GÉANT

Compendium 2020

of National Research and Education Networks in Europe

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 2000, the Compendium provides information on key areas such as NREN users, services, traffic, budget and staffing. This report primarily covers the period January to December 2019, extending to 2020 where Compendium survey data are supplemented by data from other sources. 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 2020 focused primarily on the period from January to December 2019, though some NRENs may have added more recent data if it were available. The survey questions were drafted under the guidance of subject specialists from within the GN4-3 project. It requested information grouped around the NREN's organisation itself, their service portfolio, their users, and their network. The same group of specialists that helped to draft the questionnaire 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 2019. 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 and on which NRENs can inform and shape their strategic decisions.

[1] This is especially true when percentage increases across NRENs are shown (e.g. Figure 2.1: Development of total NREN budgets since 2016; Figure 2.5: Total staff numbers of the NREN sector; Figure 5.1: Increase of traffic into the NRENs from external networks (left-hand graph) and NREN end users (right-hand graph) 2018 to 2020; and Figure 5.5: Development of the NRENs' IRU networks 2018–2020). 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 strategists and many more professionals. Subject matter experts reviewed all of the responses within a given area and summarised the main data points in this document.

A massive 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 2020 and focuses on the time period from January to December 2019; 40 out of the relevant 43 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 these areas, more recent data have been used. The full Compendium is available online at [COMPENDIUM].

Like past Compendium surveys, the 2020 results reveal changes and continuing trends in the NREN landscape, although the changes are mostly gradual – nonetheless, the on-going COVID-19 pandemic leaves traces in some of more recent data.

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

Budget & staff numbers

Reflecting the continuing increase in the importance of data networks in research and education, budgets and staff numbers as a whole have expanded between 2019 and 2020 (by 2% and 11%, respectively). The growth has enabled NRENs to upgrade their networks and further develop their service portfolio.

Pan-European activities

A clear trend over the last few years has been an increasing involvement of NRENs at the European level – the number of EC-funded projects which had at least one NREN as a participant has almost doubled from 56 in 2018 to 103 in 2020. Most of these projects are connected to European e-infrastructures, in particular to the EOSC project. However, the number of NRENs and which individual NRENs are engaging in European projects hasn't changed significantly in the last four years, meaning that about a third of NRENs have little involvement at the European level.

Traffic

The importance of research and education networks is manifest in the volume of traffic NRENs carry. Traffic volumes have continuously increased over the past years, across all NRENs - more than half of which reported a rise in traffic, with most of this growth coming from research institutes. Overall, the recorded traffic grew by almost 30% between 2019 and 2020. Moreover, NRENs expect this trend to continue into the medium term: for the years 2020–2023, 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 last year, high growth is expected to come from schools, with an anticipated traffic growth of 73%, but

unlike previous years, the highest growth is expected to come from research institutions with 75% growth anticipated. The third place is taken by universities, estimated to grow by 67%. Note however, that all these numbers are pre-COVID-19 and a drop of traffic volumes is expected for 2020 – which can already be seen in the 2020 numbers from the GEANT network.

Capacity

While traffic volumes grew significantly during the past year, the capacities of NRENs' backbone and access networks increases at a steady but much slower rate, reflecting the longer time scale of network upgrades. It is noticeable, though, that the access networks keep increasing in capacity, especially for the non-core user types like schools. The capacities for the access to an NRENs' network range from 1 Mbps up to 100 Gbps, depending on user types. Universities and research institutes are the best-connected institution types. Over half of the respondents indicate 1 Gbps as typical capacity for connected universities and research institutions but in some countries, the typical connectivity of 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 have mostly 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 & 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 like inAcademia and myAcademicID, which ascertain the student status in order to 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. One of the consequences of the rise of commercial cloud services seems to be a dramatic drop in SaaS type services, which hardly any NRENs seem to offer any more, presumably having been replaced commercial providers. On the other hand, 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.

Another development is the involvement of NRENs not just in running infrastructure used for education, but also in supporting specific education content and services. While not all NRENs follow this path, among those that do, the development of new services appears to take on a startling pace, as is shown in some detail in the chapter on education services. The NRENs active in this area may become important gatekeepers or mediators between content/service providers and consumers in their education sectors.

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

1. ABOUT GÉANT

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

GÉANT's high-speed backbone provides connectivity with 42 NRENs during GN4-3, reaching tens of millions of users in 10,000 institutions across Europe, and more than 100 countries worldwide through links with other regions. The core backbone is capable of multiple 100 Gbps over each fibre link, and Terabit connectivity can be achieved by a single node.

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

In addition to the pan-European coverage, GÉANT's global connectivity enables the European R&E community to collaborate with peers and access data sources in nearly 60 countries beyond the GÉANT backbone. Intercontinental links are provided through a variety of approaches. Some links are funded by GÉANT members and the GÉANT project (e.g. to North America, see below), while others are funded and managed in collaboration with R&E networking partners. For instance, connections to China are maintained in collaboration with the Chinese networks CERNET and CSTNET, and connections to Asia-Pacific via CAE-1 are run in partnership with NORDUnet, SURF,[3] the Asian networks TEIN*CC and SingAREN (Singapore), and AARNet (Australia).

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

- AfricaConnect3, which supports pan-African connectivity and interconnections to Europe [AfricaConnect3].
- Asi@Connect which interconnects the Asia–Pacific region and South Asia [Asi@Connect].

[2] GN4-3 has a budget of €118,879,719 (with an EC contribution of €77,500,000); GN4-3N has a budget of €63,125,000 (with an EC contribution of €50,500,000).

[3] In 2020 the NREN for the Netherlands began a series of organisational and name changes. In the text of this document, the new name, "SURF", has been used throughout; the old name, "SURFnet", appears in some of the figures and tables.

- EUMEDCONNECT3, in the eastern Mediterranean region [EUMEDCONNECT3].
- BELLA, for direct submarine connectivity to Latin America and the new 100 Gbps terrestrial RedCLARA network [BELLA].

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

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

2. NREN ORGANISATIONS

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

2.1. Budget

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

Overall, the budgets dedicated to NREN activities have increased significantly over the last four years (Figure 2.1). However, this does not mean that the trend is true for every individual NREN. The 2020 and 2019 budgets of the NRENs are shown in Figure 2.2, where the considerable variability is apparent. While the trend of increasing budgets evident in Figure 2.1 is still recognisable, 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 infrastructure investments.

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 budget, however, is much more context-dependent, and is part of the story of national circumstances.[5] The roles national NRENs are playing varies considerably which is reflected in their budgets.

[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].

[5] Some NRENs such as GRNET have a 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 and example of the alignment of national e-infrastructures that has taken place in a number of countries (e.g. the UK where the R&E network Janet has become part of the current NREN Jisc and currently comparable re-organizations are happening in Latvia, Norway and the Netherlands).

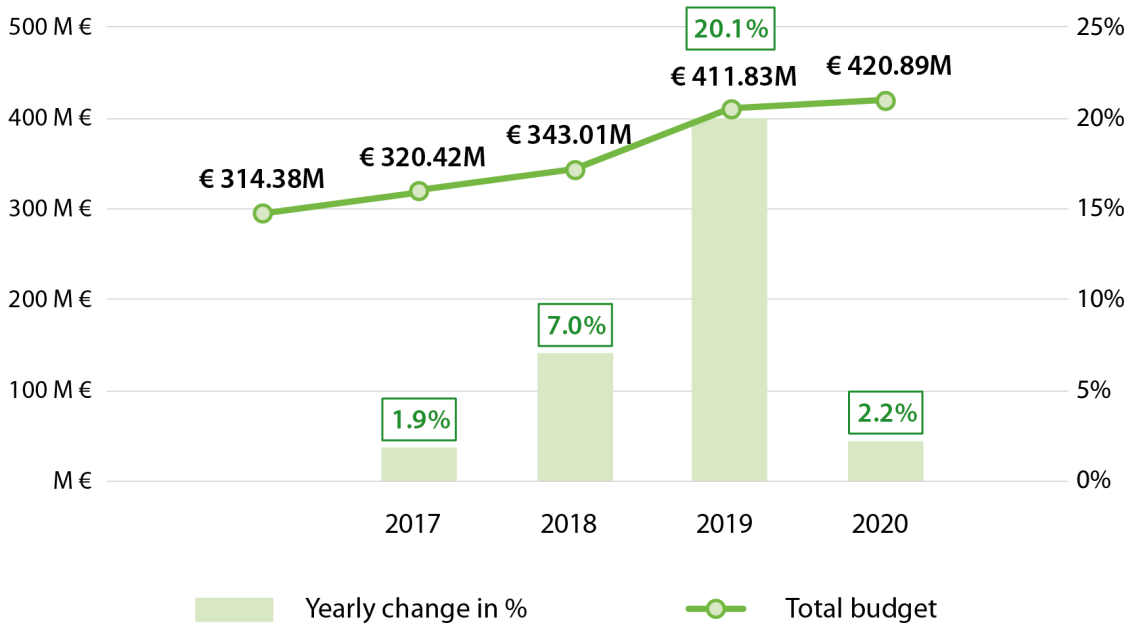


Figure 2.1: Development of total NREN budgets since 2016

The numbers are based on the 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 2020 survey results based on the data for all responding NRENs that year is €508 M). The percentage change is based on the earlier year's budget.

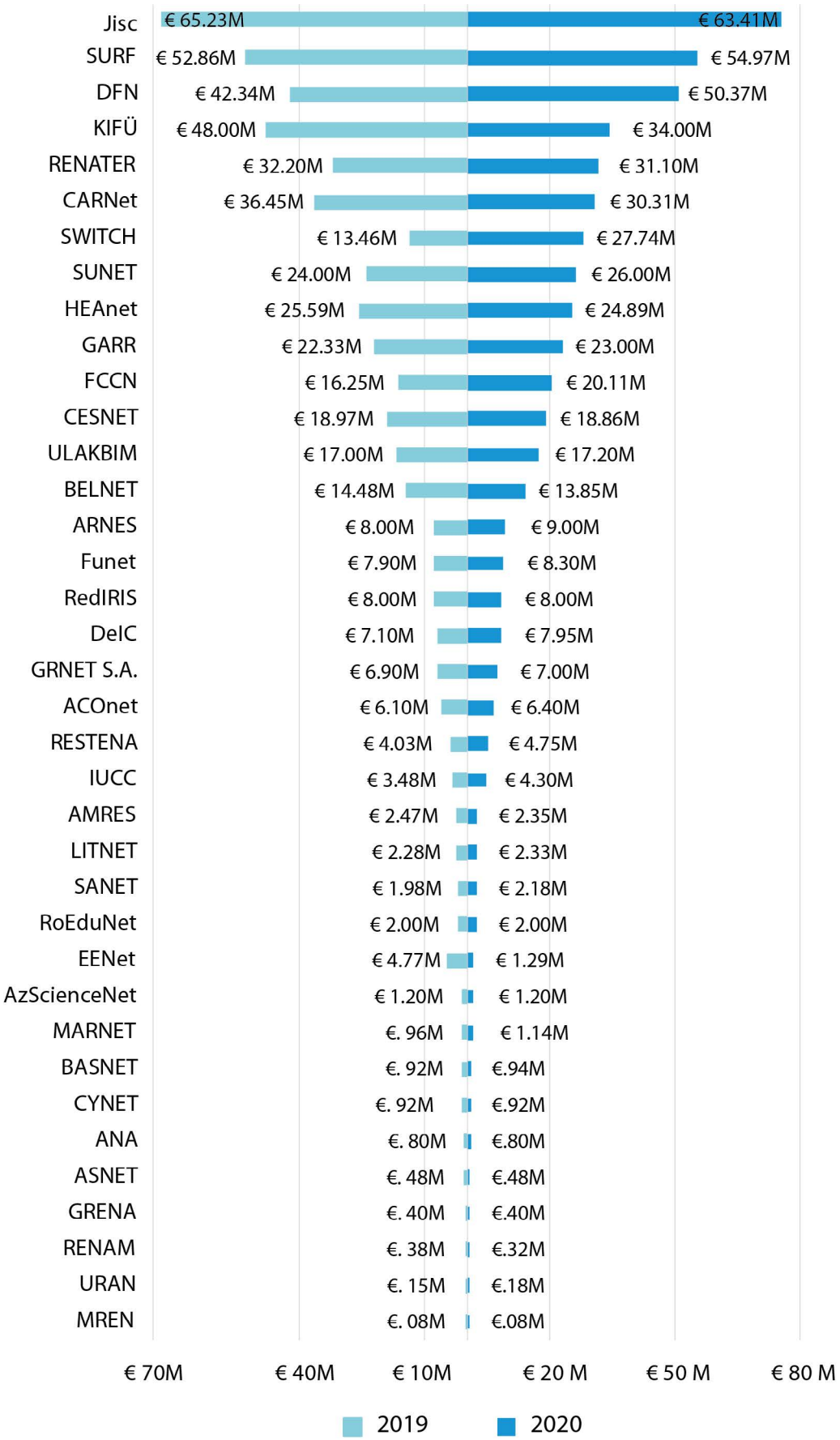


Figure 2.2: Individual NREN budgets 2019 and 2020. *The figure includes NRENs that have provided budget numbers for only one of these years, hence the occasional gap. Overall, 19 NRENs reported an increase in budget, 8 no change and 10 a reduced budget. Notably, 5 out of the top 6 reported a reduction in their budget (in CARNETs case that reflected the end of a large EC-funded project, while KIFU's budget spike in 2019 was due to them opening an HPC centre).*

Budgets reflect the size of an NREN, but this size is, of course, also related to the size of its home country. Large countries have more R&E institutions, and therefore, larger NRENs, in most instances. This can be seen in the budget list shown in Figure 2.2, where NRENs from larger countries tend to have larger budgets – although there are quite a few exceptions.[6] This becomes even clearer in Figure 2.3, which shows NREN budgets normalised to Gross Domestic Product (GDP) and population. In this case, the correlation between country size and NREN budget that is still visible in Figure 2.2 disappears.

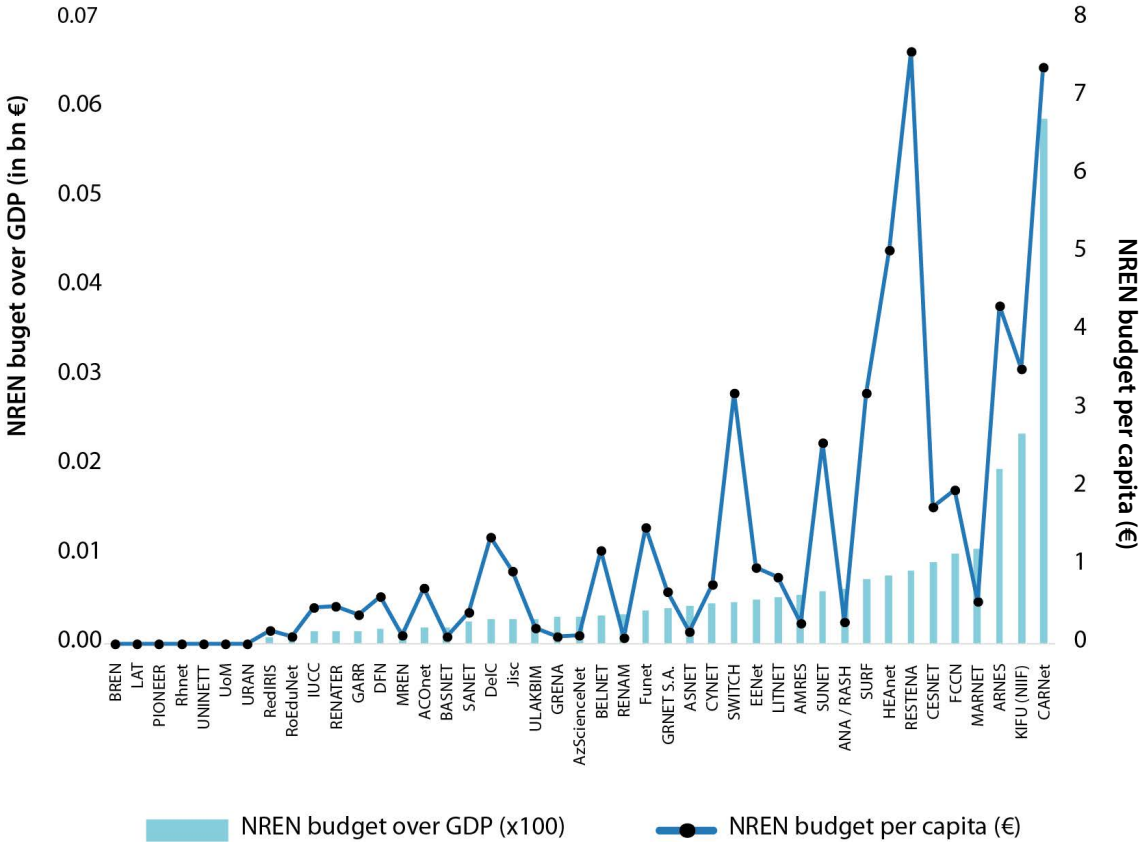


Figure 2.3: NREN budgets normalised to GDP and population
The numbers shown here are simple indexes formed by dividing the NRENs' budgets by the GDP (in Billion € x100) and population sizes. The GDP and population numbers come from the International Monetary Fund [IMF] and the UN [UN], respectively.

There are a great number of factors that lead to the differences between NRENs shown in Figure 2.3.[7] Important in the context of this report is that the business models of NRENs vary, with some going well beyond their core function as an academic Internet Service Provider (ISP). The NRENs at that come out at the top of either index (budget over GDP or budget per capita) in Figure 2.3 tend to provide a wide range of services to their customers that goes be-

[6] Note that the top ten budgets feature the NRENs of only four of the eight largest European countries (ULAKBIM/Turkey, RedIRIS/Spain, URAN/Ukraine are not in the top 10). NRENs from several significantly smaller countries, such as SURF (The Netherlands), CARNET (Croatia) or HEAnet (Ireland) make the ranking instead.
[7] Clearly, this cannot all be captured by business data – the fundamental economic strength of a country plays a part here as well. Richer countries tend to spend more on public infrastructure, which NRENs are (in a wide sense) part of. This is at least partially visible in the population-normalised data, where NRENs from less wealthy countries tend to form the tail-end of the graph.

yond connectivity (e.g. procurement support, computational resources, educational resources, etc.) and often also serve communities outside the traditional remit of NRENs; this requires more funds (and human resources – see below).[8]

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 the NRENs participate (see also Section 0 Involvement in EC-Funded Projects). Finally, some NRENs generate income by providing services to commercial partners. For the European NRENs as a whole, the importance of these four income sources is presented in Figure 2.4.

