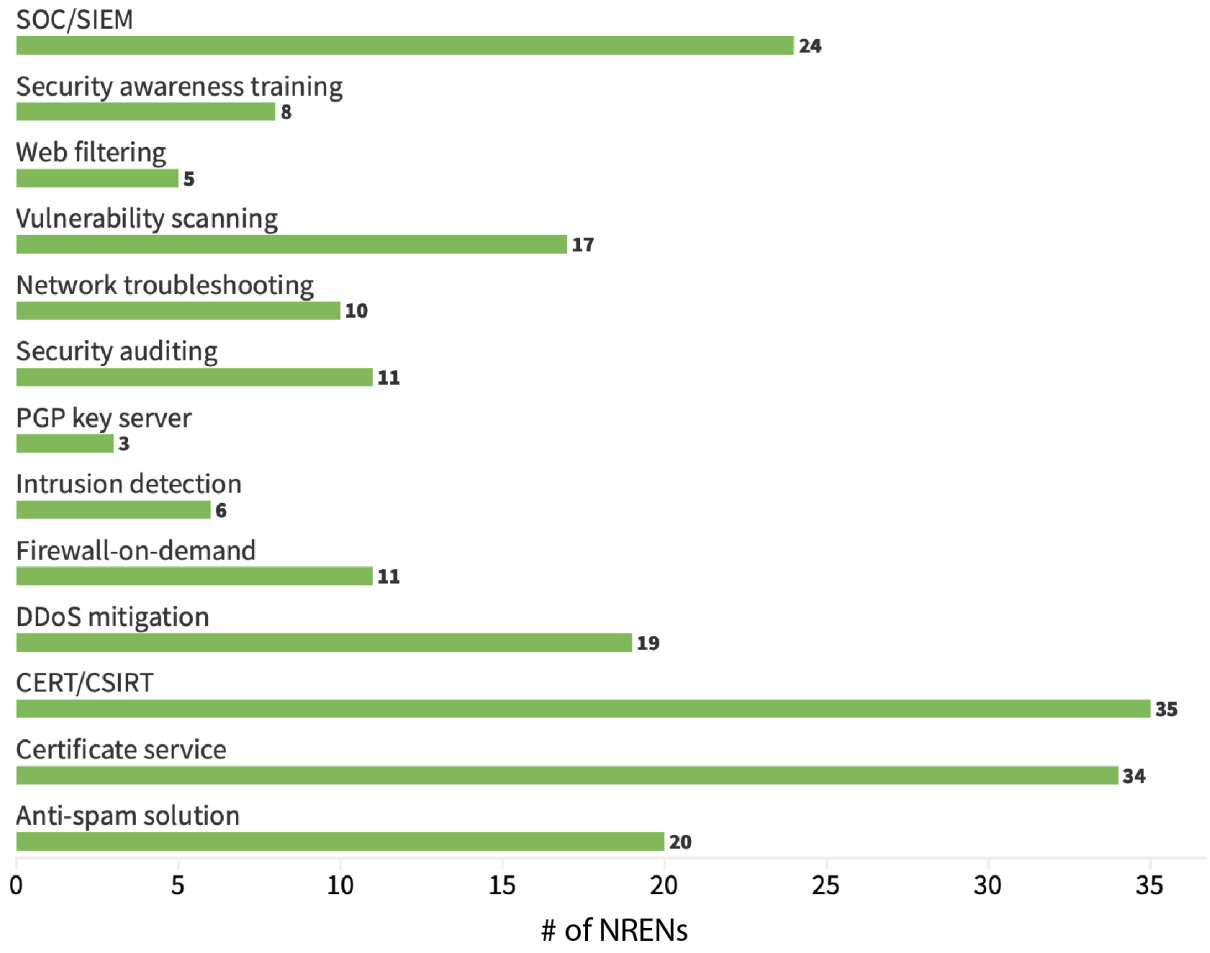


Figure 6.5: Security services offered by NRENs to their users

An important development in this area is the increase in the use of SOC/SIEM tools that has already been mentioned above. Currently, 14 NRENs have reported running a full SOC.[52] 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.[53]

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 Trusted Certificate Service (TCS),[54] which is currently used by 33 NRENs, and Firewall on Demand (FoD), currently used by 28 NRENs.

[52] ACOnet, AMRES, CARNET, CESNET, DeIC, DFN, GRNET S.A., Jisc, LITNET, RENATER, RESTENA, Sikt, SURF and SWITCH. The most common systems used are Splunk (4).
[53] eduVPN is currently offered by 8 European NRENs and tested or piloted by 11 more. It is also used by more than 100 universities worldwide.
[54] 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).

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 (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.[55] 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 and 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.[56]

Security challenges arise at different levels and involve protecting an NREN's organisation, protecting its network – and helping users to improve their security as well. Security-related activities include policies and training as well as technical measures, all of which have to be addressed. NRENs are working to fulfil requirements but the landscape is very divided. For example, a sizeable number of NRENs now offer sophisticated services like SOC/SIEM systems, but it is quite clear that this will not be achievable for others. However, the NREN community can help to close this gap to a certain point – a good example for this would be the existence of CSIRT teams across almost all NRENs, and also the option for NRENs to acquire some security services from the GÉANT service portfolio.

The challenge for all NRENs is the same: how to keep the networks secure and safe. However, depending on their size, operational scope and organisational position, the NRENs differ vastly in their ability to provide cyber security.

[55] 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.

[56] Russia's invasion of Ukraine in 2022 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.[57]

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 Section 4) or GÉANT services such as InAcademia or 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 2022 there were 87 known research and education federations worldwide (up from 83 in 2021), 78 of which are part of eduGAIN (up from 74 in 2021) (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,

[57] 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.

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.[58]

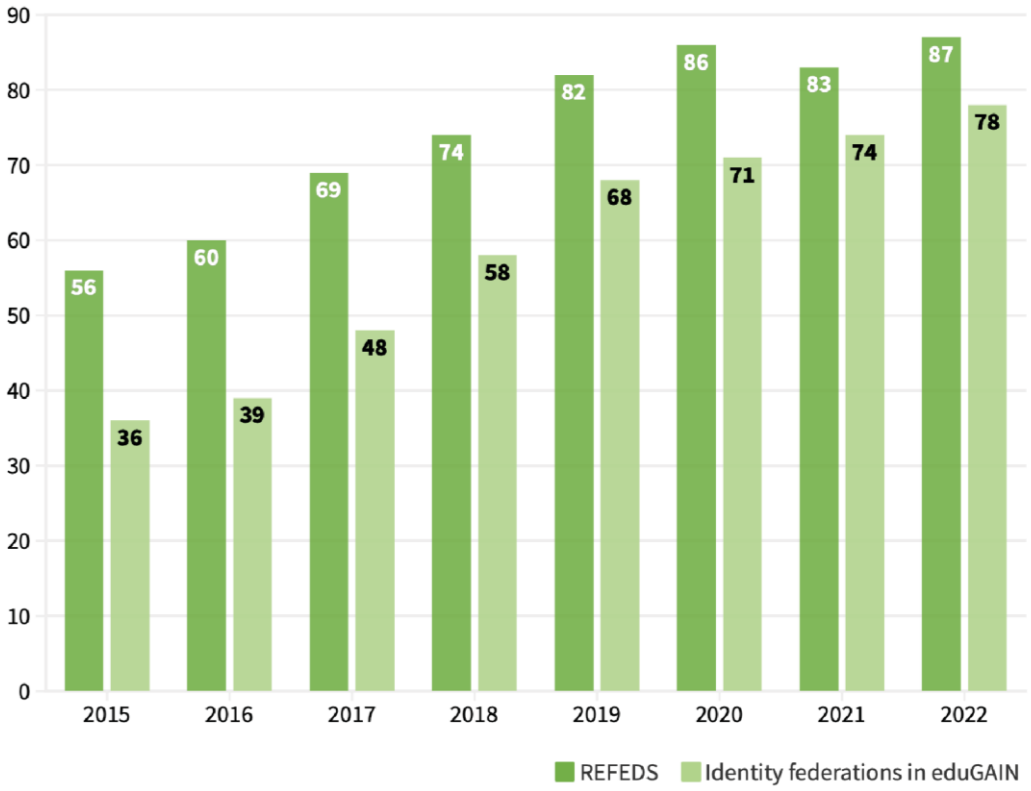


Figure 7.1: Number of known REFEDS members (darker colour) and number of identity federations using the eduGAIN service (lighter colour) 2015–2022. Note that all identity federations in eduGAIN participate in REFEDS but not vice versa. Federations will join REFEDS early on in their development process 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 ensure 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).

[58] 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].

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.[59]

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.