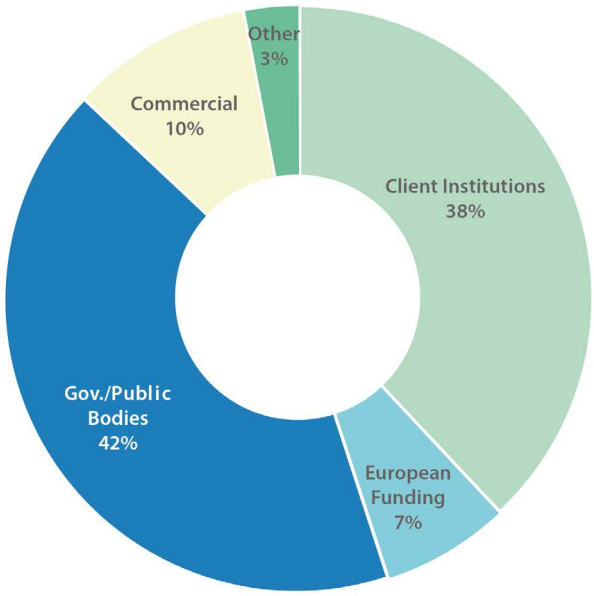


Figure 2.4: Funding sources of NRENs
This figure shows the share of different funding sources for the combined total of European NRENs' budgets. The numbers are based on the survey responses of the NRENs that provided their budget numbers as well as their income sources (37 out of 43). The percentage 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 (financial) size. Interestingly, there have been some changes compared to 2019 – the share contributed by client institutions has increased by from 33% to 38% and commercial income by from 3% to 10% while direct government funding has dropped from 51% to 42%.

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

[8] Services that are made possible by a larger budget are provided for example by EENet/HITSA 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.

	Over 75%		25% TO 75%		LESS THAN 25%
	Client Institutions	European Funding	Gov./Public Bodies	Commercial	Other
ACOnet	100				
AMRES			100		
ARNES		5	84	11	
BASNET	26	64	10		
Belnet	39	2	52	7	
CARNET		59	38	3	
CESNET	21	3	73		2
CYNET	63	25	12		
DeIC	95	1		4	
DFN	94	3	2		2
EENet		71	26		
FCCN	3	0	96		1
Funet	60		40		
GARR	89	4	7		0
GRENA	40	50		5	5
GRNET S.A.		20	75		5
HEAnet	16	1	74	9	
IUCC	91	9			
Jisc	20	2	49	30	
KIFÜ (NIIF)	4	2	94		
LITNET	10	33	57		
MARnet		20	56	24	
MREN		20	70		5
RedIRIS		7	92		1
RENAM	24	74	2		
RENATER	11	4	85		
RESTENA	6	3	34	37	20
RoEduNet			100		
SANET	7		93		
SUNET	70		20		10
SURFnet	60	2	38		
SWITCH	56	1	1	43	
ULAKBIM			100		
URAN	67		3	30	

Table 2.1: Income sources per NREN

The table shows the percentage share of their income that individual NRENs derived from different sources. The numbers in parentheses are the income share in 2019 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 the different categories. However, this is not true for everyone: a number of NRENs depend to a very significant degree on income derived from their customer base (ACOnet, DFN, GARR and IUCC to about 90% or more, and for 5 more NRENs this constitutes more than 50% of their income) and 7 (AMRES, FCCN, KIFÜ, RedIRIS, RoEduNet, SANET and ULAKBIM) depend almost exclusively on public money.[9] These "special cases" correlate relatively well with the way these NRENs are organised: the NRENs that depend mostly on their customer base for funding run the academic network on behalf of their customers (i.e. universities and research institutes), e.g. as membership organisations.[10] The other extreme, NRENs that rely very strongly on direct public money, are often public bodies themselves, or even part of the government, as part of or very closely associated with a Ministry (often, but not always, the Ministry of Research and Education, or similar).[11] Given that funding bodies usually have a strong influence, this is not very surprising – generally, where there is a high share of public money in an NREN's income stream, there will be government representatives on the board of the NREN.

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 Chapter 4 Involvement in EC-Funded Projects) and therefore varies over the years.[12]

Finally, a small number of NRENs provide services to the commercial sector and derive some income from this source. In 2020, the leading example here was SWITCH, but RESTENA, and SUNET and GRNET are deriving some income from commercial sources albeit at a lower level.[13]

2.3. Staffing

The data presented in this section shows the staff engaged in NREN activities in full-time equivalents (FTE).

Across the sector, staff numbers have increased between 2016 and 2019, as shown in Figure 2.5 – similarly to, and of course made possible by, budget increases. The total number of employees declared by NRENs in the 2019 Compendium survey reached 1,954.

[9] The threshold used here was 85% of the NREN's income derived from one source. DeIC belongs to the group of customer-funded NRENs as well, though they did not provide the exact numbers in the 2019 survey (in 2018, DeIC's customers provided 99% of the NREN's total income).

[10] Examples of the latter are DFN and DeIC. But the other 3 NRENs of this group (GARR, IUCC and ACOnet) also have a strong customer presence in their Boards. SWITCH is also a membership organisation but also has commercial activities that act as a second financial mainstay.

[11] Among the 7, FCCN, RoEduNet and RedIRIS are Ministry-associated, while ULAKBIM, SANET and KIFÜ are public bodies with close relations to the government. AMRES, the Serbian NREN, is an exception to this rule as it acts as an independent not-for profit organisation on behalf of the government.

[12] E.g. CARNET's increase in European funding is due to support for a project aimed at introducing ICT into the school system [e-Schools].

[13] 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.

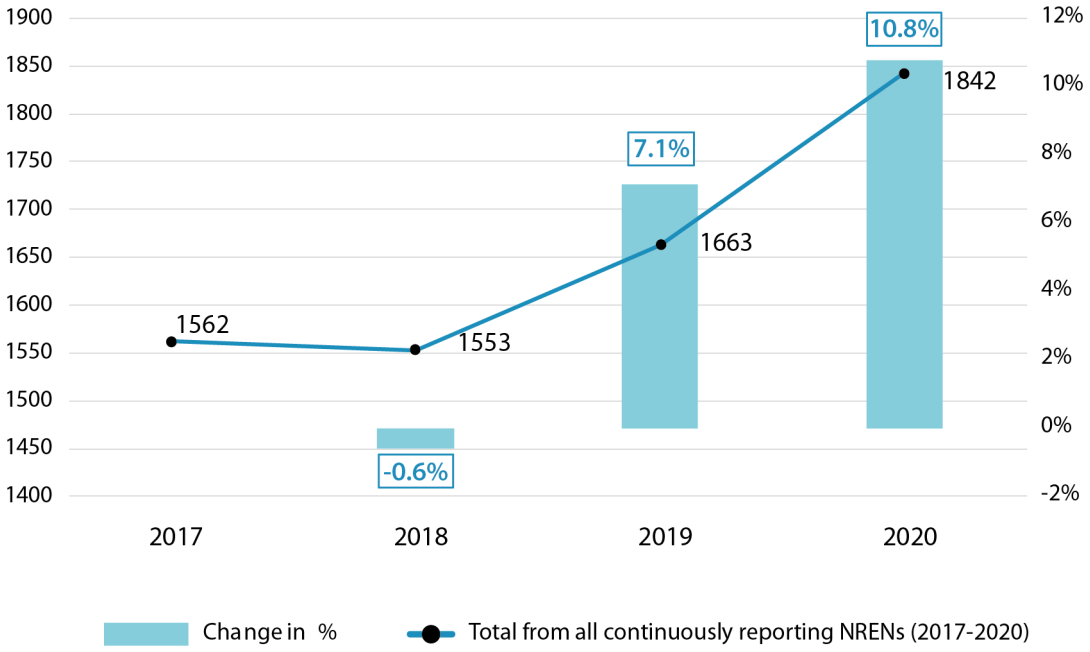


Figure 2.5: Total staff numbers of the NREN sector
The percentage change is based on the earlier year's staff numbers. While the total number of staff reported in 2020 was 2,062, the data series shown in the graph is based on those NRENs that reported their staff numbers continuously throughout this 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 2019 and 2020 is presented in Figure 2.6. While changes in employee numbers are apparent in these data, they are generally not as large as the swings in budget. This reflects the fact that most large budget changes are dedicated to transient projects (such as network infrastructure renewal), which are most often carried out with the help of contractors and therefore do 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. In general, while the overall ratio between the two employment categories has seen a slight change over the years, starting with about 10% of subcontracted positions in 2016 and increasing to about 14% in 2020, this variation might be due to the noise in the data that is generated by the variability in the survey response rate.

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

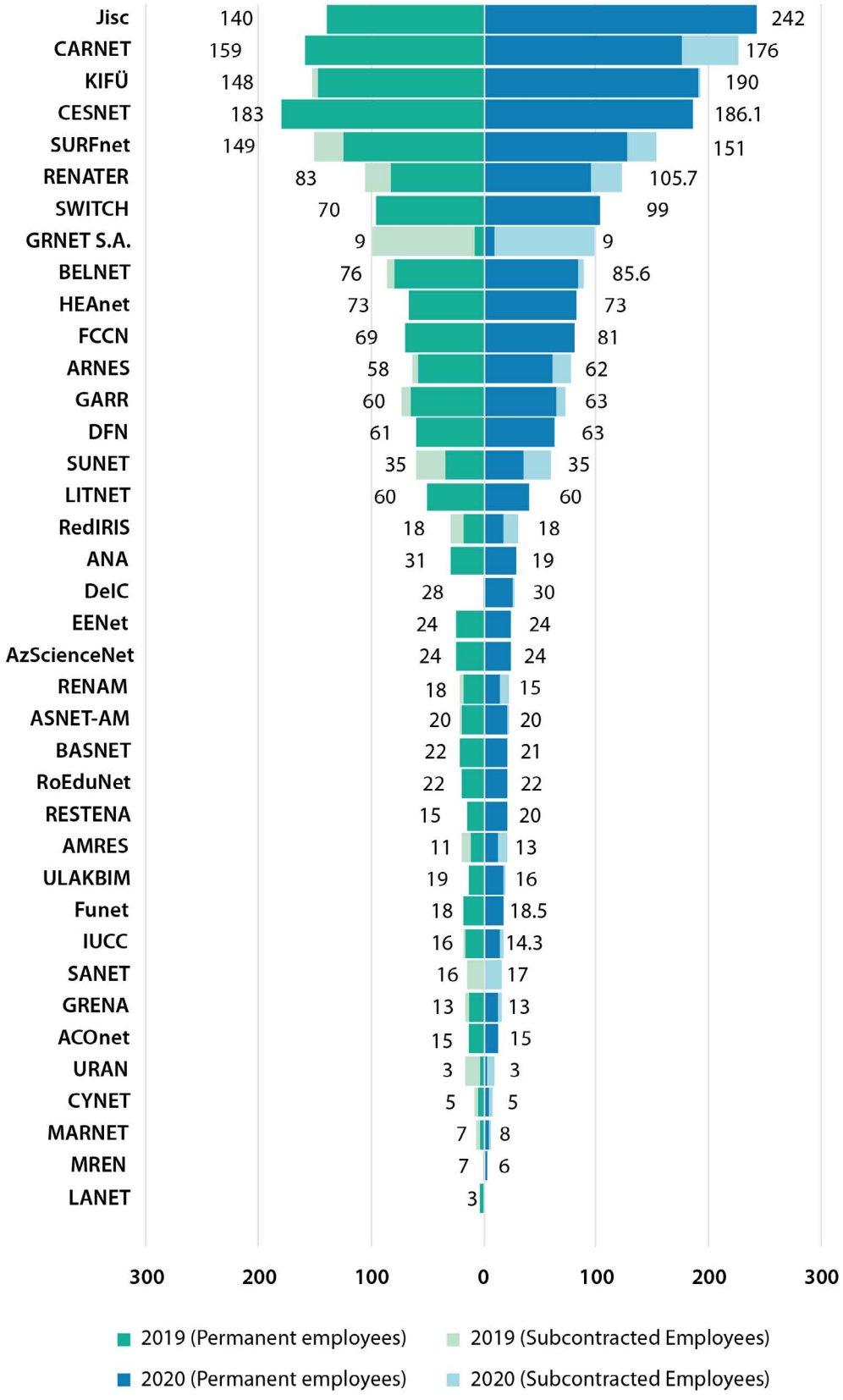


Figure 2.6: Staff numbers of NRENs in the years 2019 and 2020
The figure includes NRENs that have provided staff numbers for only one of these years, hence the occasional gap.

An interesting aspect of NREN staffing is the actual nature of the work performed by employees. For this purpose, Figure 2.7 shows staff roles broken down into two broad categories: technical and non-technical roles.[15] Not surprisingly for network providers, the majority of positions are technical roles. Nevertheless, there is considerable variation between NRENs, which again emphasises how different NRENs are from each other.

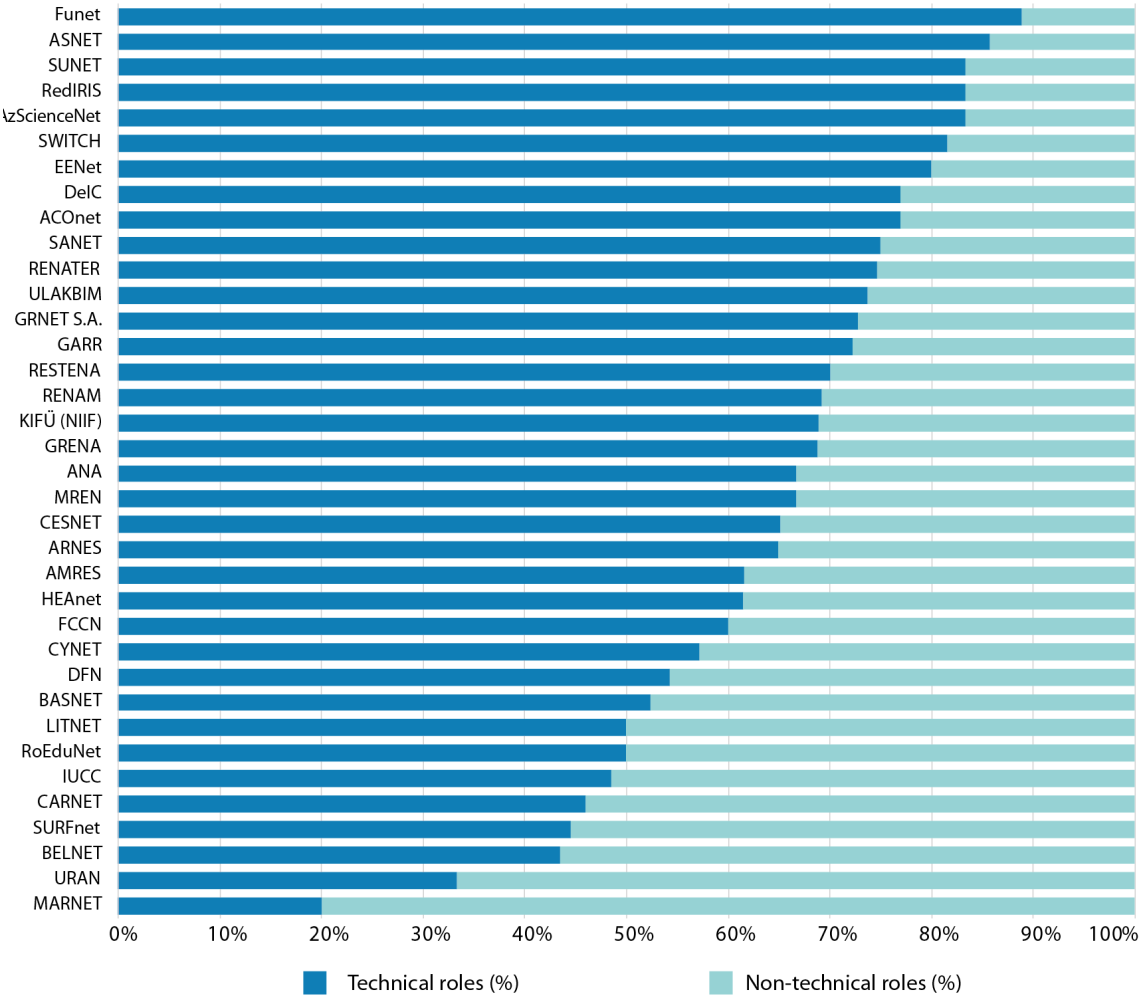


Figure 2.7: Share of technical roles among staff numbers
For the purpose of this figure, non-technical roles are e.g. legal, finance, HR and PR, while technical roles would be network operation, software development or IT security.

2.4. Summary

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

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

3. END USERS

Research and higher education institutions (i.e. universities and research institutes) are the core end users of the networks managed by NRENs. However, beyond this core "market", NRENs in different countries provide connectivity and other services to a wider group of constituencies as well. Generally, these are public institutions, e.g. 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 of the institutions connected to each NREN, and link capacities provided to different types of connected institutions. As in previous years, in order to allow a consistent categorisation across different national education systems, the classification in this section follows the ISCED 2011 classification system (the UNESCO scheme for International Standard Classification of Education) [ISCED 2011].