[59] 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.

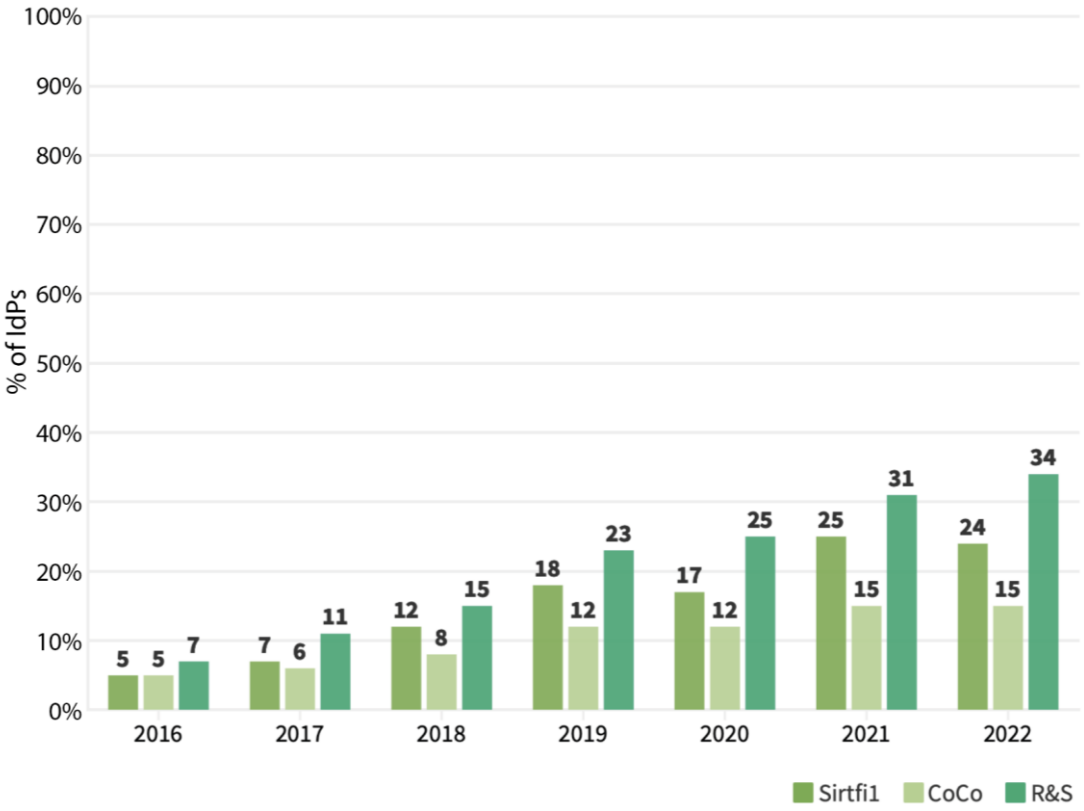


Figure 7.2: Compliance of IdPs in REFEDS members to policies. Shown are adherence to the Research and Scholarship attribute release schema (R&S), the Code of Conduct data protection requirements (CoCo) and the implementation of the Sirtfi security incident response framework (Sirtfi1). The numbers are derived from the eduGAIN metadata. This means that 34% of IdPs across all federations in eduGAIN support R&S, 24% support Sirtfi, and 15% support CoCo; in general, compliance to the standards is on a slow but steady upward trend. What makes this trend more impressive is the increase in absolute numbers of IdPs: while in 2016 there were 2,235, in 2022 there were 5,319 (see also Figure 7.4).

7.1.2 Identity Federations – Budgets and Employees

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 (of those federations that responded to this question, 20 have no dedicated budget, while 13 do). Unlike the situation with regard to dedicated budgets, most identity federations have staff dedicated to them (31 of 37) – which reflects the specialised knowledge needed. The number of dedicated staff varies but does not exceed single digits. For most organisations in the survey the total number of employees is not available but for the European federations, an analysis is possible: within Europe all NRENs run their own federation and the Compendium survey provides total employee numbers, so Figure 7.3 gives an comparison of staff dedicated to identity federations and total staff numbers for the subset of European NRENs where those numbers are available.

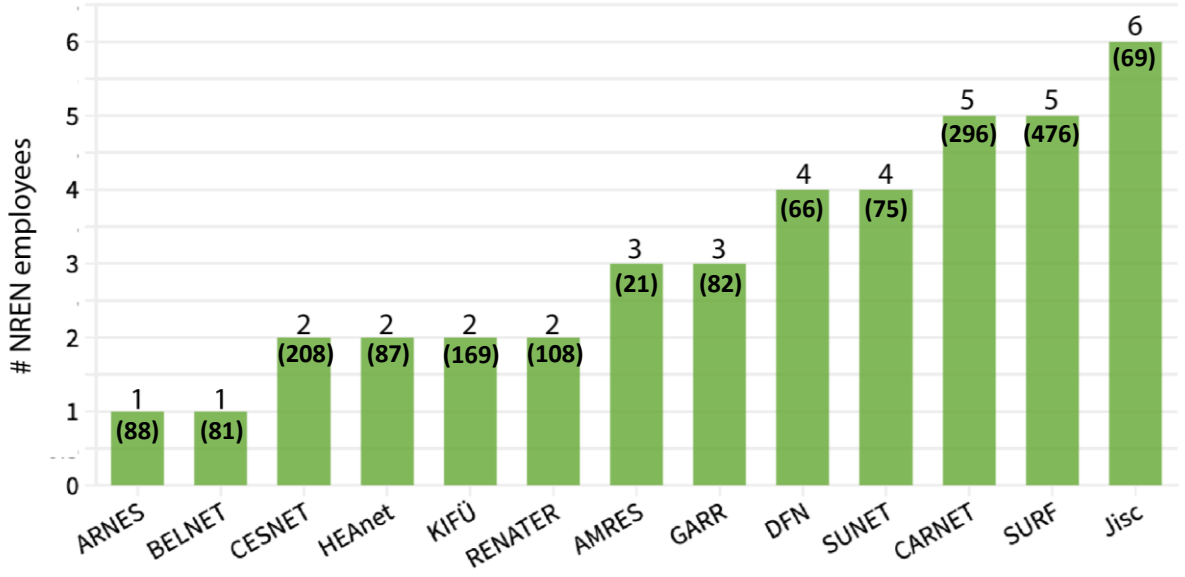


Figure 7.3: European NREN employees dedicated to work on identity federation. The first number denotes the number of employees dedicated to work on the federation; the number in parentheses is the total number of NREN employees. Only a subset (13 of 43) of European NRENs provided both numbers and those are shown in this figure. Numbers do not increase linearly with NREN size, indicating that this area requires a disproportionally larger effort from smaller NRENs.

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 2022 (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; once this work is concluded, eduGAIN will require participating federations to comply with the baseline.