3.1. Who Can Connect?

3.1.1. Connectivity Remit

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

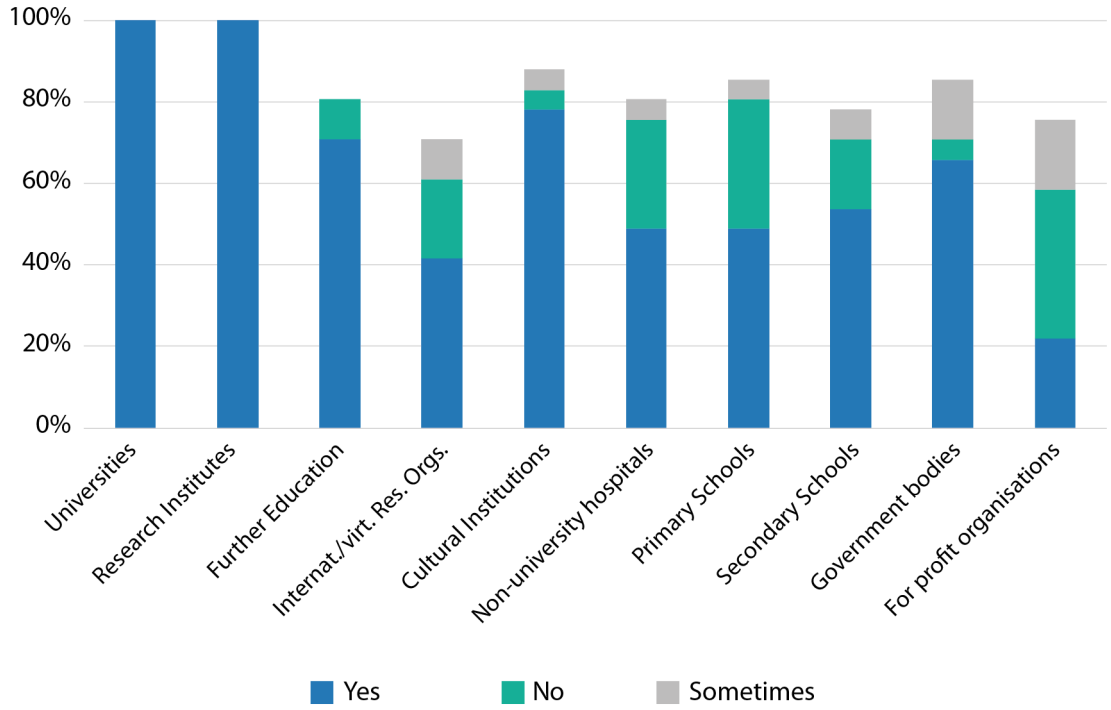


Figure 3.1: Percentage of NRENs connecting different user types
While Higher education and research is clearly the core of NREN activity, most NRENs are also serving other user groups in the public space

3.1.2. NRENs' Acceptable Use Policy

The acceptable use policy (AUP) is a key element in defining the formal remit of NRENs in terms of which institutions they are eligible to connect. According to the 2020 Compendium data, there have been essentially no changes since 2018: a large majority of NRENs have a formal AUP in place (see Figure 3.2).

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

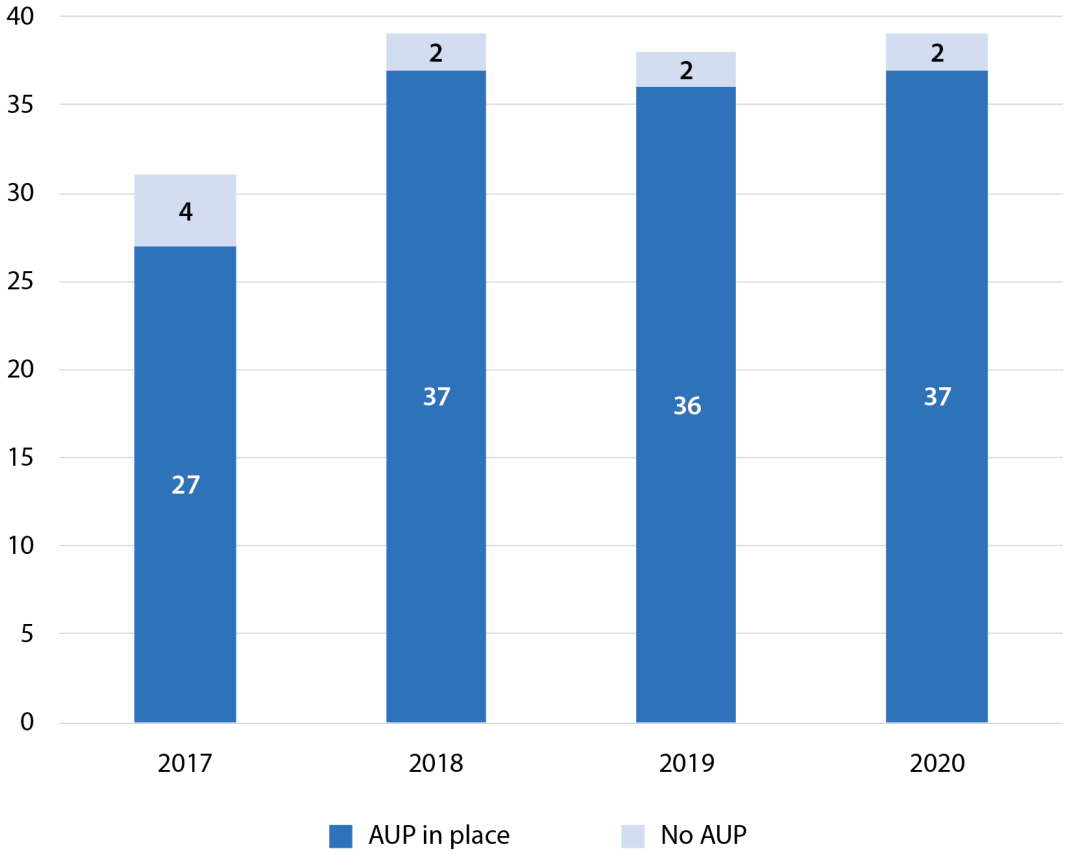


Figure 3.2: Number of NRENs that reported having an acceptable use policy (AUP) in place
The slight drop in the number of AUPs from 2018 to 2019 is due to the varying response rate. Between 2017 and 2020, no NREN has reported having abandoned an existing AUP, but some have reported that they have newly introduced a formal AUP where none existed before.

3.2. Approximate Market Shares for Connected Institution Type

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

The overall market share distribution in 2020 is comparable to that of 2019. 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.[16] Where schools fall into the NREN's remit, the NREN's market share is usually very high, and the same is true for institutions of further education. This is most often the case where NRENs are a directly state-funded "public infrastructure", which makes them a natural resource to turn to when ISP services are needed for public institutions.

[16] There are exceptions. URAN and AzScienceNet only connect about a third of the Ukrainian and Azeri universities, respectively (URAN is competing with a second NREN) and only 50% of Israel's universities are making use of IUCC's services.

Overall market shares are not very dynamic, and large jumps are rare and in most cases noticeable changes take several years.[17]

An example of where an NREN has increased its market share is provided by LITNET which have increased their market share among Further education institutions to 80% (from 60% in 2019)

	Universities	Research Institutions	Further Education	International research Institutions	Libraries	Hospitals	Primary Schools	Secondary Schools	Government	For-Profit Organizations
ACOnet	80				40	60	90	90	60	
AMRES	80	80	90		50	3	97	97	2	
ANA	74	13			4				7	
ARNES		93			87		95		10	
ASNET-AM	40	90			30					
AzScienceNet	40	90								
BELNET	90	75	1		1	5	5	5	20	
CARNet	100	98	10		1	94	98	99	81	1
CESNET	95	96	8	90	2	25	1	5	11	
CYNET	100	70	40							
DeIC	100	25	62	50	10	60		1	5	1
EENet	83	4	69		8		13	41	4	
GARR	60	80		20	0.5	4.4	2	4.6		
GRENA	60	50								
GRNET S.A.	100	100	50		2	35	100	100	2	
HEAnet	100	50	5				98	100	5	
IUCC	50									
Jisc	100		100							
KIFÜ (NIIF)	80	99	2	100	90	5	96	96	5	
LITNET	90	100	80		18	10	17	59	10	1
MARnet	40									
RedIRIS	90						45	45		
RENAM	72	80	11		9	7		0.01	5	
RENATER	100	100								
RESTENA	80	96					85	100		
RoEduNet	95	80	50		60		60	70	10	
SANET	99	70	95		15	10	10	52	5	1
SUNET	100		100							
SURFnet	100	90	90	20	5	6	8	8		2
SWITCH	100				5					
ULAKBIM	95				0.1				2	
URAN	30	13	5	10	4	5			2	1

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

Table 3.1: Estimated percentage market share per institution type, per NREN

Not all NRENs have given an estimate of their market share – empty fields reflect missing responses, not missing connectivity. Note also that this figure differs from the connectivity remit of NRENs (Figure 3.1). Theoretically, an NREN could count for example hospitals into its connectivity remit but not connecting a single one.

[17] 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 re-assessing the market share with new methods can therefore yield different results without a change in the situation on the ground. GRNET is a case in point here where are a new assessment of their market share among libraries and non-research hospitals resulted in a significant correction of the former estimates.

3.3. Typical and Highest Capacity of Connected Institutions

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

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

Interestingly, though link capacities are only slowly increasing, traffic increases are considerably higher (for details, see the Networkchapter), reflecting the overcapacity that needs to be built into networks that represent long-term investments. While the link capacity increase in the area of core users (i.e. Higher education and research) is continuous but slow, the increase in other areas is much larger. Although not shown in the figures, school links have almost doubled on average between the 2019 and the 2020 survey and so have links to cultural institutions.

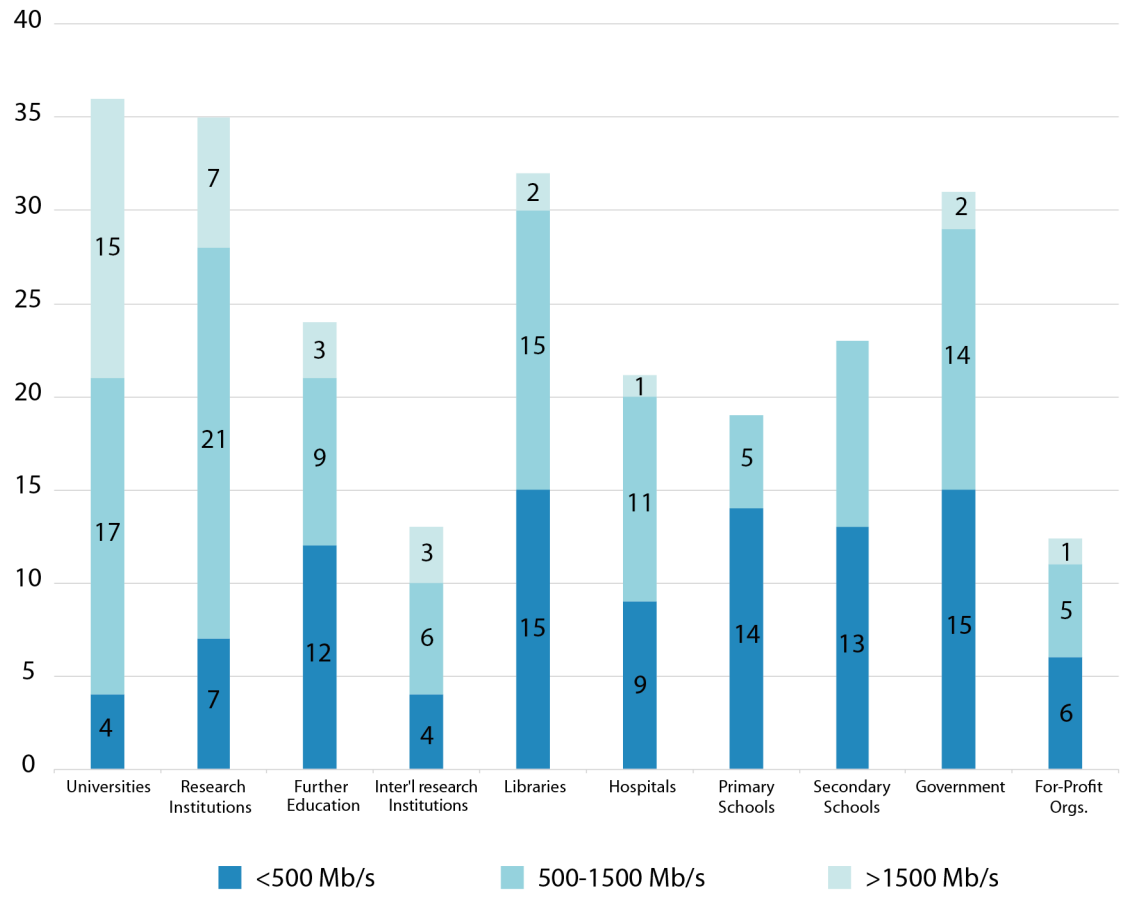


Figure 3.3: Typical link capacities provided to different types of connected institutions
For the purpose of this figure, link capacities have been grouped into three capacity categories (less than 500 Mb/s, 500-1500 Mb/s and beyond 1500 Mb/s. Most NRENs typically provide their core users (universities and research institutes) with high capacity links, reflecting the capacity needs of these institutions. Other user groups (e.g. libraries or schools have lower needs and therefore often receive lower capacity links).

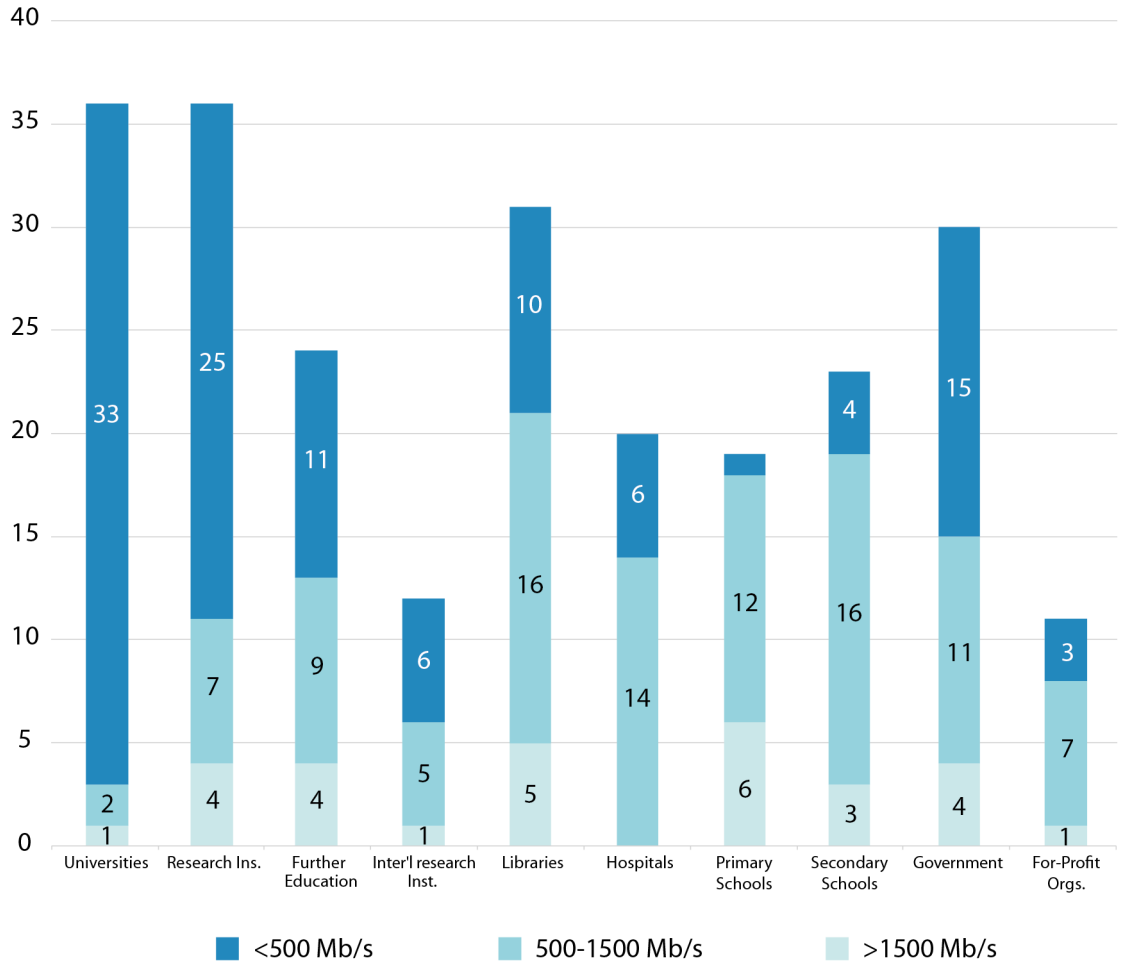


Figure 3.4: Highest link capacities provided by NRENs to different types of connected institutions
For the purpose of this figure, link capacities have been grouped into three capacity categories (less than 500 Mb/s, 500-1500 Mb/s and beyond 1500 Mb/s

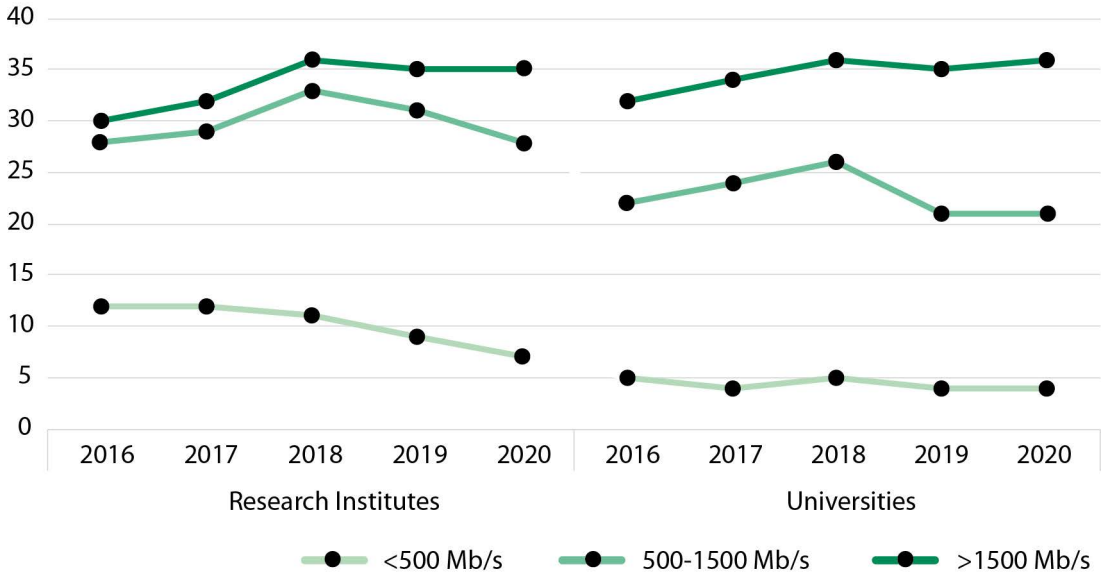


Figure 3.5: Development of link capacities for universities and research institutes 2016 to 2020
The numbers show how many NRENs provided their research institutes (left panel) and universities (right panel) with typical link capacities of <500 Mbps (blue line), 500–1,500 Mbps (orange line) and >1,500 Mbps (grey line) in the years 2016–2020. The decrease seen in 2019 is due to the overall lower number of NRENs responding to this question that year.

3.3.1. 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 3.2).

	Universities	Research Institutes	Further Education	International Research Institutions	Cultural Institutions	Hospitals	Primary Schools	Secondary Schools	Government	For profit organisations
AzScienceNet	100,000	9,000			1,200					
BELNET	543,947	28,669	900	375	2,369	21,791		61,796	123,852	900
CARNet	200,000	5,000	1,000	100	300	14,000	400,000	205,000	53,000	1,000
CESNET	380,000	50,000	4,000	500	1,600	5,000	2,500	22,000		4,000
CYNET	50,000	650	2,000							2,000
DeIC	150,000	1,200	100,000	100	1,000	80,000		7,000	1,000	100,000
FCCN	401,174						802,133	297,610		
Funet	360,000	14,000			1,000				4,000	
GARR	1,500,000	30,000		2,700	1,000	8,000	85,000	205,000		
GRENA	86,000	2,500								
GRNET S.A.	300,000	40,000	20,000		10,000	20,000	100,000	100.000	1,000	20,000
HEAnet	230,000						450,000	350,000		
IUCC	140,000									
Jisc	2,500,000		2,500,000							2,500,000
KIFÜ	100,000	50,000	1,000	200	200,000	5,000	600,000	600,000	100	1,000
MARNET	60,000									
MREN	20,000									
RENAM	74,500	2,900	850					208		850
SURFnet	750,000	120,000	430,000	10,000	20,000	30,000	60,000	60,000		430,000
SWITCH	318,663		770		0		0	0		770
ULAKBIM	3,900,000	5,500							5,000	
URAN	500,000	1,600	1.000	200	180	1,000	0	0	170	1,000
Total	**12,664,284**	**361,019**	**3,061,520**	**14,175**	**238,649**	**184,791**	**2,499,633**	**1,908,614**	**188,122**	**3,061,520**

Table 3.2: Estimates of the number of individual users per institution type
Remarkably, some NRENs provide connectivity to a quite significant number of end users in the commercial sector

While there are many gaps in the data that NRENs can provide about the number of end users, it is possible to estimate the number of end users using the market share estimates provided by NRENs (Table 3.1) and the number of students in Europe in schools and universities, as these make up by far the largest user group in terms of headcount. A smaller, but still significant, contribution comes from the staff of universities and schools. Using publicly available numbers of students and an assumed staff-student ratio of 1:12.5, the number of end users of NREN networks and services in Europe in 2018 amounted to about 41 million users.[18]

[18] 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) + users in the commercial sector.
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 haven't 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 the other user groups (research institutes, hospitals, government bodies, etc.) have a much lower headcount compared with schools and universities, so adding them wouldn't significantly change the estimate. That this assumption is plausible is also illustrated by the end-user estimates in Table 3.2. The

3.4. 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 (with individual exceptions), reflecting the NRENs' function as a public infrastructure rather than a for-profit enterprise.

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

number of users from the commercial sector is the sum of the estimates provided by the NRENs (ca. 3 Million).

4. INVOLVEMENT IN EC-FUNDED PROJECTS

NRENs participate in a number of EC-funded projects. The objectives of these projects vary, but they can roughly be grouped into three categories:

- **e-infrastructures**. The EC attaches strategic importance to the e-infrastructures that provide services to the research and education community across Europe and therefore finances several projects in this field. NRENs are uniquely well placed to support these EC projects to build or improve digital infrastructure. Such projects are based on the concept of providing shared ICT infrastructure – essentially, centralised computing and storage facilities – which generally interact with GÉANT as a network service provider, enabling remote access from researchers to the centralised facilities.[19]
- **Science collaborations**. Many other EC-supported projects are pan-European science collaborations that depend on network infrastructure and know-how for communication, data exchange and data processing; again, a field in which NRENs are a natural source of expertise.
- **Technology projects**. The third category comprises projects working on technologies that are part of the core competency of NRENs, i.e. network and above network services.

This section looks at the participation of NRENs in such EC projects.

Figure 4.1 gives an overview of NRENs' interactions with EC-funded projects other than GN4-3. The data show that 31 individual NRENs participated in a total of 103 unique projects (up from 29 NRENs and 78 projects in 2019). Many of the projects are related to EOSC and Open Science, underlining the growing importance of above-net services to many NREN portfolios. Figure 4.1 also shows that a number of NRENs are active in several projects at once. This shows their commitment to supporting collaborations in international science, however this does require resources that are not available to every NREN. 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. Five NRENs are active in over 10 projects, namely CSC/Funet, CARNET, PSNC/PIONIER, GRNET and CESNET. In addition, most EC-funded projects are not fully funded and the NREN needs to contribute a certain level of their own resources.

[19] This section is about projects other than GN4-3 (and GN4-3N), which are of course the central projects for a pan-European research and education network, in which all NRENs are partners.

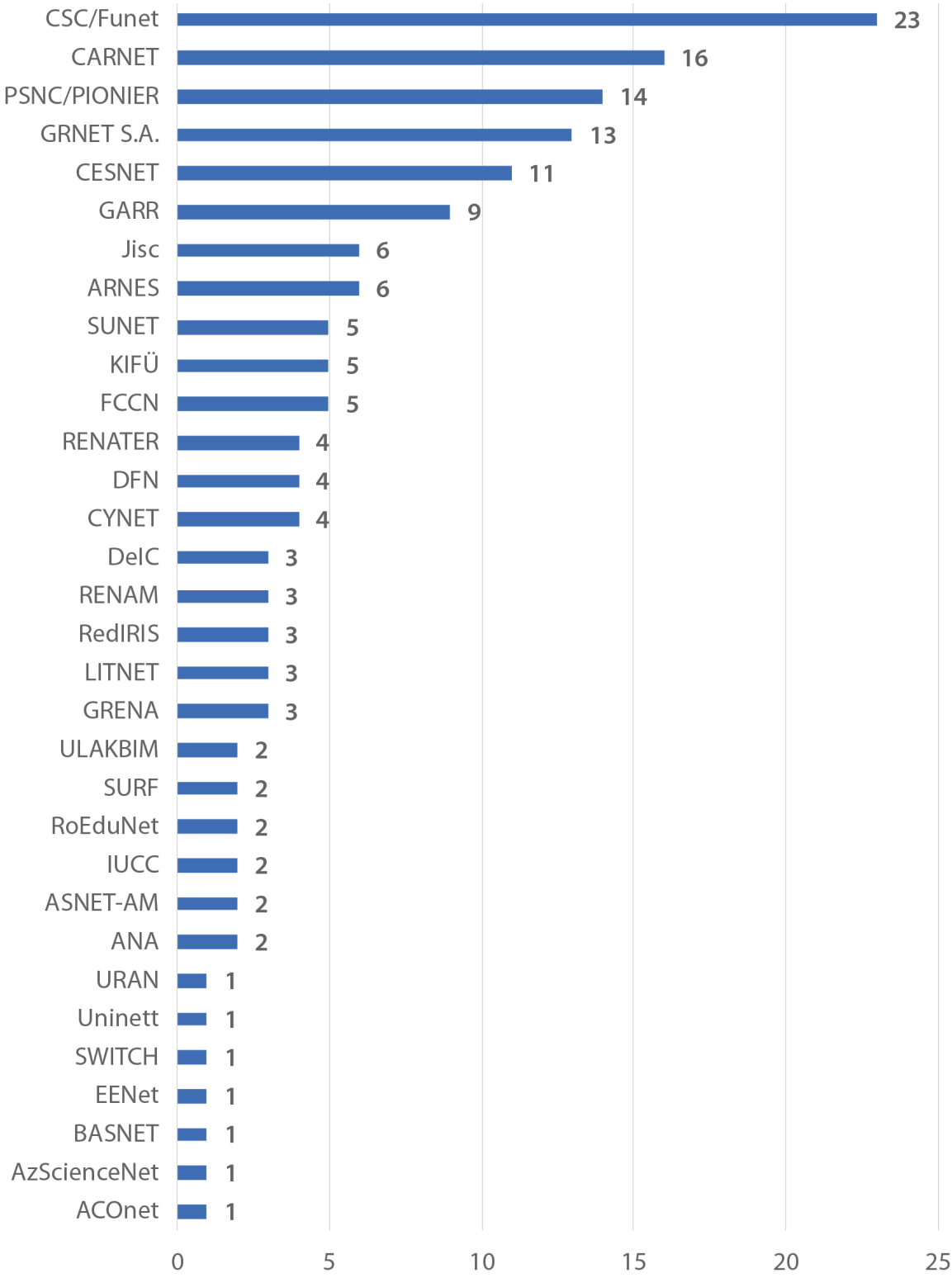


Figure 4.1: NRENs' participation in EC-funded projects – total number of projects per NREN

4.1. Overview of Top 7 EC-Funded Projects

This section gives a brief overview of seven 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.

Top 9 for 2020 were:

- EAP connect – 12 & EAP connect 2 – 14
- EOSC Hub – 11
- PRACE – 9
- NI40S – 6
- EOSC synergy – 6
- Bella – 5
- UP2U – 6
- OCRE - 5
- EuroCC – 4

4.1.1. European Open Science Cloud (EOSC)

The European Open Science Cloud (EOSC) is an EC-funded initiative to create a pan-European cloud environment for scientists, through which scientific data, services and digital resources can be offered and accessed. This far-reaching initiative has a number of constituent/supporting/associated projects to accomplish its goal. Several of these have enlisted NRENs among their supporters. All of these projects receive EC funding through the EU Horizon 2020 (H2020) programme. An overview is provided in Table 4.1.

Project	Project Profile	Contributing NRENs[20]
EOSC-hub [EOSC-hub]	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, DeIC, EENet, GRNET S.A., Jisc, PSNC/PIONIER,23 RENATER, SURF, ULAKBIM, Uninett
EOSC Enhance [EOSC Enhance]	Activities to co-design, develop and improve the functionality of the EOSC Portal, connecting thematic communities to the EOSC.	PSNC, GRNET
OCRE [OCRE]	OCRE has established a procurement framework to make commercial cloud and earth observation services available via EOSC	HEAnet, DFN, SURF, Uninett, CARNET
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.**	
EOSC Nordic [EOSC_Nordic]	Bundling initiatives from Finland, Sweden, Norway, Denmark, Iceland, Estonia, Latvia and Lithuania	
EOSC-Pillar [EOSC-Pillar]	Bundling initiatives from Austria, Belgium, France, Germany, and Italy	GARR
EOSC Synergy [EOSC_Synergy]	Bundling initiatives from Spain, Portugal, UK, Czech Republic, Slovakia, Poland, the Netherlands, and Germany	CESNET, FCCN, Jisc, PSNC, RedIRIS, SURF
NI4OS Europe [EOSC_NI4OS]	Bundling initiatives from Cyprus, Slovenia, Croatia, Bosnia Herzegovina, Montenegro, Serbia, Albania, North Macedonia, Greece, Bulgaria, Romania, Hungary, Moldova, Georgia, Armenia	ARNES, ASNET, GRENA, GRNET S.A., KIFÜ, RASH, RENAM
Disciplinary clusters		
ExPaNDS [EOSC_ExPaNDS]	Collaboration between 10 national Research Infrastructures	
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)	

Table 4.1: 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 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 Authorization infrastructure (AAI) and stakeholder engagement. In addition, GÉANT and the NRENs are active in the newly formed EOSC Association[21]. GÉANT was one of the founding members and is represented on the Board of Directors along with HEAnet. 7 NRENs have also been appointed as Mandated Organisations to represent national interests.

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

[21] The EOSC Association was founded in Brussels on 29 July 2020 as an international non-profit association (AISBL). Comprising 187 Members and Observers representing research performing organisations, service providers and funders, it will be an organisational umbrella to coordinate the various EOSC initiatives and provides the legal entity that is needed to maintain contractual arrangements with the EC to make the EOSC ecosystem sustainable. More information can be found under https://eosc.eu.

4.1.2. PRACE

The Partnership for Advanced Computing in Europe (PRACE) [PRACE] is a project (and an organisation) that organises the access to supercomputing capacities among 26 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, SURF and Uninett are partners in PRACE.

PRACE project partners have received, or are receiving, EC funding through a number of implementation projects.

4.1.3. BELLA

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

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

BELLA receives funding from the European Union through the Horizon 2020 programme.

4.1.4. Up2U

Up to University (Up2U) [Up2U] is a project to develop a digital learning environment that helps to bridge the gap between secondary schools and higher education and research institutions. The emphasis of the Up2U learning environment is on interoperability and modularity. The project is intended to allow the integration of elements ("containers") from various origins, with the option to adapt to a given purpose by combining different modules. Up2U can be deployed on top of a wide variety of cloud infrastructures.

FCCN, GARR, GRNET S.A., IUCC, KIFÜ, PSNC/PIONEER are partners in Up2U.

Up2U received funding from the European Union through the Horizon 2020 programme from 2017 to 2020.

4.1.5. EaPConnect

Eastern Partnership Connect (EaPConnect) [EaPConnect] , now going into its second iteration, EAP Connect 2, 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. Part of EaPConnect is to support the deployment of eduroam and to stimulate the integration of GÉANT services generally. The project will also facilitate the participation of local scientists, students and academics in global R&E collaborations.

EaPConnect 2 partners – in addition to the NRENs of the six partner countries (ASNET, AzScienceNet, BASNET, GRENA, RENAM, URAN) – are DFN, EENet of HITSA, LITNET, GRNET, GARR, PSNC/PIONEER, RoEduNet and SURF, who provide extra support and expertise.

4.1.6. EuroCC

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.

The objective of the EuroCC project is to create an infrastructure for the access to High

Performance Computing (HPC), High Performance Data Analytics (HPDA) and artificial intelligence (AI) in the participating countries. The EuroCC project aims to establish National Competence Centres (NCCs), to survey and document the core HPC, HPDA, and AI activities and competencies in on a national lever. The goal is to make HPC capacities available to different users from science, industry, public administration, and society.

GRNET, CSC/Funet, Uninett and ARNES are partners in EuroCC.[22]

The EuroCC project is funded 50 percent through H2020 (EuroHPC Joint Undertaking [JU]) and 50 percent through national funding programs within the partner countries.

4.2. Summary

The diversity of EC-funded projects presented in this section and the large number of NRENs that participate in them show that NRENs are 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. This trend is set to continue with 13 NRENs involved in the forthcoming EOSC Future project and a range of INFRAEOSC-07 projects to increase uptake of services in the EOSC Portal, including EGI-ACE, RELIANCE and C-SCALE. Indeed, several NRENs play roles in multiple of these projects. The involvement in PRACE and other high performance computing projects such as EuroHPC is also relevant as this is seen as a growing area of relevance. A programme of coordination meetings and infoshares has begun in early 2021 to support NREN engagement and alignment of EOSC and EuroHPC.

[22] In addition to the direct involvement of NRENs, organization that are closely associated with local NRENs are partners in EuroCC, e.g. TUBITAK (Turkey), FCT (Portugal) and SurfSARA (Netherlands). The direct involvement of NRENs in the European HPC infrastructure will grow in the coming years.

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.

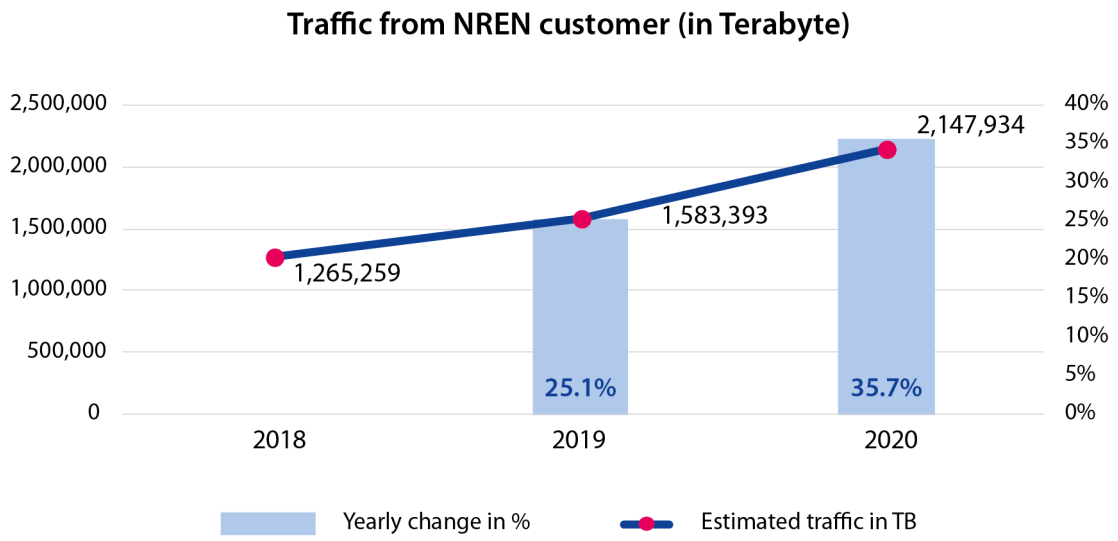
NREN networks, like the countries in which they reside, are unique and tailored to fit the community they serve, within the limits of the resources at their disposal. This section presents an overview of NREN network traffic, infrastructure, and services.

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 and from NREN end users for 2018 to 2020. While these figures are only representative of a subset of NRENs, the yearly two-digit growth rates are indicative for NRENs as whole – they also suggest a doubling of the traffic within approximately 5 years.

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 more than 800,000 Tbytes of data from outside the NREN, and ANA/RASH, with just 65 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.

The volume of traffic that NRENs carry continues to rise. Around a third of all GÉANT NRENs (15) reported an increase in traffic (at the top here was GRNET, reporting an increase of traffic from outside of 97%). Four NRENs (BASNET, GRENA, RESTENA and SURF) reported decreases.