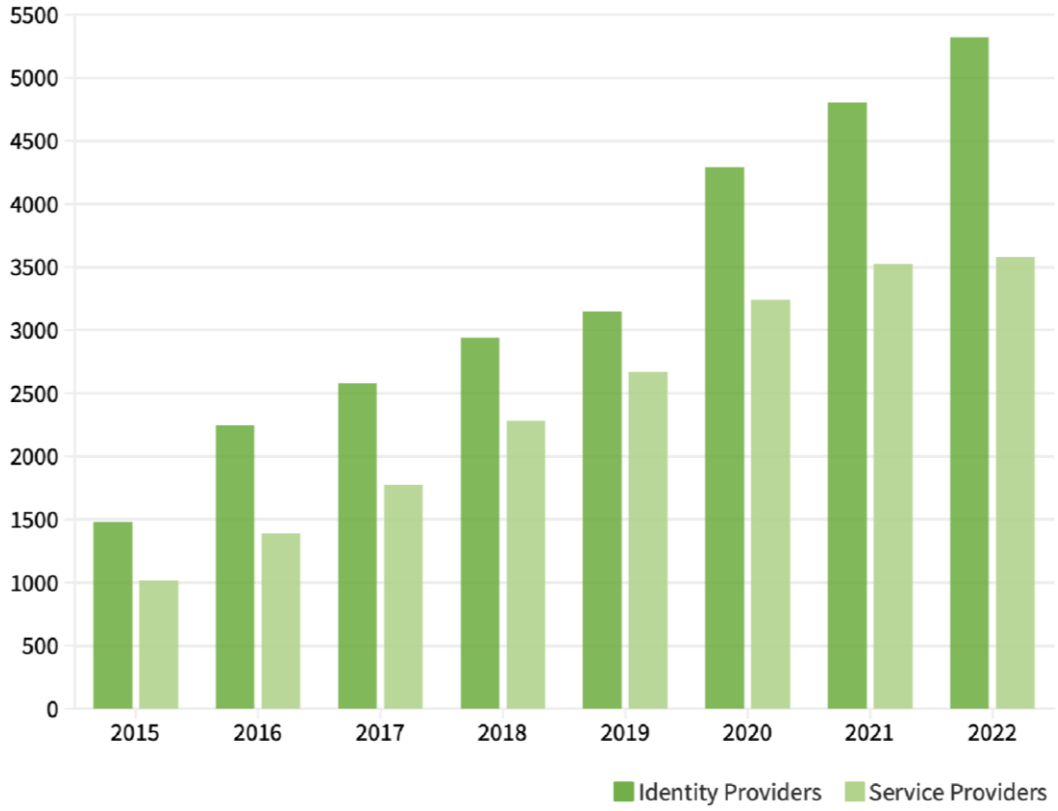


Figure 7.4: IdPs and SPs that are part of the eduGAIN service. The numbers have increased considerably over the years, with varying but overall impressive growth rates (increase of IdPs 2015/16: 52%; 2016/17: 15%; 2017/18: 14%; 2018/19: 7%; 2019/2020: 36%; 2020/2021: 12%; 2021/2022: 11%; increase of SPs 2015/16: 37%; 2016/17: 28%; 2017/18: 29%; 2018/19: 17%; 2019/2020: 22%; 2020/2021: 9%; 2021/2022: 1%).

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 global collaboration between thousands of institutions. In Europe, the national and international operation of this infrastructure is undertaken respectively by the Roaming Operators (ROs) and a central eduroam Operational Team funded by the GÉANT project.

Since its inception in 2003, eduroam has expanded enormously and is now available in 106 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 autonomous roaming services who agree to a set of defined organisational and technical requirements that ultimately constitute eduroam.

eduroam is present in all European countries, and its usage is growing, with the majority of authentications happening nationally. In 2022 the effect of recovering study, travel and movement activities after the COVID-19 pandemic was evident: both international and national eduroam traffic has recorded approximately 70% growth compared with 2021.

eduroam continued engagement with OpenRoaming [OpenRoaming], to widen the footprint of eduroam access locations to spaces other than academic institutions and positively influence eduroam usage and traffic. The latest developments concentrate on improving the support for users' onboarding of eduroam and OpenRoaming, while also providing new managed services for Service Providers (SPs) and Identity Providers (IdPs). One notable

collaboration involves partnering with the geteduroam project [geteduroam]. The geteduroam project provides apps and managed IdP features, and integrates with the services from the central Operational Team.

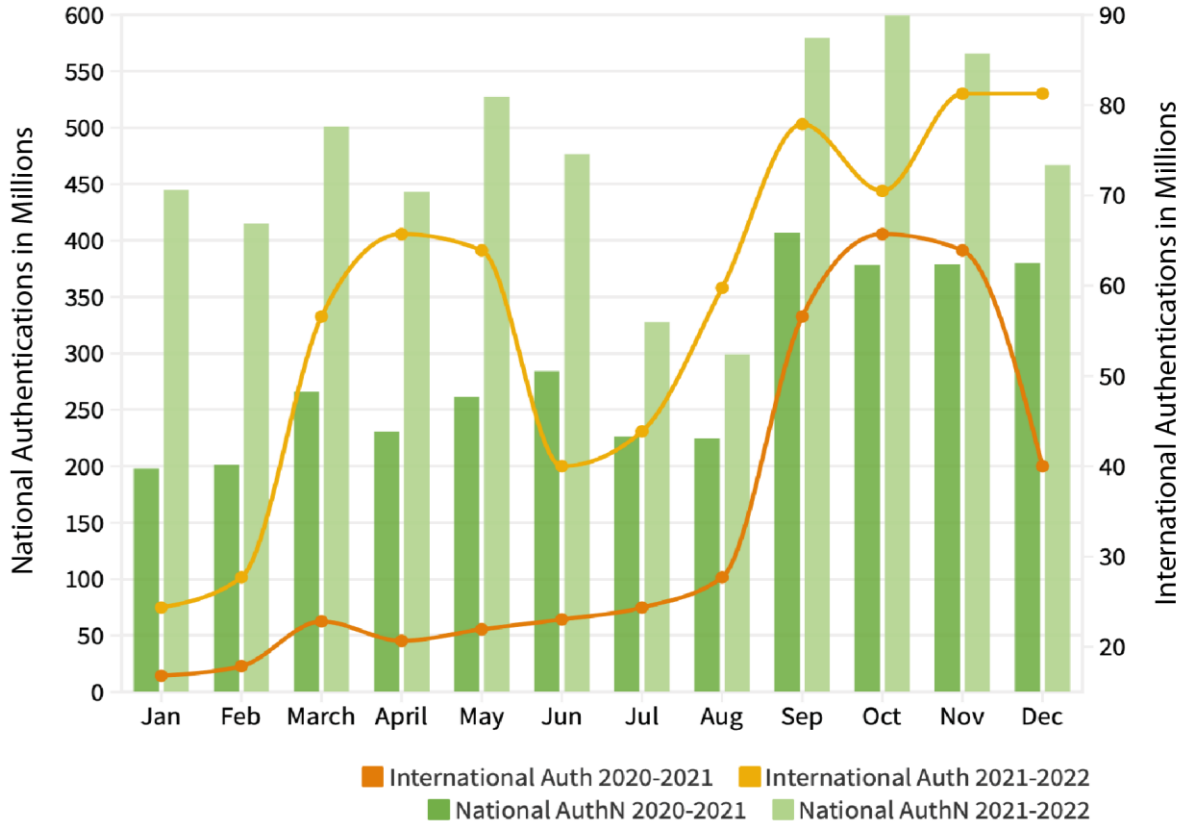


Figure 7.5: Authentications by eduroam month on month for the years 2021–2022. The majority of authentications happen nationally, while international authentications (e.g. visiting scholars, exchange students, etc.) are considerably lower, making up about10% of authentications in 2021 and 2022. A post-COVID-19 effect is evident in 2022 as recovery of both national and international traffic is tracked, with an increase of approximately 70% compared with 2021.

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 2022, 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 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) 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

InAcademia is a service that allows online retailers to easily validate if a customer is a student or otherwise affiliated to an education institute, as a member of staff or faculty for example [InAcademia]. It performs this service by asking users to authenticate at participating Identity Providers available in eduGAIN. It offers an OIDC protocol interface that connects online retailers with the SAML protocol that is used within eduGAIN and R&E federations, which releases the attributes that InAcademia uses to determine whether a user is a student. The InAcademia service is available in two service offerings: “Commercial” for online retailers that profit from offering paid-for services to users and “Community” for Service Providers that are not for profit and need only a simple validation of affiliation.

End users and Identity Providers benefit from InAcademia as it provides a privacy-preserving way to validate the user’s affiliation, compared to alternative methods that might expose more personal information to the retailer than is necessary, such as asking users to upload personal documents. Identity federations are encouraged to actively participate in promoting InAcademia to their constituents and are invited to participate in the InAcademia Steering Committee. The InAcademia support model relies on collaboration with federations operators to resolve issues regarding the institutions from the member groups.

In 2022, the service has continued to grow, with over 2.3 million authentications processed in 2022, and now has an established revenue stream from merchants using InAcademia. As shown in Figure 7.6, users in the Netherlands, Germany, Denmark, Spain, France, Italy, Sweden, Turkey, Austria, Iceland and Finland 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.