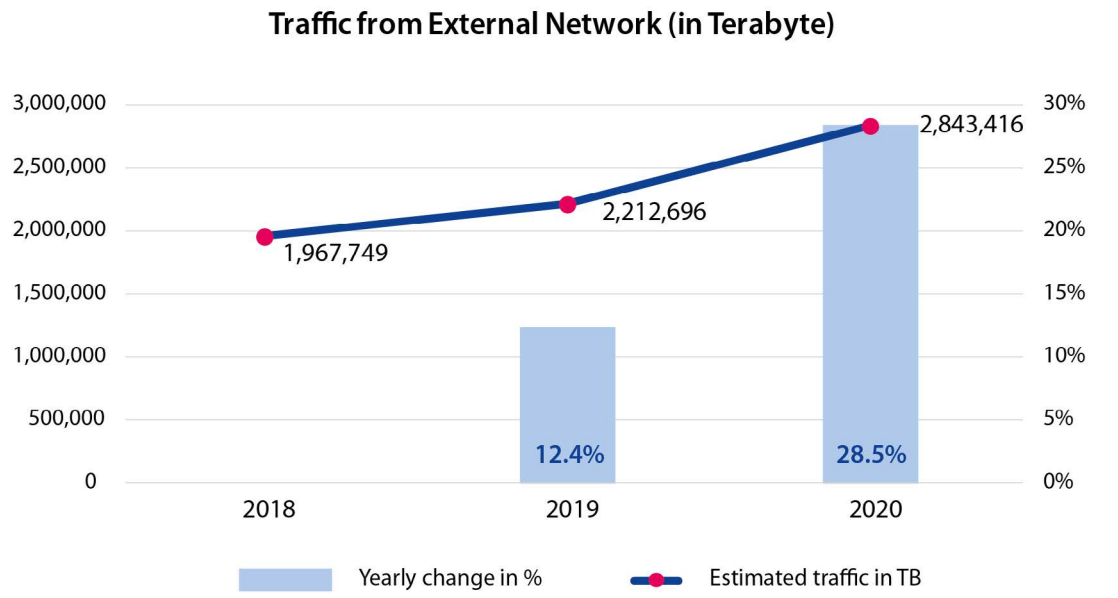


Figure 5.1: Increase of traffic into the NRENs from external networks (upper graph) and NREN end users (lower graph) 2018 to 2020

"External networks" denotes sources that are outside the NREN's domain, such as GÉANT, general/commercial internet, internet exchange, peerings, other NRENs. "NREN customer" denotes sources that are part of the remit of an NREN's domain. The figures are based on traffic data from 20 NRENs for which there are continuous traffic records from 2018–2020 (ANA, BASNET, BELNET, CARNet, CESNET, DFN, FCCN, GARR, GRENA, HEAnet, Jisc, PIONIER, RedIRIS, RENAM, RENATER, RESTENA, RoEduNet, SURFnet, SWITCH, ULAKBIM).

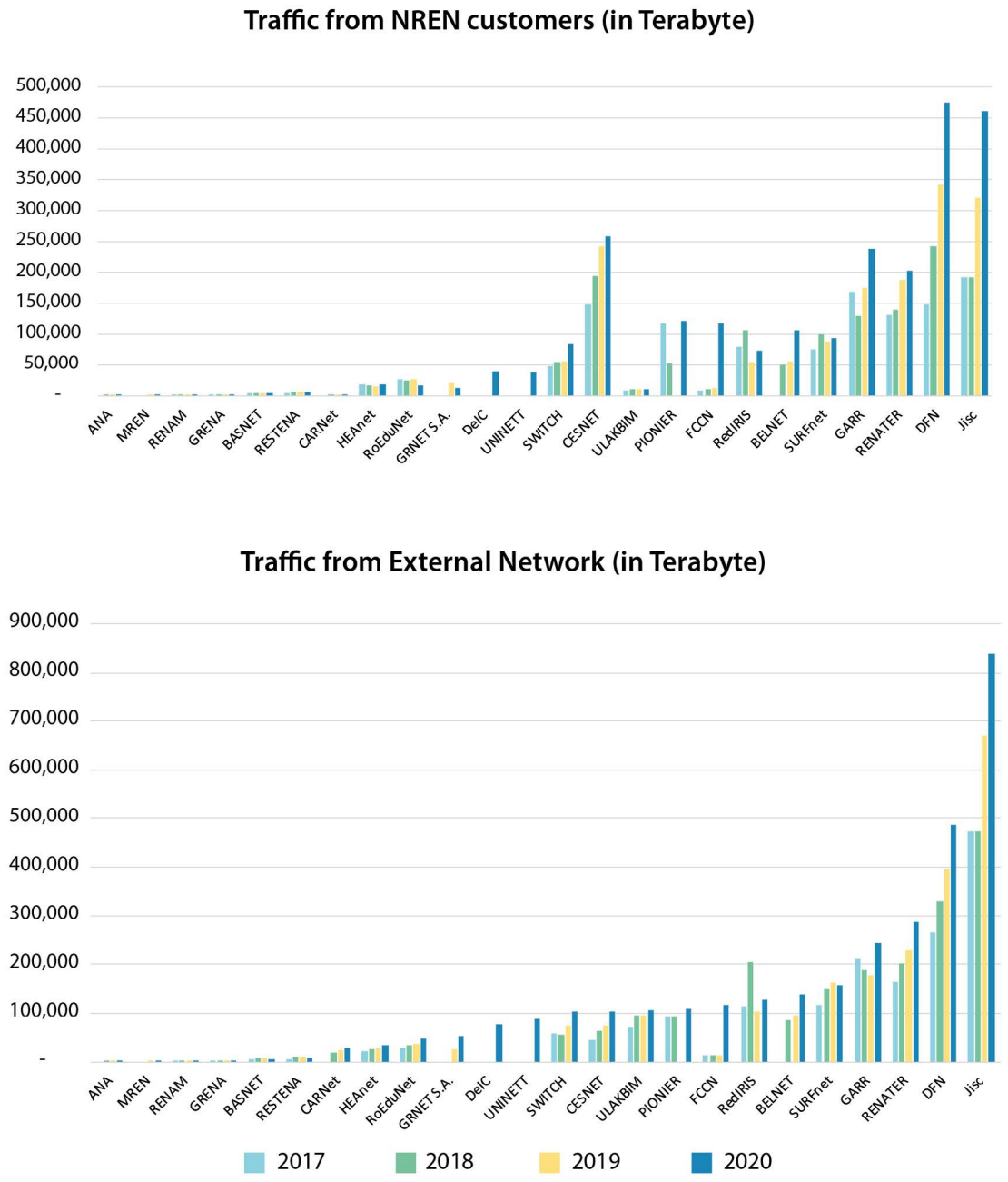


Figure 5.2: Traffic per NREN from external networks (upper panel) and NREN end users (lower panel) 2017 to 2020
The figure shows all NRENs that reported their traffic volumes in the 2020 survey – where available, data from the years 2017-2019 are shown as well. As in the previous figure, "External network" denotes sources that are outside the NREN's domain, such as GÉANT, general/commercial internet, internet exchange, peerings, other NRENs. "NREN customers" 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 over the coming three years, by institution type.[23]

NRENs expect traffic to grow in the medium term: All 34 responding NRENs expect traffic growth over the three years 2020 to 2023, 13 of them by more than 50%, across all organisations within their remit. The highest growth is expected to come from research institutes, closely followed by schools (the latter are divided in primary and secondary schools, with an anticipated growth of 72% and 74%, respectively. Not far behind are universities, with traffic estimated to grow by 67%.

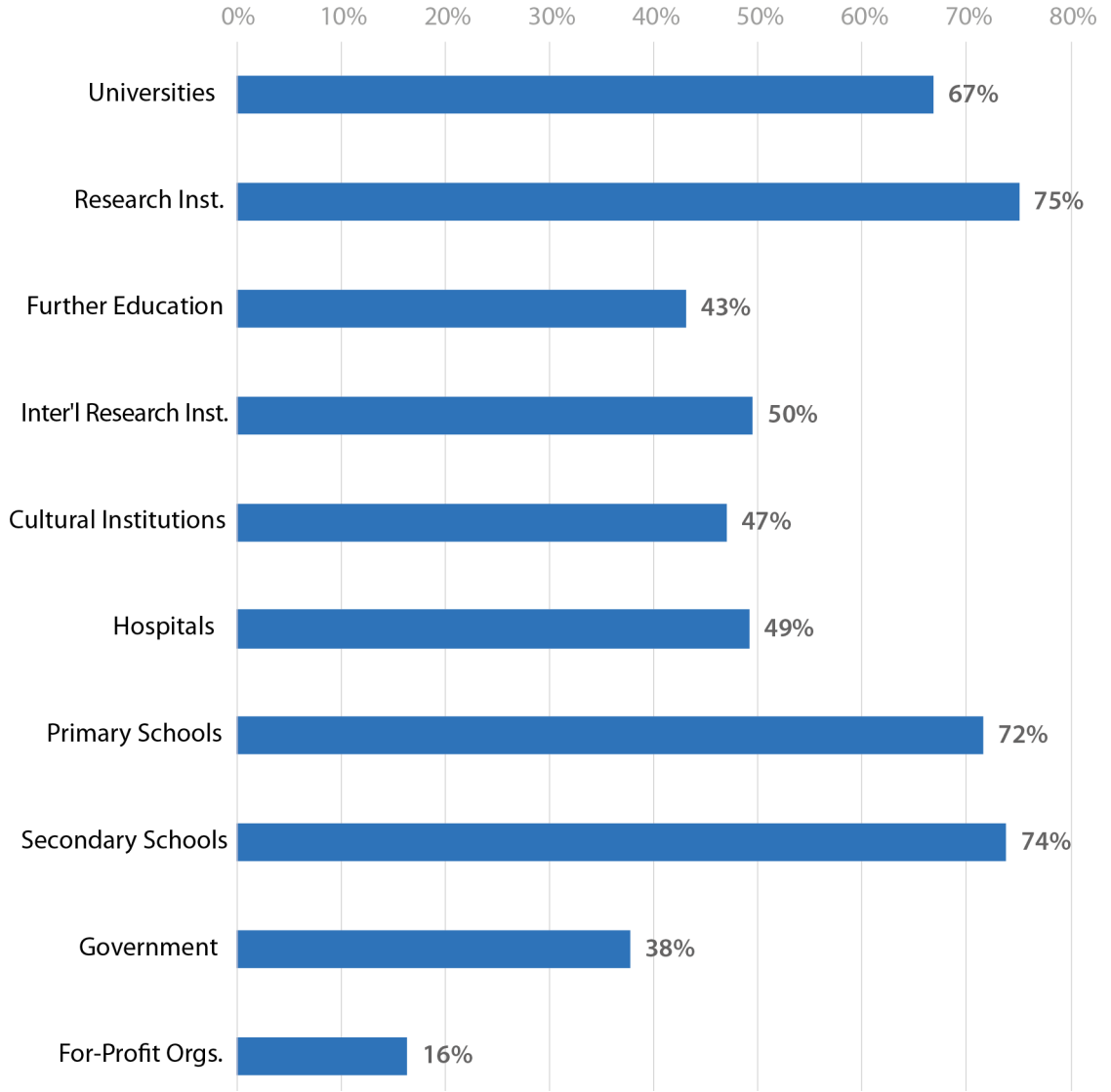


Figure 5.3: NRENs' forecast traffic growth by institution type (based on 34 responses)
Note that these forecasts were made in 2020 and therefore likely include the effects of COVID-19

[23] 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.

The traffic growth in the research sector, especially from research institutes probably reflects the accelerating trend of data digitalisation and possibly the increasing role of centralised research facilities. The high anticipated growth rate in the school sector is in line with the relatively recent expansion of NRENs into this sector. The traffic growth rate forecast in other categories is lower, but still significant. Note, however, that these growth numbers are percentages – the absolute expected growth in the volume of traffic is vastly bigger for universities and research institutions than it is for schools, the latter having much more modest needs.

Table 5.1 below gives an overview of the expected growth in traffic over the three-year period 2020 to 2023, by NREN, and by institution type..

	Universities	Research Institutions	Further Education	International Research Institutions	Cultural Institutions	Hospitals	Primary Schools	Secondary Schools	Government	For-Profit Organisations
ACOnet	100	75	70		50	50	100	100	50	
AMRES	30	30	30		30	30	50	50	30	
ANA	40	30	20		10				10	
ARNES	25	50	1		15	15	25	25	15	
ASNET-AM	80	80		20	40				30	
AzScienceNet	100	100			100					
Belnet	172		72							
BREN	5									
CARNET	30	30	40		20	30	40	40	30	50
CESNET	10	10	5	10	10	5	5	12	10	
CYNET	30									
DeIC	120	100	100	100	50	200			50	
EENet	10	50	10		5		10	10	10	
FCCN	50	50		20				20	50	
Funet	30	50			30				50	
GARR	60	40		100	40	100	100	100	20	
GRENA	80	80		80	80	80			80	
GRNET S.A.	50	30	40		10	200	500	500	10	
HEAnet	10	20	10				40	41		
IUCC	50	30			30					
Jisc	100	100	100	100	100	100	100	100	100	100
KIFÜ (NIIF)	200	200	200	20	200	100	200	200	100	
MARnet	100	100								
MREN	100	50			50				50	
RedIRIS	60	60	60		30	30	60	60	30	
RENAM	10		10			10				
RENATER	220	400	220	400	220		220	220		
RESTENA	80	80	30				30	50		
RoEduNet	50	200	20	50	30		20	20		
SANET	40	40	40		40	40	40	40	40	40
SUNET	80	75	50		40	1				
SWITCH	35	35	35	35	35	35	35	35	35	35
ULAKBIM	60	50			30				50	
URAN	55	80		55	20	55			55	70

LESS = 40	OVER 40 -100	OVER 100

Table 5.1: Forecast traffic growth by NREN and institution type 2020 to 2023

5.3. IPv6

Internet Protocol version 6 (IPv6) is the most recent version of the Internet Protocol (IP), the communications protocol that provides an identification and location system for computers on networks and that routes traffic across the Internet. IPv6 was developed to deal with the problem of address exhaustion posed by the limited address space provided by the predecessor protocol IPv4 IPv6 is intended to replace.

IPv6 was first published as RFC1883 back in 1995, and updated to RFC2460 in 1998. The core protocol has remaining largely unaltered since then and was republished by the IETF as a full Internet Standard as RFC8200 in 2017, indicating a high degree of technical maturity and a generally held belief that the specified protocol or service provides significant benefit to the Internet community. Its key advantage over IPv4 is its significantly larger 128-bit address space, which is important to support further growth in the number of connected hosts in our R&E networks.

The deployment of IPv6 among networks is geographically very uneven, reaching more than 50% in some places (e.g. India) but usually being much lower. IPv6 is usually deployed to run in parallel with "traditional" IPv4 networking, a model known as "dual stack". R&E networks have a higher rate with at least 85% of NRENs offering IPv6, while the GÉANT network is fully IPv6-enabled.

Overall, around 35% of Internet traffic is IPv6, based on a variety of measurements from different sources such as APNIC and Google, which are included on a list at the World IPv6 Launch site.[24] The past 3-4 years have seen a shift where commercial IPv6 Internet traffic has significantly overtaken NREN IPv6 traffic, as the commercial ISPs and content providers have adopted IPv6 and the campuses and networks connected to our NRENs generally have not.[25] The challenge with IPv6 widely available in R&E backbones is to now see its deployment grow on campuses.

That said, R&E networks started to show some substantial increases in traffic using IPv6 in 2020. 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 – an increase of 5.5 times. Similar numbers have been found for September 2020: 119 Gbps of IPv6 traffic, representing 27.6% of the total traffic. This is approaching the worldwide average.

This traffic seems to be mostly associated with "big science" projects that use GÉANT's network to transfer and share data. Figure 5.4 shows the IPv6 traffic average into GÉANT from its partners during September 2020. Most traffic comes from the NRENs, which hides the origin of the traffic, but, in line with the role that "big science" projects play for IPv6 traffic, a large part originates from institutions like CERN, where the Worldwide Large Hadron Collider Computing Grid (WLCG) has set a policy to dual-stack its sites around the world, ultimately with a view to introducing IPv6-only networking in the future. Currently 77% of the WLCG Tier2 storage sites have IPv6 enabled[26], and over 50% of transfers are using IPv6. GÉANT believes that such flagship examples of IPv6 deployment and use will bring benefits to the community and help spread best practices to ensure sustainability and robustness of the networking infrastructure.

[24] https://www.worldipv6launch.org/measurements

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

[26] https://twiki.cern.ch/twiki/bin/view/LCG/WlcgIpv6

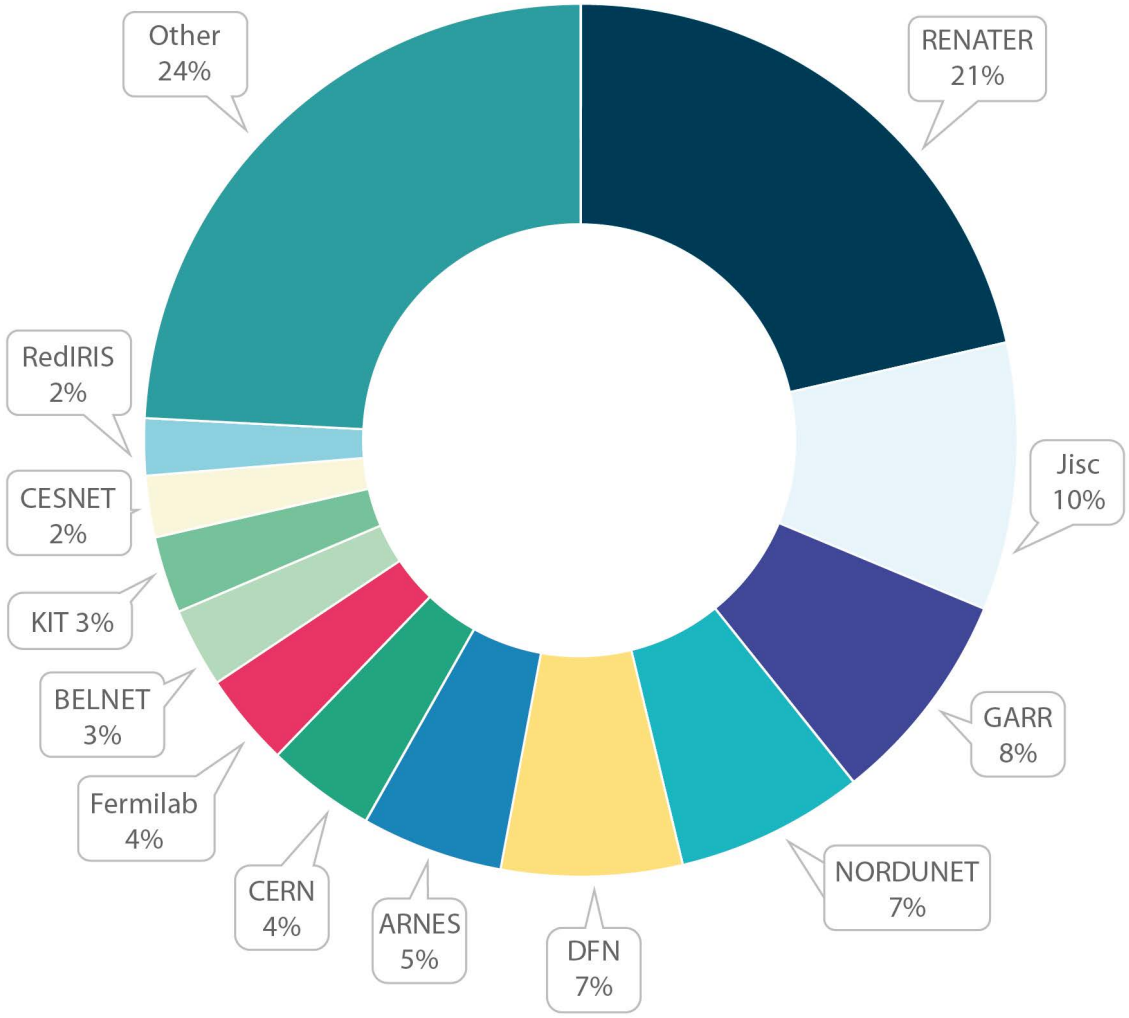


Figure 5.4: Top 12 GÉANT IPv6 traffic sources in April 2021
The total IPv6 traffic in April 2021 was 105 Gbps, which represented 26.3% of all traffic in April [Source: GÉANT Kentik tool].

5.4. Network Infrastructure: Dark Fibre

Dark fibre refers to fibre optic cable leased or purchased from another supplier in the dark (i.e. unlit) state, 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 the term Indefeasible Rights of Use (IRU) (see textbox).

The NREN community has gradually increased its ownership of dark fibre over the years. Changes in IRU are slow, reflecting the considerable costs involved, and the long-term commitment of capital that is required.[27]

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

[27] Not all NRENs use IRUs – while 32 NRENs affirmed their use of IRUs, 7 NRENs stated that the did not use IRUs (BASNET, CARNET, CYNET, GRENA, MARnet, UL-AKBIM, URAN)

The increase is documented in Figure 5.7. In 2020, the NRENs reported a total of a bit more than 150,000 km of dark fibre. Figure 5.8 below shows the number of kilometres of fibre each NREN reported in its own network. This NREN-operated fibre interconnects with GÉANT's 11,000 km of intercity dark fibre, forming a strong community infrastructure (see GÉANT Network Updates, **below**).

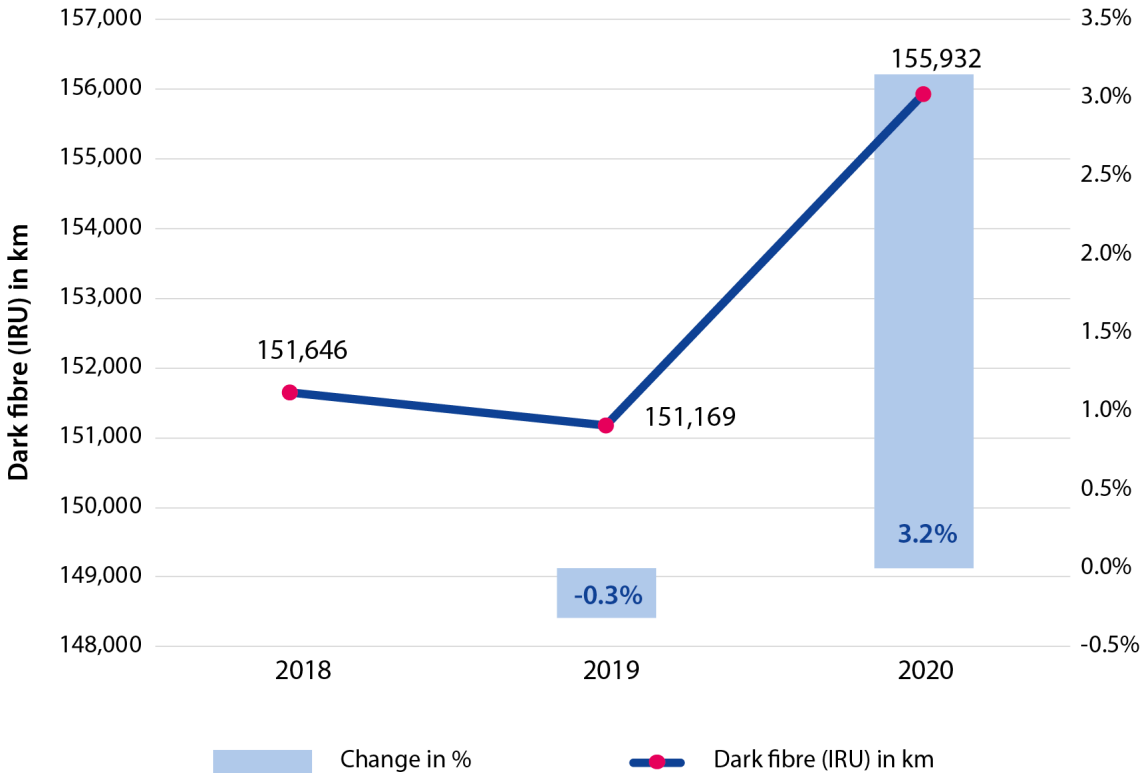


Figure 5.5: Development of the NRENs' IRU networks 2018–2020
To make numbers comparable across the years, the figure shows only the IRUs of NRENs that have provided IRU data in all Compendium surveys from 2018 to 2020.

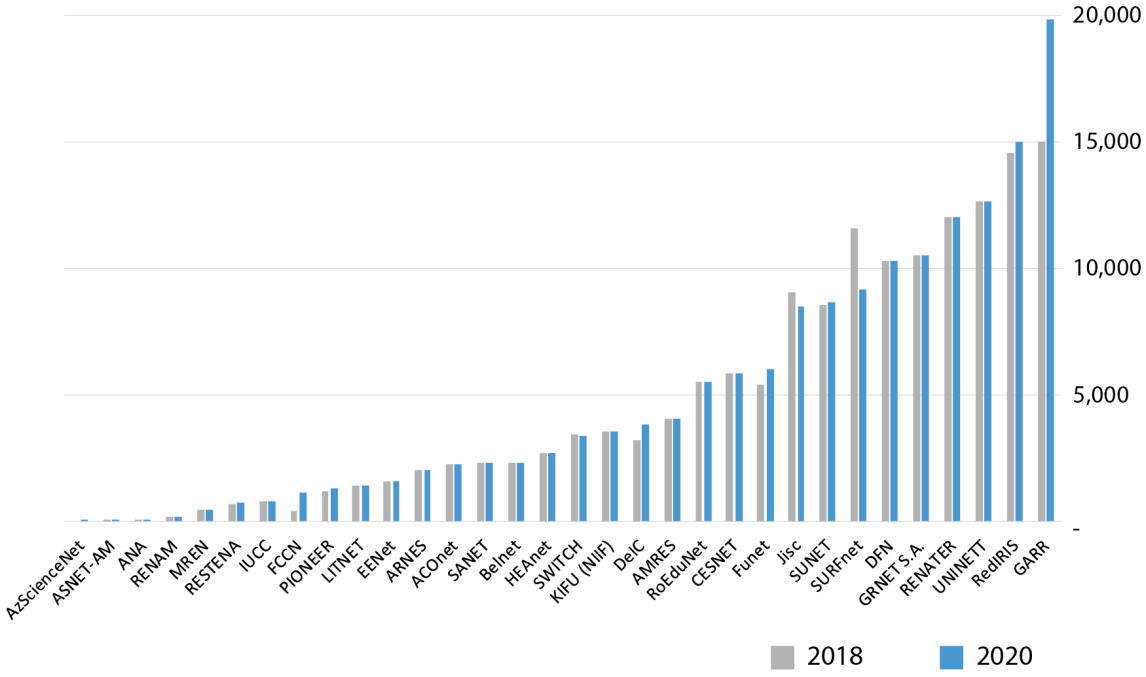


Figure 5.6: Number of kilometres of IRU network per NREN 2018 to 2020
For visual clarity, 2019 was omitted from the graph. Even so, it is clear that overall, only small changes have taken place, though GARR reported significant additions to their network. The figure shows numbers for all NRENs that reported on their IRU network in the 2020 Compendium survey, i.e. NRENs that reported in previous years but did not do so in 2020 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[28]. According to the survey results, the number of NRENs making use of alien waves within their network has not changed, and in 2020 was still the same as in 2019 and 2018 (15 NRENs), which means that the majority of European NRENs that responded are currently not using this technology.

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

- NORDUnet has taken steps towards building its entire network using spectrum provided by its local NREN members (DelC, Funet, RHnet, SUNET, Uninett).
- Planned for 2022, GÉANT will offer a new service in GN4-3 called the Spectrum Connection Service. This service will allow NRENs to inject coloured DWDM light directly into the GÉANT network without the cost of optical–electrical–optical (OEO) conversion at the GÉANT/NREN interface.

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

- GÉANT will make use of as much NREN spectrum as possible when building the new network in 2020–2022. For example, the GÉANT link from Copenhagen to Helsinki is planned to make use of spectrum provided by NORDUnet/SUNET.

5.6. IP Backbone Capacity

Principal data routes, to which customers are connected, are the backbone of an NREN's network. This means the capacity of the network has to fit the needs of a country's research and education sector. As a consequence, the different capacities of the NRENs' backbones reflect the size of this sector – as well, of course, as factors such as the funding that is available. An overview of the typical backbone capacity of individual NRENs is shown in Figure 5.9.

NRENs that serve a large research and education sector are increasingly using 100G technology to light their fibre. 17 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 5.9). This is also reflected in the median capacity across NRENs that has now reached 40 Gbyte/s while it had hovered around 20 for several the years before. However, this increase is slow which reflects that there is a long tail of relatively small NRENs that do not necessarily have the need for high capacities (or, in some cases, might lack the means to achieve them). Also, increases of the typical capacity result from network renewals, which are undertaken only in intervals of several years.

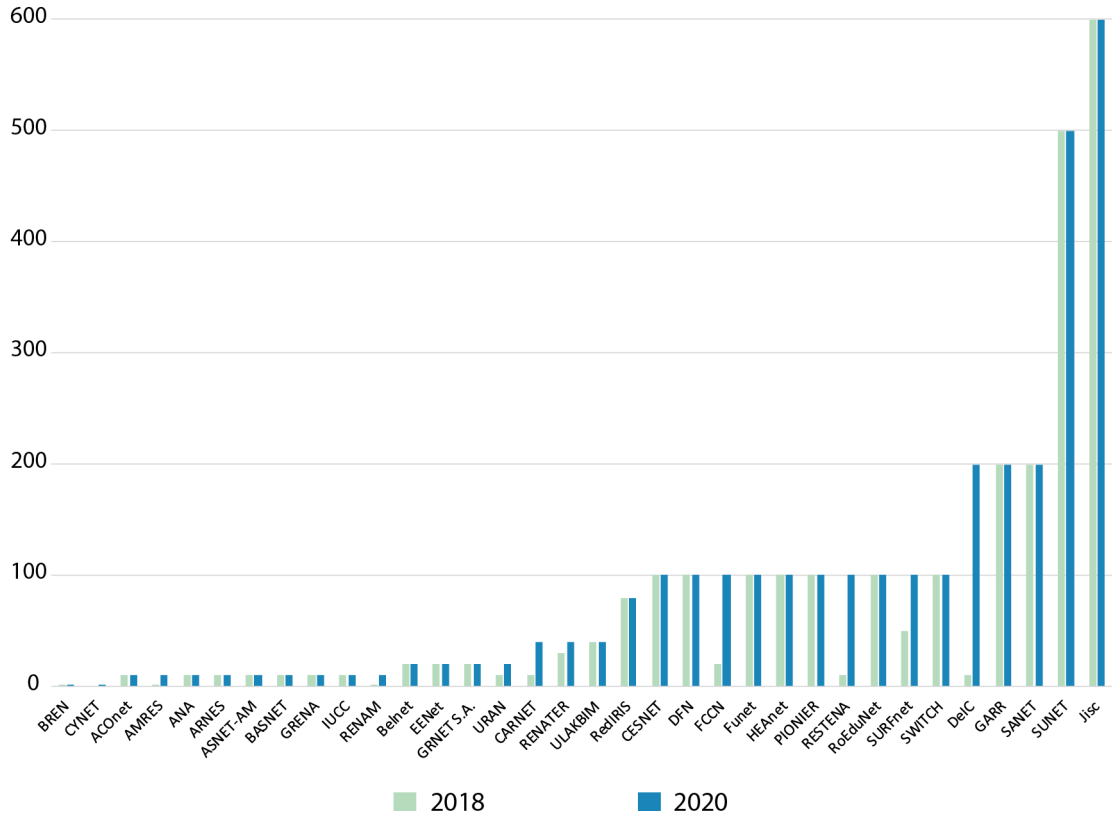


Figure 5.7: NRENs' typical core usable backbone IP trunk in Gbps 2018 to 2020

The figure shows all NRENs that provided data on their trunk capacity in the 2019 survey. For visual clarity, the 2018 data were omitted from the graph. It is clear, that most NRENs backbone capacity hasn't changed. However, there are some notable increases: AMRES, RENAM, URAN, FCCN, RESTENA, SURF and DeIC have significantly increase their capacity. The figure shows all NRENs that provided data on their trunk capacity in the 2020 survey, i.e. NRENs that reported in previous years but did not do so in 2020 are missing.

5.7. Network Peering

"Network peering" refers to the direct exchange of internet traffic between two networks. For this to be possible, the two networks need to be physically connected, which often happens via an Internet exchange (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[29].

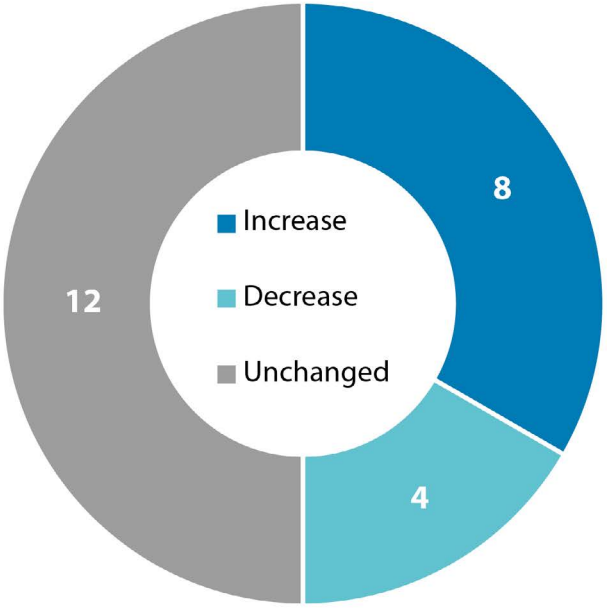


Figure 5.8: Non-R&E network peering development of NRENs 2019 to 2020
In the 2020 survey, of the 36 NRENs responding to this question, 8 reported an increase in the number of non-R&E peering networks, 4 reported a drop, while the remaining 12 NRENs did not see a change in the number of peering agreements (see Figure 5.8). The number of peering agreements per NREN is shown in Figure 5.11.[30]

[29] NRENs can negotiate peering agreements with any number of networks and some NRENs maintain many such agreements. Another solution that is available to NRENs are 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.

[30] In terms of absolute numbers, the number of peering agreements across all NRENs has increased from 2393 in 2018, to 2615 in 2019, and to 3417 in 2020. Interestingly, SWITCH alone is responsible for 70% of the 2018/2020 increase, which is also visible in **Figure 5.11**.

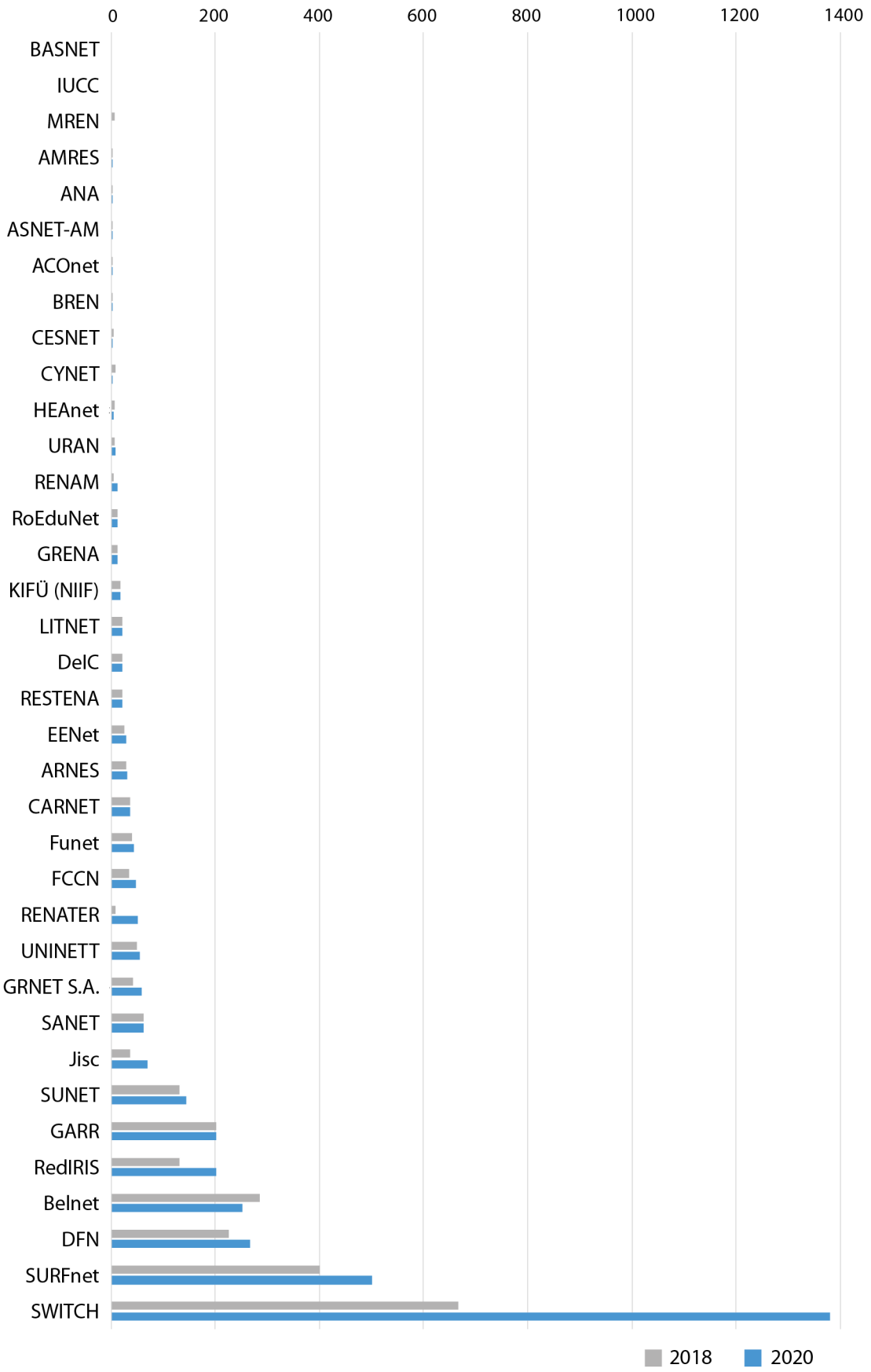


Figure 5.9: Number of non-R&E peering networks 2018 to 2020. The figure shows numbers for all NRENs that reported on their peering agreements in the 2020 Compendium survey. *For visual clarity, the 2019 data were omitted from the graph. Generally, the number or peering agreements has increased for most NRENs, between 2018 and 2020, but in most cases only modestly. The figure shows numbers for all NRENs that reported on their peering agreements in the 2020 Compendium survey, i.e. NRENs that reported in previous years but did not do so in 2020 are missing in the graph.*

5.8. GÉANT Network Updates

5.8.1. GÉANT Network and Statistics

The GÉANT network interconnects 43[31] research and education networks in Europe and has 38 active routers and 19 Infinera (DTNx) transmission nodes. This section presents a snapshot of the GÉANT network, including statistics such as IP/MPLS traffic growth. This section will give an overview of the ongoing network refresh activities as part GN4-3N.