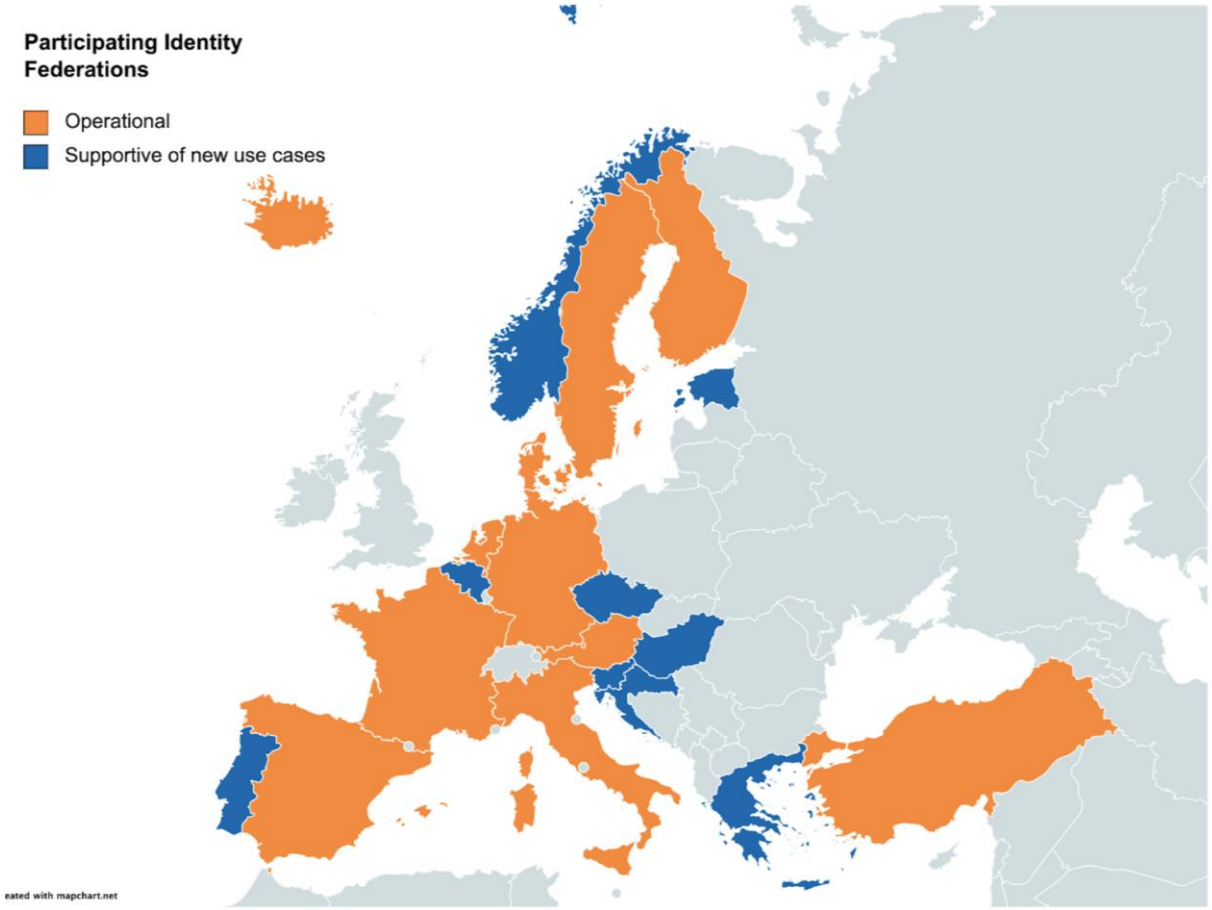


Figure 7.6: Federations Participating in InAcademia

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 constantly increasing. It is also clear that more recent services such as Core AAI Platform and InAcademia, built on top of pre-existing T&I infrastructures such as eduGAIN and eduroam, in turn make the latter business proposition more attractive and create a kind of virtuous cycle.

There is, however, still something of a gap between these flagship projects and the less high-profile but nonetheless essential efforts that maintain identity federations, where coordination of stakeholders is indispensable but 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 is constantly increasing in importance.

8 Cloud Services

The previous three years (2020–2022) have seen an incredible acceleration in the development and adoption of advanced digital services and platforms. This shift has happened 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. As the IT service facilitators for R&E, NRENs 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. The COVID-19 pandemic has demonstrated the value of digital online services and communications platforms in enabling distributed collaboration – in short, of cloud-based services.

Similar priorities have been expressed from within the NREN community. The 2021 GÉANT CTO workshop on Clouds, Collaboration, and Education Services resulted in the production of a roadmap for collective GÉANT community activities on digital services, which prioritises a focus on collective procurement and adoption support for new framework contracts, as well as collective strategy development within the R&E community, to integrate positions on both commercial as well as community-developed services. This informed the project planning for the new GN5-n GÉANT projects, including its current iteration, GN5-1. The roadmap was reaffirmed by the 2022 CTO workshop.

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.

Cloud Services Delivery

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.

8.1 Benefits for Users

Individuals and teams benefit from the location-independent use of cloud 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 are incentivised to use available public cloud services for their work in an individual and ad hoc way, out of a perception of greater accessibility, usability, or performance. This may not be in the best interest of their home institutions, but these may also struggle with offering viable equivalent private cloud 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: directly providing cloud resources themselves, facilitating the use of community clouds, and brokering commercial clouds. To further add value to such a service offering, an NREN can become a cloud competence centre for their institutions.

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 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.[60]

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 soon 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,[61] trusted by all parties involved, to handle the financial 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.

[60] 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 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.
[61] For example, DFN-Cloud “Federated Services”, by the German NREN DFN.

Task 3 Service Development: Cloud Offerings, of the GN4-3 project Work Package 4 Online Services Development and Delivery, 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 GN4-3 deliverable [D4.3].

8.2.2 Brokerage or Procurement Support for Public Clouds

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

Such Framework Contracts do not solve all challenges faced by institutions when adopting cloud services, and the detailed work of developing and implementing a digital transformation strategy remains unique to each institution. However, Frameworks remove a considerable amount of effort and uncertainty from an institution at an early stage of that process. The effort and time saved at institutions across Europe makes the time invested in the GÉANT cloud tender effort well worth it.

8.2.3 Cloud Competence Centre

Independent of direct cloud procurement support activities, NRENs can add tremendous value to their community by collating and drawing together specialist knowledge and circulating experiences, thereby developing into a centre of competence for their community on matters of cloud usage. A solid base of cloud consulting capability, available to all institutions as they start their journey, is a great 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 2022, once more ratifying the 2021 GÉANT Cloud Roadmap. This places a strategic priority on maintaining continuity for the Infrastructure as a Service Plus (IaaS+) Framework by re-tendering in 2024, and on developing a forward-looking NREN strategy on cloud and above-the-net services. Both these objectives are dedicated activities in the GN5-1 project (Work Package 4 Above-the-Net Services). In total, the NRENs, together with their IT partners at institutions, can evolve their role from IT resource operators to include more full-service solution facilitators and thereby keep their value visible to their user communities in an increasingly digitalised environment.[62]

8.3 Community Feedback

Community feedback was gathered via the GÉANT Cloud Survey for National Research and Education Networks (NRENs) and Research and Education (R&E) institutions. In preparation for the next pan-European tender, the GÉANT Cloud Team needed an overview of the R&E community's awareness and use of the GÉANT cloud services, along with institutions' cloud usage plans and future requirements, to learn of obstacles to framework adoption, as well as to gather feedback on what kind of support was most needed and what can be improved or solved in

[62] 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.

the next tender. A brief summary of the 2023 survey results is provided below, pointing out some of the trends that have become apparent in comparison with the 2021 survey.[63]

8.3.1 2023 Cloud Survey Results

Half of the respondents reported both buying and building infrastructure-cloud services, confirming a trend towards hybrid cloud usage; in addition, the number of institutions that consumed these services via their NRENs increased.

Generally, satisfaction levels with the services and the resellers of the Framework were high, although satisfaction with the services and resellers of the 2016 Framework was higher than with those of the 2020 IaaS+ Framework. This possibly reflects the unexpected size and complexity of the more recent Framework.

It emerged that the main obstacles to using the pan-European infrastructure-cloud frameworks were differences in national procurement policies and needs of the countries (especially in, but not limited to, non-EU countries), and certain requirements for data management. While most respondents from institutions who already use the GÉANT cloud services in conjunction with OCRE plan to continue using them in the future, both surveys revealed the need to actively promote the advantages of the Frameworks (e.g. significant discounts). Knowing the intricacies of the Frameworks also turned out to be an important (and sometimes limiting) factor for NRENs as well as institutions. This fits well with the continuing interest in cloud training (with a particular emphasis on security, cost-control mechanisms and legal aspects). In summary, supporting the usage of the Frameworks therefore needs investment in communication, cloud training, legal and risk assessment, and cloud evangelisation to trigger pilots.

8.4 Uptake of the GÉANT IaaS Cloud Frameworks

Since 2016, the GÉANT Frameworks for infrastructure clouds (in the following called 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 from December 2020 on (here termed either IaaS+ or OCRE framework)[64] 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. The year-on-year growth in 2022 (more than €22 million over 2021) approximates to another +47%.

[63] The 2023 GÉANT Cloud Survey was carried out in March–April 2023, addressing National Research and Education Networks (NRENs) and Research and Education institutions. 137 responses were gathered from 24 European countries. Most respondents (ca 70%) were from large institutions (more than 500 employees), i.e., universities and research institutions. Approximately 80% of all the respondents were from Northern or Western European countries and about 20% from Southern or Eastern European countries.

[64] The tender for the 2020 IaaS+ Framework was run by the Open Clouds for Research Environments (OCRE) project [OCRE].

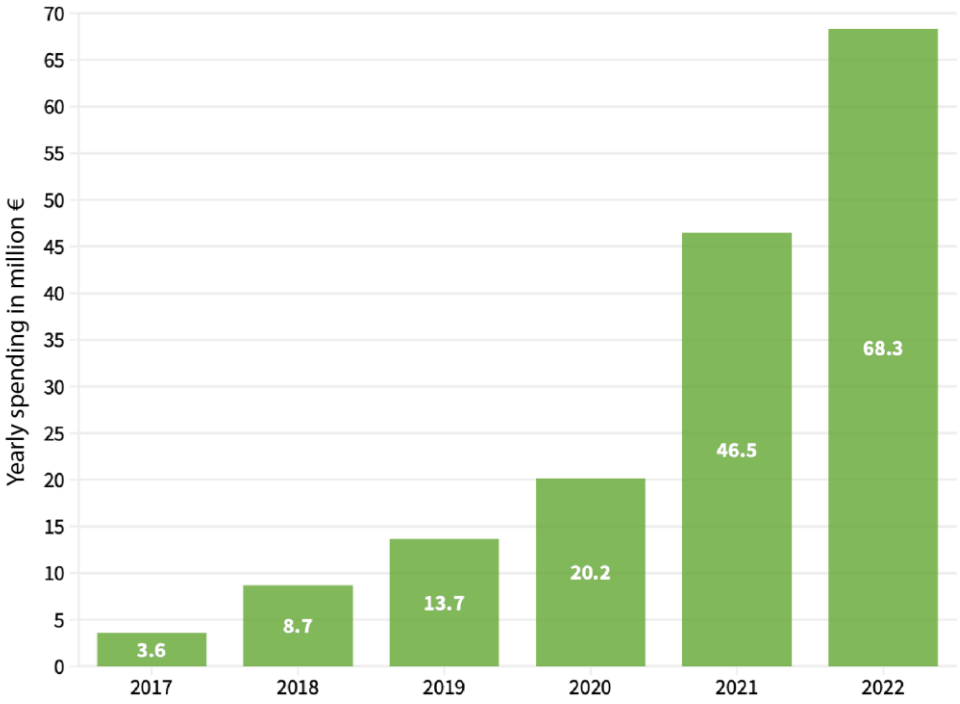


Figure 8.1: Yearly spending via the GÉANT Cloud Frameworks (IaaS and IaaS+) 2017–2022

Moving beyond the initial group of NRENs making up the usage under the first Framework, the growth in consumption under the 2020 IaaS+ Framework is significantly driven by growth of usage in additional countries. These growth numbers demonstrate national-level cloud procurement aggregation through the Frameworks, indicating the progress that 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, rising to 26 countries with consumption in 2022 (Figure 8.2). The remainder are mostly in non-EU countries that face some additional procurement challenges around making use of the Framework, which is governed by the EU Procurement Directive.

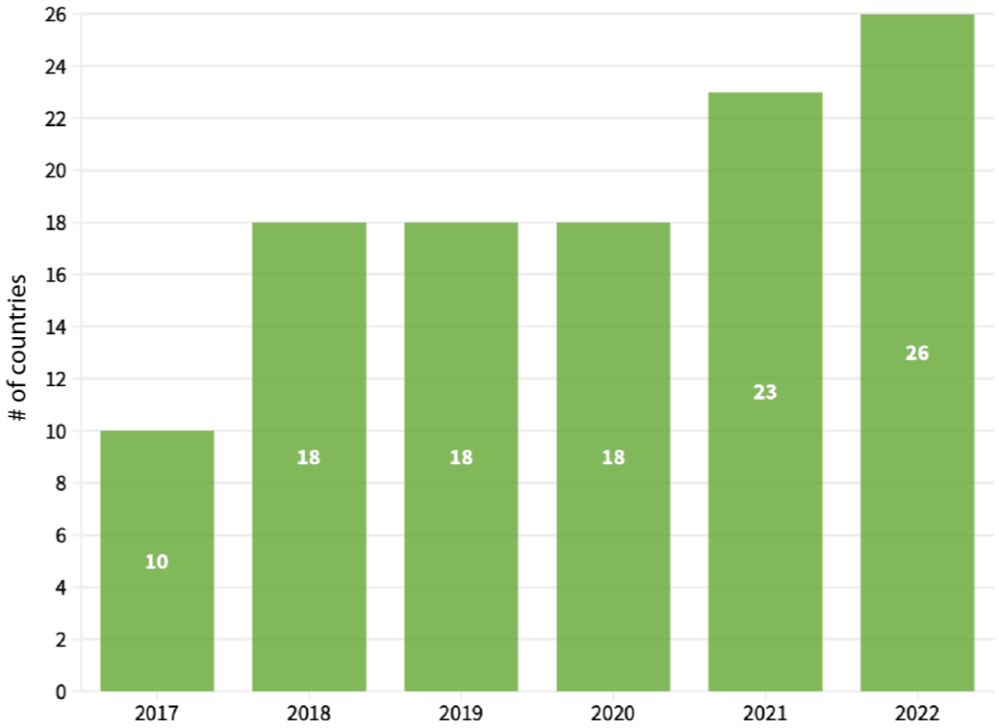


Figure 8.2: Number of countries with active Framework consumption

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 access to discounts negotiated by the GÉANT procurement. Cost reductions of this order are unachievable to any single institution, so the Framework is 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 and service management 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 are not adopting infrastructure-cloud services at the same rate as other sectors, with some notable exceptions in individual countries. There are several driving and delaying factors at play here, many of them cultural:

Driving Factors

- End-user demand. The capability to deliver state-of-the-art digital experiences quickly and flexibly 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 services with highly developed user interfaces and functional integration. Software (cloud-connected "as-a-service") is the first choice where the desired functionality is available, whereas for flexible and powerful application/research development with low IT-management overhead, Platform as a Service (PaaS) – with integrated features such as autoscaling databases, accelerated compute, or machine learning – is state of the art. Older IT paradigms such as virtual machines or container platforms have become infrastructure that end users have little interest in personally interacting with any longer.

- 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 elastic 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 their end-of-life and the necessary investment decisions for a 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. This capability also enables resilience against instability in any one cloud service platform.

- 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)
    - Most R&E infrastructure operators consider the legal risks (and necessary efforts) of data protection to be 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. Community experience shows that this additional effort naturally becomes best practice anyway, as digital transformation matures in the organisation. Meanwhile, the associated public uncertainty and doubt over the issue is slowing adoption of all cloud services, even in clearly legal use cases. The next iteration of the trans-Atlantic agreement is under development, and it remains to be seen how this will affect the community debate in future.

- 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 and IT decision makers are comfortable with the idea that their data might be stored outside of their "comfort zone", be that their immediate organisation or further afield, even outside national jurisdiction. In some edge-case legal contexts, a certain physical location and access to hardware infrastructure may still be a legal requirement. These reservations overlap partially with the legal concerns that led 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 NREN's points of contact. This is a missed opportunity to connect demand with an optimised NREN-community 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 the 2021 and 2023 Cloud Surveys show clearly that state-of-the-art digital services are in high and rapidly growing 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 2022 GÉANT CTO workshop round and the 2023 GÉANT Cloud Survey, most NRENs recognise and acknowledge this development.

Cloud services developed and operated from within the R&E community can differentiate themselves from generic public services by being highly integrated with the R&E service ecosystem and by addressing community 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 consumption data for the IaaS+ Framework in conjunction with OCRE show a steady increase in the number of NRENs that report significant uptake by their institutions, which in turn indicates that the NREN has taken effective steps to orchestrate procurement aggregation activities and demonstrates the value and savings that NRENs can deliver to their communities. Total consumption across all the IaaS+ Frameworks since 2017 has exceeded €160 million as of April 2023. 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

The increasing use of ICT tools in teaching and learning creates a continuous and growing expectation for NRENs to provide services specifically for the education communities. Everyday life and work in education now rely on online communication, e-content, digital learning environments and on a variety of information systems needed for teaching and learning practices as well as education administration. This is true not only for the new education initiatives but also for the traditionally oriented institutions and whole national education systems. Support for this development is in great demand and is obviously beyond the power of individual institutions. NRENs are therefore often seen as potential central, national providers that already have the expertise and procedures in place and that could expand their services beyond connectivity and beyond academia. However, data collected through the annual TF-EDU survey show that not all NRENs have the means or the capacity to respond to this need, which has been growing fast over the past years, a process that has been further accelerated by the COVID-19 pandemic.

9.1 Education Services

This section is based on the work of the Task Force on Educational Services and Activities (TF-EDU][65] and gives an overview of the activities of NRENs in supporting education, detailing how many and which services they offer; it 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, 2022 and 2023 about their activities in education.[66]

9.1.1 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.