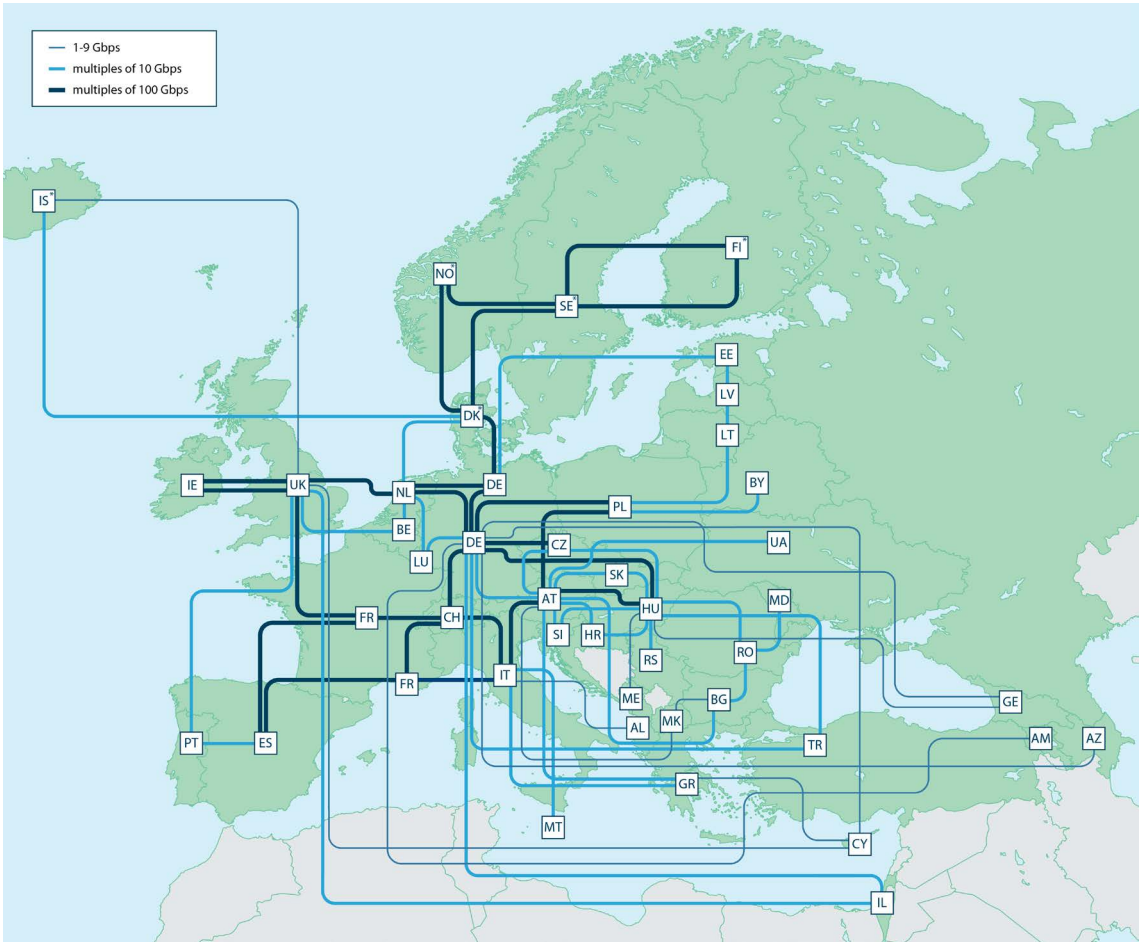


Figure 5.10: GÉANT pan-European network topology map (December 2018).

5.8.1.1. Current GÉANT Network Structure

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

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

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

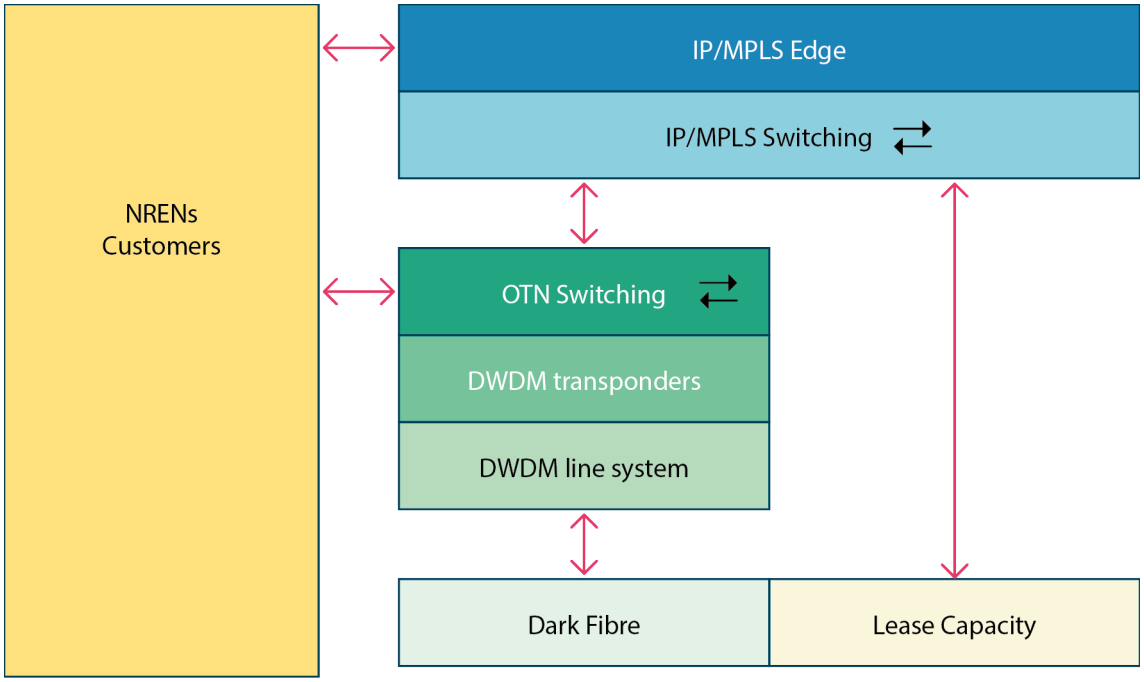


Figure 5.11: The current layered structure of the GÉANT network
The IP/MPLS routing part of the network, provided by Juniper MXs, is shown in blue while the optical transport network (OTN) / DWDM part, provided by Infinera, is shown in green. The arrows represent demarcation points between building blocks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

5.8.1.2. GÉANT Network Statistics

In 2020 the GÉANT network received 2.35 Exabytes of traffic, representing a reduction of 22% from the previous year figure.[32] Fig 5.12 shows the year-on-year traffic growth from 2015 to 2020. For 2020, as previously mentioned, the yearly growth rate has turned negative for the first time since granular traffic data have been collected.

[32] 2019 total volume revised up from 2.8EB to 3.01EB as part of a recent review.

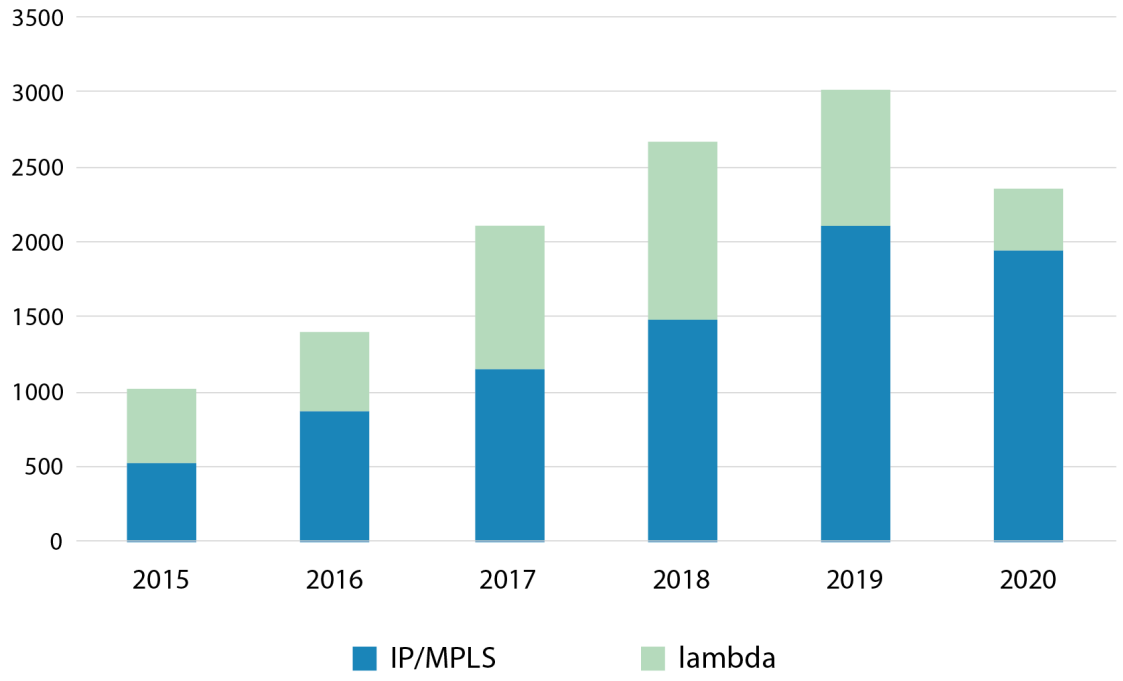


Figure 5.12: Overall volumes of traffic (IP/MPLS and Lambdas) received by GÉANT (in Petabytes) 2015 to 2020
IP/MPLS is increasingly dominating over lambda traffic. Looking at the total traffic, tThe figures clearly illustrates the continuously increasing traffic volumes across the GÉANT network and suggests – notwithstanding the COVID-19-correllated drop in 2020 – that further growth in the future.

The decline is due, to a large extent, to the impact of COVID-19 and the subsequent move of a large number 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 like LHCONE[33] has increased. (a summary is shown in Figure 5.13).

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

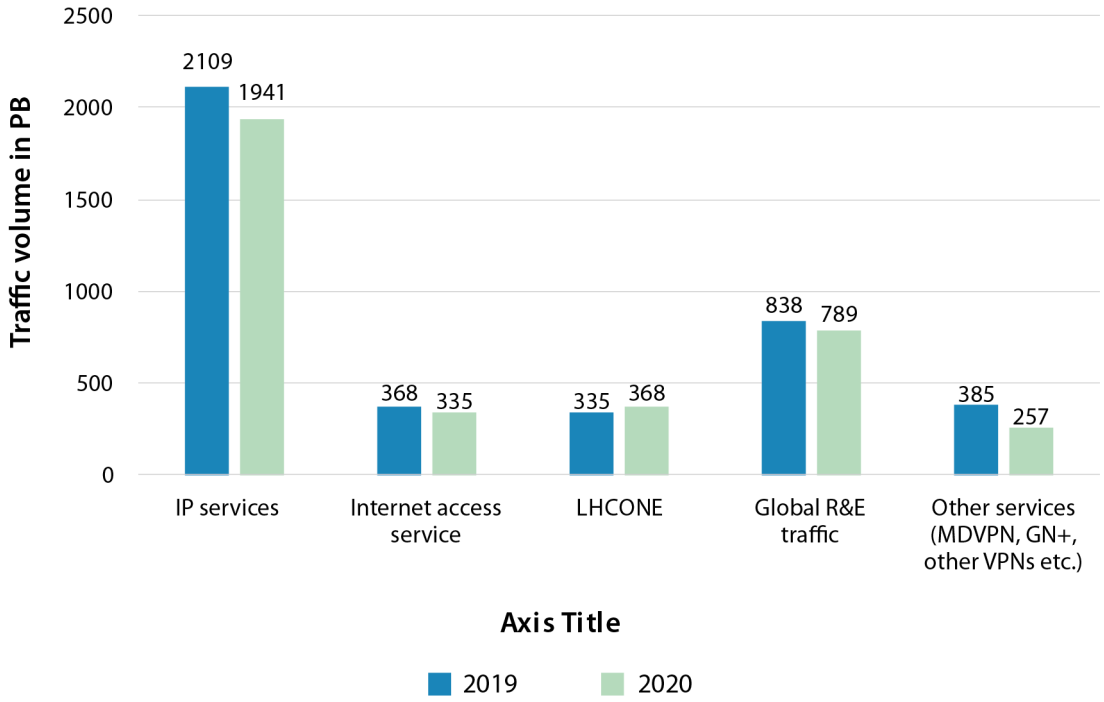


Figure 5.13: The figure shows the sum of all IP/MPLS network traffic (IP services) and then its components which are Internet access service, Global R&E traffic, Other Services and LHCONE traffic
Only LHCONE traffic, which is dominated by machine-to-machine data has grown, while the other traffic types, where users are a major source of data, have decreased

While the decrease has affected all areas of the network, the decline in traffic levels has been much more limited for the IP/MPLS network (8% decrease) than it has been for Lambdas (55% decrease). This reflect the long-term trend already observed in previous years where Lambdas traffic growth has been progressively slowing down and even declining more recently (was down 22% in 2019 compared to 2018).

5.8.2. Evolution of the GÉANT Network

5.8.2.1. Network Topology

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

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

The new, improved network footprint will be based on fibre or spectrum (fibre shares) under contracts of 15 years or longer. The GN4-3N topology has been developed in close collaboration with the NRENs and envisages a large expansion of fibre/spectrum to cover areas previously connected via the use of lease capacity (normally procured on short-term contracts of 1 to 3 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 Fig 5.14 for details).

It is important to note that a considerable number of connections planned to be part of the new network will be provided by NRENs, sharing existing infrastructure with GÉANT. This will ensure that GN4-3N funding can be directed towards places where it is most needed and infrastructure duplication is minimised[34]. Full details can be found in the GÉANT Network Evolution Plan [D7.1].

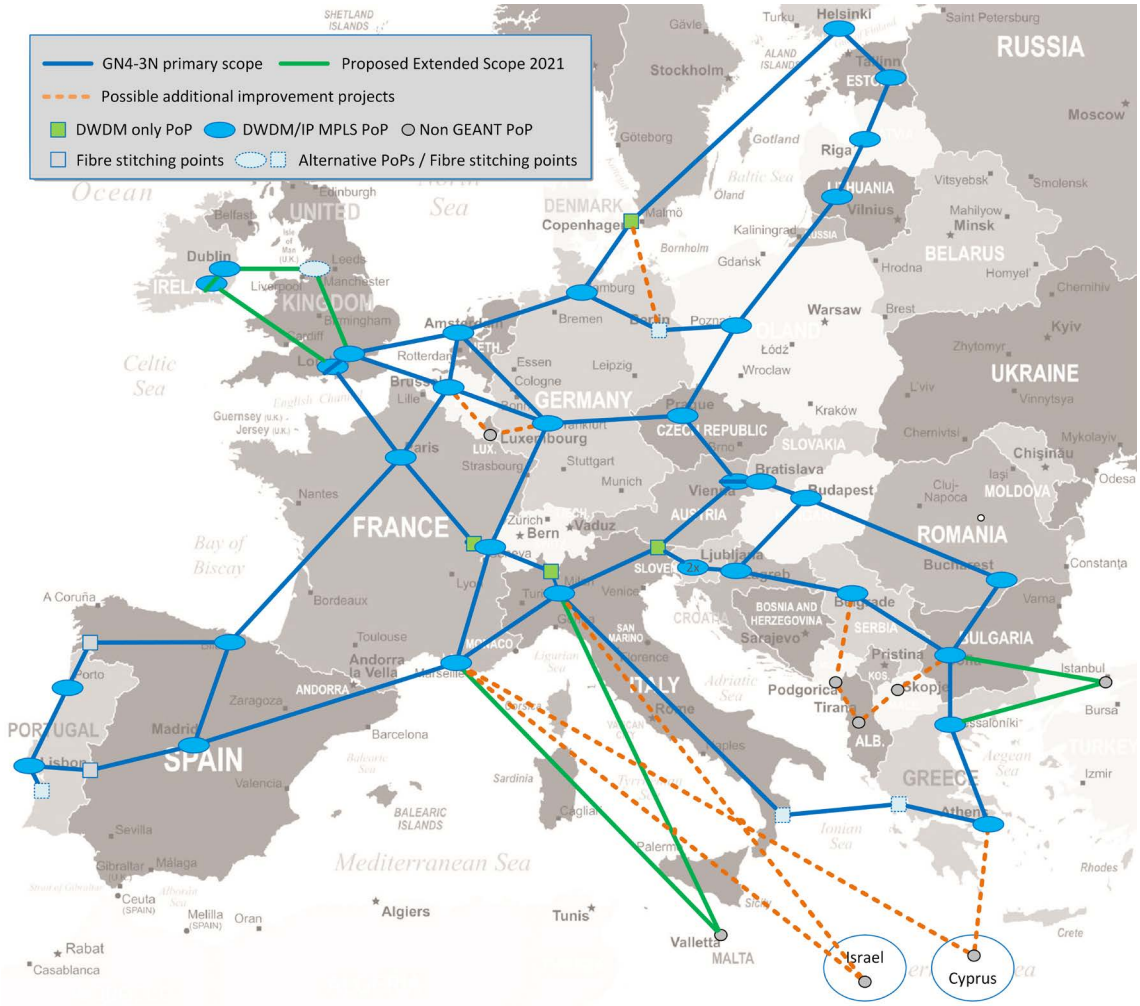


Figure 5.14: A view of the current reference topology for GN4-3N. The map represents the "default" scope of the GN4-3N project

Additional improvement projects are being worked on and may become part of the scope if funding is available. The map shows only the GÉANT backbone; it does not include infrastructure run by NORDUnet, EAP countries, other projects, or connectivity used to allow access for countries where a GÉANT PoP is not present, i.e. Israel or Malta.