[65] 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. One of the main TF-EDU activities is scanning the landscape of NRENs' educational offers and providing aggregated information on those offers back to the GÉANT community.

[66] The most recent survey was conducted in February and March 2023 and collected 44 responses.

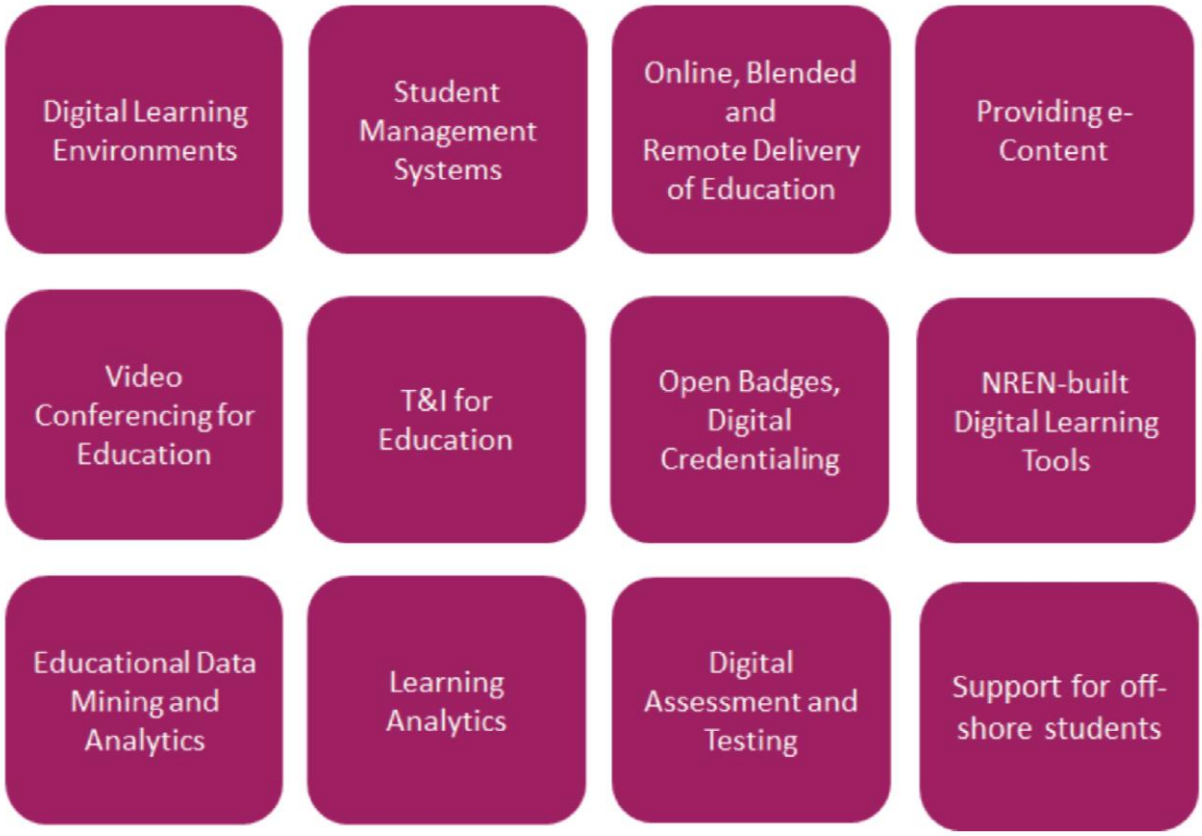


Figure 9.1: Categories of education services NRENs offer

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.

9.1.2 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 four years, indicating a slight upward tendency and a steady trend in the

last two years. The number of such services offered varies considerably between NRENs, as is shown in Figure 9.3.[67]

A look at the details (shown in Figure 9.3 and Table 9.1) reveals that in the 2023 survey NRENs very commonly offer videoconferencing for education and trust and identity services. 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.

Digital learning environments and e-content are also frequently encountered, with more than 20 NRENs offering these services.

Comparing results across the years, there has been an increase in the numbers of education-related services offered by NRENs. In absolute numbers, 100 such services are being offered across the 22 NRENs in 2023, while in 2022 there were just 88. In addition, a number of services are still in development – here the numbers for 2022 and 2023 stand at 56 and 57, respectively.

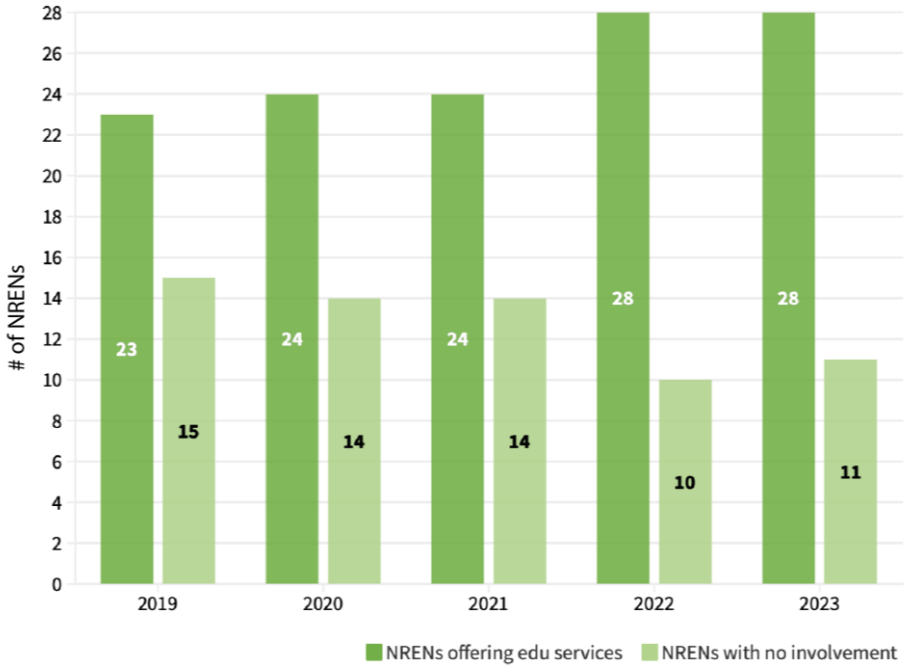


Figure 9.2: Number of NRENs offering education-related services 2019–2023. The majority of NRENs offer services that specifically target education, and the figure even shows a slight increase over the years. Note that the extent of the commitment differs, as becomes clear in Figure 9.3 and Table 9.1. Only NRENs for which consistent information was available are counted in this figure.

[67] The figure shows European NRENs (which are members of GÉANT) and some international NRENs that participated in the survey. However, the analysis in the text only considers European NRENs.

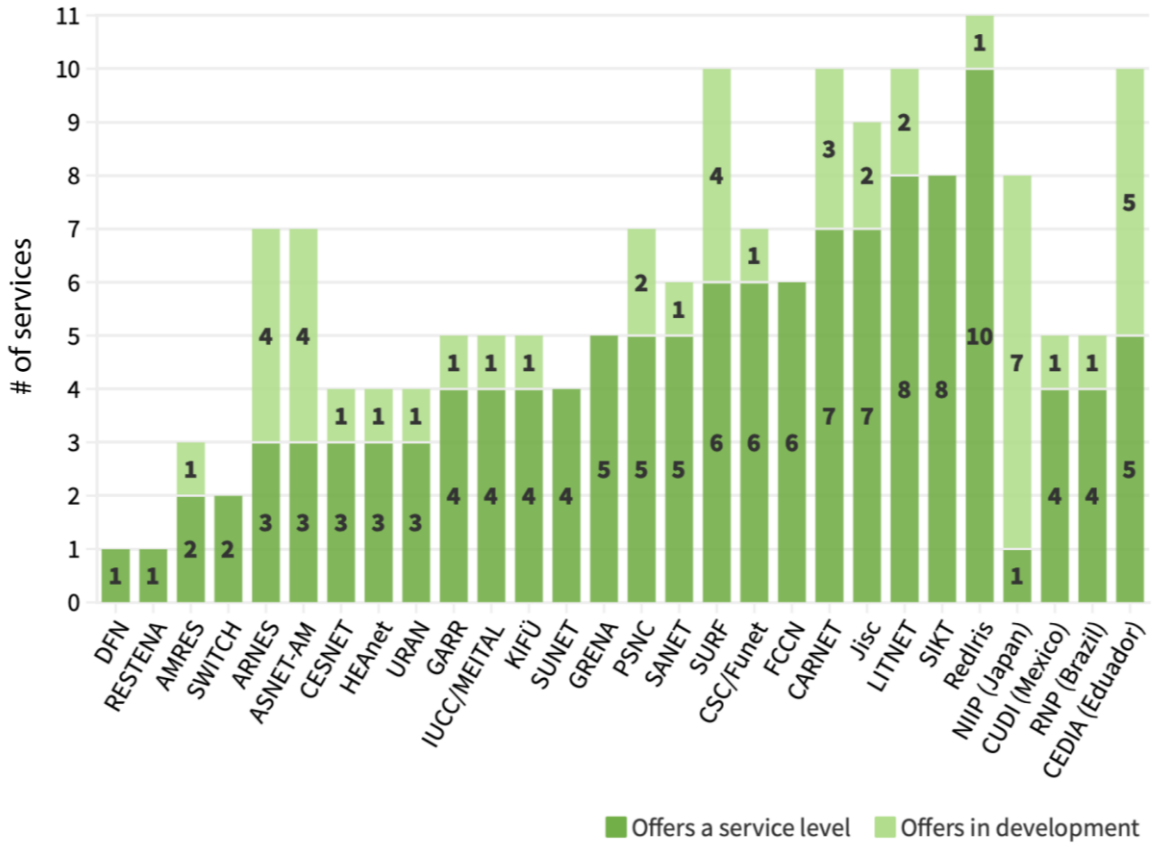


Figure 9.3: Number of education services provided and in development, by NREN according to the 2023 TF-EDU survey. The figure shows all European NRENs that provided information as well as some international NRENs that participated in the survey (on the right), which allows a glimpse beyond the confines 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, many of which will eventually become a part of the NRENs' service portfolio. Among the services in development, the three most common categories are "Open badges, digital credentialing" category (10), "Digital assessment" (8) and "Learning Analytics" (7).

NREN	Digital Learning Environments	e-Content	Online or blended education	Digital assessment	Open badges, digital credentialing	Learning Analytics	Student Management System	T&I for education	Educational data mining and analytics	Videoconferencing for education	Support for Offshore students	In-house built tools for digital learning
European NRENs												
AMRES	X	X	X				X	X		X		
ARNES	X	X	x	x	x	x		x		x		
ASNET-AM	x	x	x	x	x	x	x	x	x	x	x	x
CARNET	X	X	X	x	x	x	X	x	x	x		x
CESNET	x	X						x		x		x
CSC/Funet	X	X		X	x		x	x	x	x		X
DFN	X							x		x		
FCCN	x	x	x	x	x	x		x	x	x		x
GARR	x	x	x					x		x		
GRENA	X		x	x						x		x
HEAnet	x						x	x		x	x	
Jisc	X	x	x	x	x	x	x	x	x	x	x	
KIFÜ	X	x	x		x	x		x		x		
LITNET	x	x	x	x	x	x	x	x	x	x	x	x
IUCC	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	x	x
RESTENA								x				
SANET	x	x	X	x				x		x		
SIKT	x	x	x	x	x	x	x	x	x	x	x	
SUNET	X			x				x		x		
SURF	X	X	X	x	x	x	x	x	x	x	x	x
SWITCH						x		x				
URAN	X	X		x					x	x		
International NRENs												
CUDI (Mexico)	x		x					x		x		x
CEDIA (Ecuador)	x	x	x	x	x	x	x	x	x	x		x
NIIP (Japan)	x	x	x		x	x			x	x	x	x
RNP (Brazil)	x	x	x	x	x	x	x	x	x	x	x	
TARENA (Tajikistan)		x	x				x	x		x		

Table 9.1: 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 with 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).

9.2 Reflections on Past and Future Horizons

Although demand for the most popular services, videoconferencing and learning management systems (LMS), dropped in 2022 compared with the pandemic years, their use is still higher than in pre-pandemic years, as reported by NRENs. Moreover, their focus in the coming years will stay strongly on VC, video services and LMS, including the necessary computing infrastructure – there is a need to "*improve the video infrastructure and processing capacity*". There is a trend of moving from proprietary solutions to considering more procurement options; for example, one NREN reported that they were "*continuing to expand the procurement portfolio*" and were "*phasing out in-house VC services*". This trend is not universal though, as there is still a mixture of approaches, illustrated by one NREN stating that they were "*combining in-house development and market procurement, with development in project partnerships*".

In terms of needs (and wishes), many NRENs reported a high demand for user training, and for skilling up the digital competence in general, as well as the need to consider supporting users in their efforts to modernise teaching and learning, for example "*skilling up knowledge about creating and using digital content for LMS platforms more efficiently*".

When it comes to popular services, student management services seem to be on a constant rise, although some NRENs report difficult challenges in addressing those needs, for example: "*For our members there is a high priority need for a Student Management System (admissions, records, finances, certificates and similar). But because of lack of resources, we cannot make any significant step forward*." When it comes to services that currently have little actual presence but are on the wish list of a fair number of NRENs, micro credentials are top, followed by digital assessment and learning analytics, with the use of AI in education occasionally being considered.

9.3 Summary

Supporting the digital transformation needs of the education sector is a growing field. Digital tools became unavoidable during the recent COVID-19 crisis, and although user demand for educational services has lessened slightly after the pandemic, it is still considerably higher than in pre-pandemic years.

The NRENs' portfolio of educational services is under constant review, but some common trends are visible in this year's survey. Most of the NRENs are now involved in offering services for teaching, learning and student management to educational institutions, across most levels of education.

Looking into the future, the challenges that NRENs report are financial constraints and resource scarcity, including both skilled people and finances, while future decision making is mainly concerned with sustainability.

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.

Changes in the world of NRENs are generally slow, but happen on many levels. Some concern the NREN organisations themselves: over the past years a number of NRENs have gone through reorganisations, in most cases resulting in a larger organisation with responsibilities that extend beyond those of a "typical" NREN. Others reflect the developing needs of the NRENs' users and/or technological possibilities. To track and present such changes, 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. One example is the role of NRENs in education, which has had a section of its own in the Compendium for some years now, documenting an expanding set of services that a significant subset of NRENs offer to the education sector. A possible burgeoning trend in the education sector is the introduction of micro credentials which would make participating NRENs part of an accreditation system for digital diplomas.

A recent addition to the Compendium reports on activities of the NRENs in the Digital Health sector. While providing connectivity to hospitals has been part of the portfolio of many NRENs for a long time, more recent initiatives at the European level have brought up Digital Health as a possible area for NREN involvement. Future developments here might lead to an expansion of this section.

Examples of trends can also be found among the services that NRENs have been running for a long time – the T&I sector was from the beginning by its very nature an area where NRENs interacted intensely. Out of this, supra-national infrastructures and services have been born that go beyond the activity of individual NRENs. The international integration in this field is continuing – which of course is documented by the Compendium.

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 RRENs and NRENs that responded to the 2022 Compendium survey and contains links to their respective websites (see also [ASSOCIATION].

Short Name	Full Name	Country	Website
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	https://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	http://science.gov.az/
BASNET	UIIP NASB	Belarus[68]	https://basnet.by/en/
Belnet	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
CSC/Funet	Finnish University and Research Network	Finland	https://www.csc.fi/en/funet-all-services
CyNet	ΚΥΠΡΙΑΚΟ ΕΡΕΥΝΗΤΙΚΟ ΚΑΙ ΑΚΑΔΗΜΑΪΚΟ ΔΙΚΤΥΟ (KYPRIAKO EREVNITIKO KAI AKADIMAIKO DIKTYO)	Cyprus	www.cynet.ac.cy
DeIC	Danish e-infrastructure Cooperation	Denmark	https://www.deic.dk/en/front

[68] Suspended as a member of the GÉANT Association in 2022.

Short Name	Full Name	Country	Website
DFN	Verein zur Förderung eines Deutschen Forschungsnetzes e.V.	Germany	www.dfn.de
EENet	EENet, a structural unit of Harno (Haridus- ja Noorteamet – the Education and Youth Board)	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	http://www.lumii.lv
IUCC	Inter University Computation Centre	Israel	www.iucc.ac.il
Jisc	Jisc Collections and Janet Limited	UK	https://www.jisc.ac.uk/
KREN	Kosovo Research and Education Network	Kosovo*	https://www.kren-ks.eu/
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	http://kifu.gov.hu/kifu/
NORDUnet (Representative Member)		Denmark, Finland, Sweden, Norway, Iceland	www.nordu.net

* This designation is without prejudice to positions on status, and is in line with UNSCR 1244/1999 and the ICJ Opinion on the Kosovo Declaration of Independence.

Short Name	Full Name	Country	Website
PSNC/PIONIER	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	https://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
Sikt	Sikt – Norwegian Agency for Shared Services in Education and Research	Norway	https://sikt.no/en/home
SURF	SURF b.v.	Netherlands	https://www.surf.nl/
SWITCH	SWITCH	Switzerland	www.switch.ch
ULAKBIM	Turkiye Bilimsel Ve Teknolojik Arastirma Kurumu	Turkey	www.ulakbim.gov.tr
UoM	L-Università ta' Malta	Malta	http://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 2022 Compendium survey respondents

Appendix B Compendium Authors

Marina Adomeit, T&I Project Manager (SUNET), focuses on international projects and T&I services. She has been working in the NREN community since 2006, with long experience of participating in GÉANT projects in tasks related to AAI, and is currently joint leader of the Trust and Identity Work Package in GN5-1. Marina has been working within international projects such as Seamless Access Consortium, Puhuri AAI infrastructure for access to EuroHPC LUMI supercomputer and others.

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.

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 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.

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 GN5-1 where he is joint Work Package Leader of Work Package 8 Security. Before joining GÉANT, Alf was Corporate Security Officer for SURF, the Netherlands NREN.

Mario Reale, Senior Research Engagement Officer (GÉANT), holds a PhD in High Energy Physics from the University of Wuppertal, Germany (1997). He worked as Grid middleware tester and integrator on Grid Computing for DataGrid, EGEE, and EGI. In 2006, he joined the Italian NREN GARR, where he worked on the IPv6 compliance of Grid Middleware. Subsequently, Mario joined the GARR Cloud activities, dealing with the automation of the deployment of OpenStack clusters in Italy. He joined the activities of IDEM, the Italian Identity Federation, in 2018–2019. In July 2019 he joined the GÉANT Association as a Senior Research Engagement Officer, supporting large international user communities in the adoption of GÉANT Community Services, and as coordinator of special interest groups on eHealth and Cloud. He is also involved in the business development of eduGAIN, supporting the establishment and onboarding of new Identity Federations worldwide.

Maria Ristkok, joint Work Package Leader for the GN5-1 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.

Maarten Kremers, Technical Product Manager Trust, Identity and Security (SURF), joined the Dutch NREN SURF in 2007 and in his current role as a project manager and technical product manager is responsible for the innovation and development of SURF Trust and Identity services. Within the current iteration of the GÉANT project (GN5-1) Maarten is joint leader of the Trust and Identity Work Package (WP5) for the European Research and Education community.

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, 2021 and 2023.

Leonie Schäfer, Global Liaison Manager (DFN), is responsible for coordinating the DFN contribution to international projects and joint developments. At GÉANT, Leonie takes on various tasks in the area of EU Liaison, International Relationships and Stakeholder Management within the framework of GÉANT projects. Prior to

joining DFN, Leonie spent several years in Science where she conducted own research and was responsible for managing EU research projects. Later she served as Scientific Officer at the EU Commission, DG INFSO, dealing with innovation policies, new research trends and emerging research communities in respect to ICT-related technologies. Leonie graduated and received her PhD in Computer Science from the Technical University of Berlin.

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.

Jasna Tingle, Head of Service for Research and Development in E-learning (CARNET), is actively involved in projects related to integration of digital technology in education in Croatia. Her experience includes coordination of online and face-to-face education, programme development, student mentoring, staff support, project management and research. Jasna's efforts have been aimed at promotion of e-learning since its beginning, but her interests are wider and encompass educational research and educational policy in the context of a highly technologised and globalised world. Following these interests Jasna has completed the Master of Distance Education Programme at Athabasca University (Canada) and has received her PhD in Information Science from University of Zadar, Croatia.

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

The 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 Croatian 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 has 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 Mohács, 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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Glossary

AAI	Authentication and Authorisation Infrastructure
AARC	Authentication and Authorisation for Research and Collaboration
AER	Asia-Europe Ring
AI	Artificial Intelligence
AISBL	Association Internationale Sans But Lucratif / International Non-Profit Association
ANA	Advanced North Atlantic
API	Application Programming Interface
APNIC	Asia Pacific Network Information Centre
AUP	Acceptable Use Policy
AW	Alien Wave or Wavelength. Data transmission laser light from third-party equipment; an alien wave system multiplexes alien light together with local signals using DWDM.
BEAA	Bridging Europe, Africa and the Americas
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
CER	Critical Entities Resilience
CERN	European Organisation for Nuclear Research
CINECA	Largest Italian computing centre. Not-for-profit Consortium of 70 Italian universities and 44 Italian national institutions and agencies.
GCP	GÉANT Community Programme
CISO	Chief Information Security Officer
CJEU	Court of Justice of the European Union
CLAW	Crisis Management Workshop for the NREN Community
CoCo	Code of Conduct
CORDIS	Community Research and Development Information Service
CRA	Cyber Resilience Act
CSIRT	Computer Security Incident Response Team
CTO	Chief Technology Officer
DCI	Data Centre Interconnect
DDoS	Distributed Denial of Service
DG Connect	EC Directorate-General for Communications Networks, Content and Technology
DG DEVCO	EC Directorate-General for International Cooperation and Development
DG INTPA	EC Directorate-General for International Partnerships
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 (10^{18} 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
EHDS	European Health Data Space
EHR	Electronic Health Record
eID	Electronic Identification
eIDAS	Electronic Identification, Authentication and Trust Services
ELIXIR	A European intergovernmental organisation that is made up of life scientists, computer scientists and support staff. Its goal is to help researchers take advantage of the huge amounts of data produced in life science, so that new insights can be gained into how living organisms work in health and disease.
EO	Earth Observation
EOSC	European Open Science Cloud
ERDF	European Regional Development Fund
ESCI	European Student Card Initiative
ESFRI	European Strategy Forum on Research Infrastructures
ESI	European Student Identifier
EU	European Union
EUDI	EU Digital Identity
EuroCC	EuroHPC Competence Centres
FAIR	Findable, Accessible, Interoperable and Reusable
FE	Further Education
FoD	Firewall on Demand
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
GN4-3N	GÉANT Network 4 Phase 3 Network project, part-funded from the EU's Horizon 2020 research and innovation programme under Grant Agreement No. 856728
GN5-1	GÉANT Network 5 Phase 1 project, part-funded from the EU's Horizon Europe research and innovation programme under Grant Agreement No. 101100680
GPPC	GÉANT Programme Planning Committee
H2020	Horizon 2020
HPC	High-Performance Computing
HPDA	High-Performance Data Analytics
HR	Human Resources
IaaS	Infrastructure as a Service
IaaS+	Infrastructure as a Service Plus Framework
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
LUMI	Large Unified Modern Infrastructure (the EuroHPC JU supercomputer located in Finland)
MAN	Metropolitan Area Network
MEF	(formerly) Metro Ethernet Forum
MEF-CECP	MEF Carrier Ethernet Certification Program
MFA	Multi-Factor Authentication
MPLS	Multiprotocol Label Switching
MyAID IAM	MyAcademicID Identity and Access Platform
NI4OS	National Initiatives for Open Science
NIS2	Network and Information Security Directive
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).

OIDC	OpenID Connect
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 (10^{15} bytes of data)
PID	Persistent Identifier
PR	Public Relations
PRACE	Partnership for Advanced Computing in Europe. The mission of PRACE is to enable high-impact scientific discovery and engineering research and development across all disciplines to enhance European competitiveness for the benefit of society.
PRACE-6IP	PRACE 6th Implementation Phase Project
R&E	Research and Education
R&S	Research and Scholarship
REFEDS	Research and Education Federations group
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
RREN	Regional Research and Education Network
SaaS	Software as a Service
SAML	Security Assertion Markup Language
SIEM	Security Information and Event Management
SIG	Special Interest Group
SIG-ISM	Special Interest Group on Information Security Management
SIM	Security Information Management
Simpl	The smart middleware that will enable cloud-to-edge federations and support all major data initiatives funded by the European Commission, such as common European Data Spaces
Sirtfi	Security Incident Response Trust Framework for Federated Identity
SOC	Security Operations Centre
SP	Service Provider
SPAN	Switch Port Analyser
T	Task
T&I	Trust and Identity
TAP	Test Access Point
TB	Terabyte (10^{12} bytes of data)
TCS	Trusted Certificate Service
TF	Task Force
TF-CSIRT	Task Force on Computer Security Incident Response Teams
TF-EDU	Task Force on Educational Services and Activities
TF-eHealth	Task Force on eHealth
TI	Trusted Introducer
TLD	Top-Level Domain
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
VLE	Virtual Learning Environment
VPN	Virtual Private Network
WG	Working Group

WLCG	Worldwide Large Hadron Collider Computing Grid
WP	Work Package
WP8	GN4-3 Work Package 8 Security