[34] 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.

5.8.2.2. Transmission/DWDM

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

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

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

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

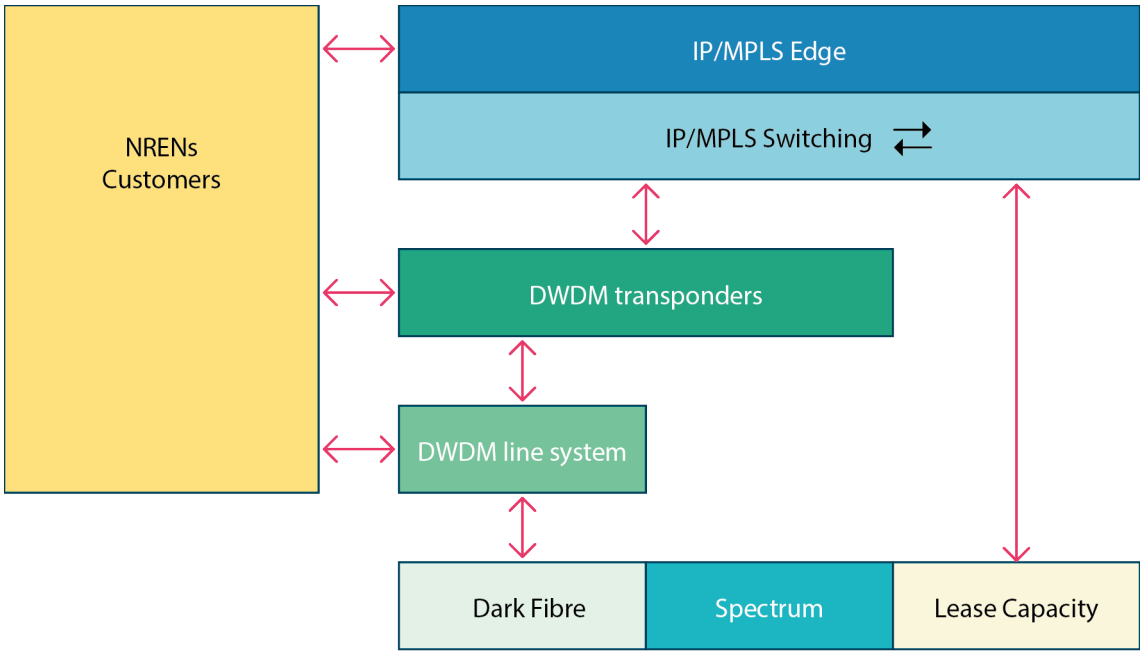


Figure 5.15: Layers of the network as it will be after the transition to a partly disaggregated DWDM system
The three layers are transport, transmission (in green) and packet (in blue). The transmission portion of the network will be composed of only two blocks (OTN switching having been removed), which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

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

5.8.2.3. Packet Layer

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

Based on the current generation of Juniper MXs, the packet layer has provided GÉANT with a good-value and high-performance IP/MPLS system for the last 8–10 years. With the arrival of 400G Ethernet, however, the current system is now starting to show its limits. A significant review will be required to determine how to economically support the rate of data at the scale now demanded.

GÉANT is actively looking at a successor to the current MX platform. A new IP/MPLS platform will be needed to support the connectivity requirements of the largest sites on the longer term. GÉANT is now working on planning for a significant procurement activity for this part of the network to take place in GN5. Structured market engagement activity has already started and will be ongoing for the next 2 years with a view of running the procurement in early 2023.[35]

This is a change from the previously communicated timeline that would have seen GEANT looking at the procurement of a new platform (for the central, highest capacity, portion of the network) already in 2022. This change has been made possible by the fact that the network as seen lower traffic levels due to COVID-19 allowing GEANT to aggregate IP/MPLS network refresh activities as single, larger, piece of work within GN5. This should provide efficiency especially when looking at the long term.

5.9. Summary

Reflecting the ever-increasing importance of digital services in the R&E world, network traffic is expected to keep growing in the coming years. To allow for the expected traffic growth, network capacity is built based on such estimates so there is headroom for traffic growth. Also, R&E networks, like GÉANT, are overprovisioned by design, to ensure that bandwidth is no limitation to data exchange or processing and that additional traffic can be accommodated. While the overall increase of network capacity seems modest year on year, some significant updates of individual networks are happening, among them 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.

[35] As shown in Fig 5.13, the COVID-19 pandemic has interrupted the steady increase of R&E traffic. For the GN4-3N project, that meant a windfall as the network renewal could be delayed meaning that more advanced equipment can be procured.

6. SECURITY SERVICES

6.1. Introduction

Cyber security is a growing issue in any ICT environment and the R&E sector is no exception. As the central providers and enablers of ICT services for the research and education sector, NRENs regard security as a key competency and recently appointed security the number one topic strategic interest (GÉANT GA, March 23rd and 24rd 2021). In the past years, we have seen large number of (successful) major cyber security attacks on R&E institutions, both universities on research organisations.[36] In most of these cases the NREN is involved in one way or the other in controlling the incident and in sharing information with its constituents to prevent other victims succumbing to similar attacks. The pandemic caused an even larger dependency on online connectivity with the massive move to online education and remote working. Having a demonstrably trustworthy and secure service becomes inescapable.

Security for NRENs has two aspects:

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

The European Union also recognises the need for good security practice and is preparing additional legislation and directives to stimulate and regulate trust in digital infrastructures. This upcoming legislation will also affect Research and Education.

In general, there is a growing demand to show compliance in a number of areas of information security, one example being the General Data Protection Regulation (GDPR) which encourages everyone to do so with commercial suppliers that process privacy sensitive information. And while a number of NRENs have already achieved formal security certifications against international standards[37], so far they are a minority (see below). The data presented in this chapter illustrate the current efforts of the NRENs in these two broad areas. The data originate from the NREN Compendium survey, where NRENs provide data about their service portfolio, and from GÉANT's Partner Relations team and from the Trusted Introducer[38] program.

6.2. Organisational security

The data about 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][39].

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

[37] 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 9 NRENs reported having an ISO 27001 certification or similar.

[38] https://www.trusted-introducer.org/ : Services for security and incident response teams. The TI-program has a maturity scheme for CSIRT teams. Teams can be listed, accredited, or certified.

[39] Only some of the sub-topics defined in Security Baseline for NRENs can be assessed using the data available in the

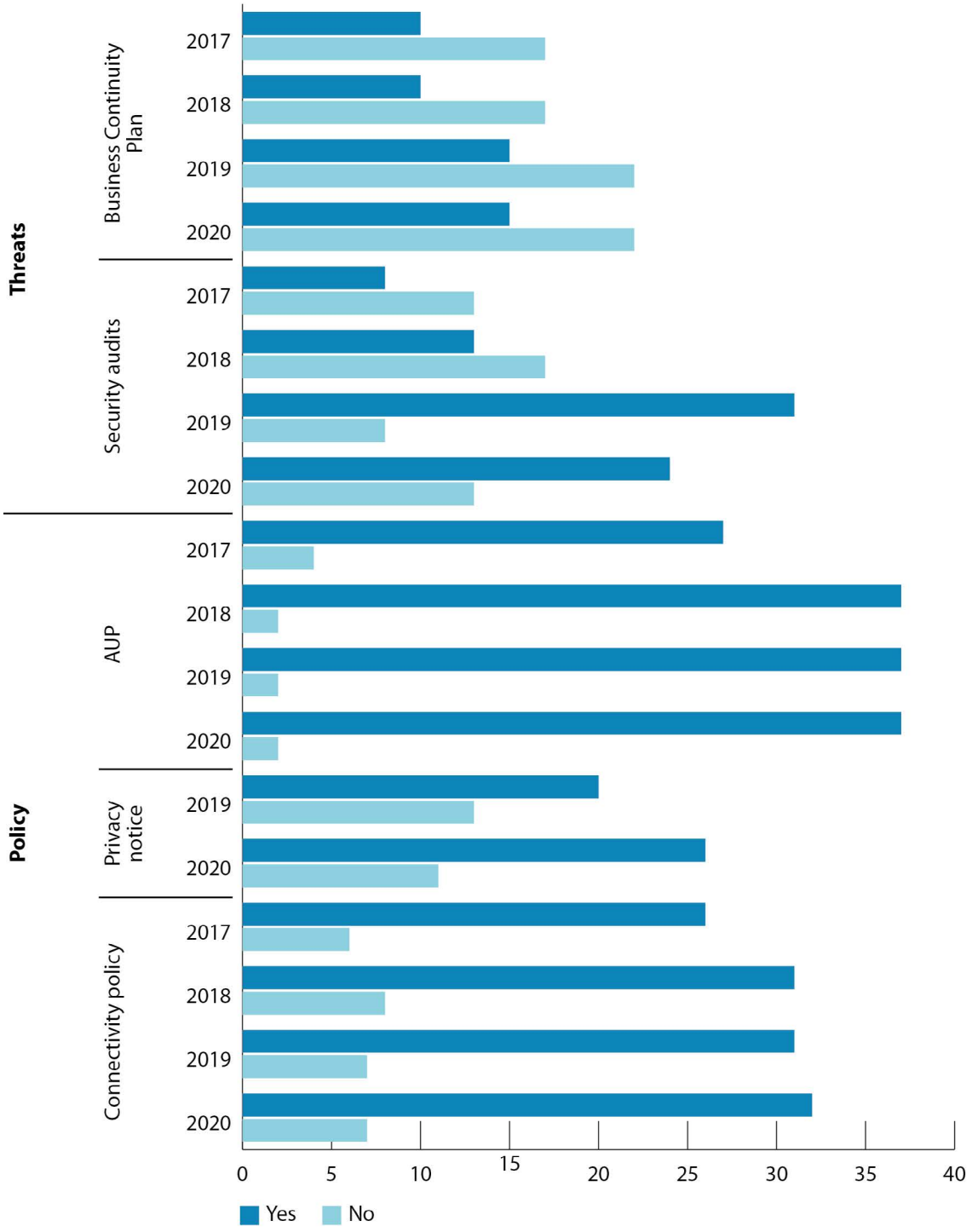


Figure 6.1: Development of the adoption of organisational security features by security area.
Not all data are available for all years. The number of surveyed NRENs was 43 for all years. Numbers missing from that count are due to non-responding NRENs. A privacy notice is now a legal requirement but was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

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.

An Acceptable Use Policy (AUP) and a Connectivity Policy are important security-related policies. The number of NRENs with such policies has increased since 2017; almost all NRENs have this in place now (see also the section on NRENs' Acceptable Use Policy in chapter 3).

Another important policy area is the adherence to the GDPR. 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 2020 about 60% of the NRENs stated having a privacy notice and 11 explicitly stated a lack thereof – which is an increase compared to 2019 but it still means that 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).

6.2.1. People

An important factor to improve IT security is training.[40] Some opportunities are provided by GEANT that offers some security training (TRANSITS, CLAW)[41] which some members are using, but there are many other training options available. Large strides have been made in terms of threat management. Most NRENs have some kind of security audit of their organisation (often according to international security standards such as ISO 270001) and most also have a computer security incident response (CSIRT) team. Those NRENs that do not have a CSIRT team usually have this function covered by closely associated organisations.

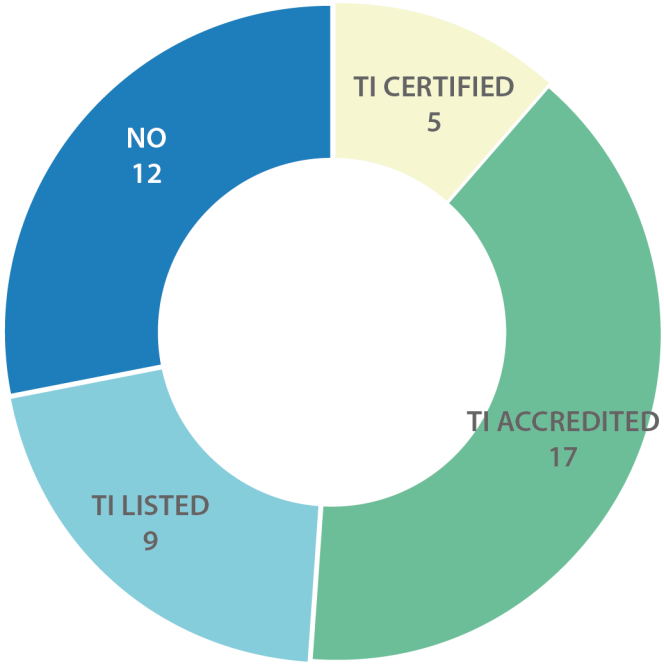


Figure 6.2: The numbers of NRENs with CSIRT teams.

[40] Unfortunately, there are no numbers available that would document how NRENs make use of training opportunities.
[41] 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 (link). However, it is not possible to track how many NRENs participate in such courses. CLAW is an annual workshop on Crisis management for NRENs carried out since 2017.

31 out of 43 NRENs have a CSIRT team that is participating in the Trusted Introducer (TI) program. In December 2020 5 CSIRT teams were certified, 17 were accredited and 9 were listed. Listed means that there is contact information listed in a central, public register. When a team hands in a basic set of documentation which are prove 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 prove a confirmed level of maturity as defined by the TI Security Information Management framework (SIM), by means of an external audit.

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

6.2.2. Operations

The only part of operations that the survey can touch upon is the use of security tools in ICT security. This is a very wide field, which ranges from the use of mundane applications such as anti-virus suites and firewalls, to more sophisticated measures such as integrity checkers or network segmentation. Again, responses of "no" in this survey most likely reflect the fact that tools are provided to the NREN by another organisation of which the NREN is a part, rather than that an NREN is operating without even the most basic security tools.

6.3. Security Services

NRENs run a number of services that support their customers' ICT security, as summarised in Figure 6.3 below.

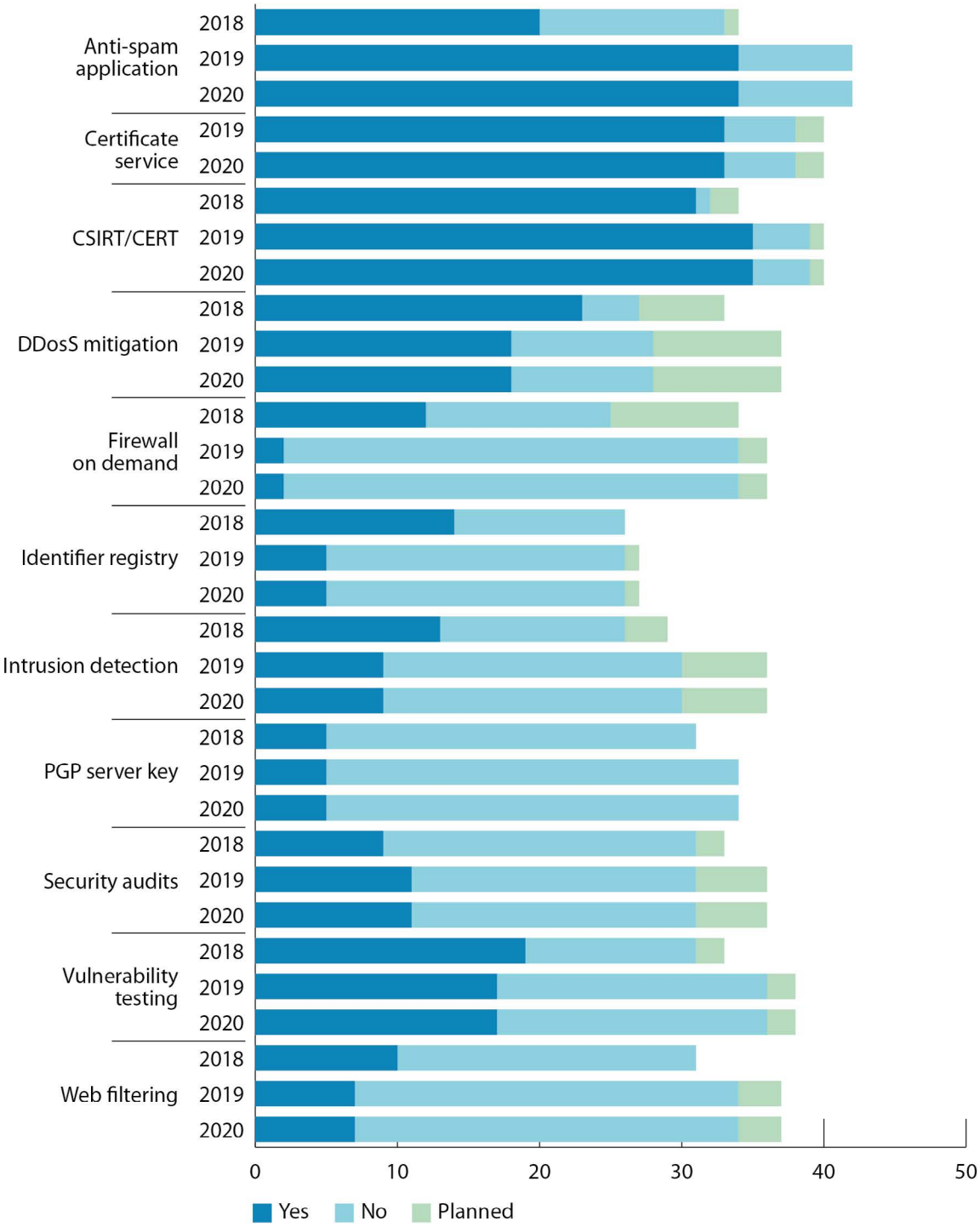


Figure 6.3: Security services offered by NRENs.

For 2020 we see that most of the services are quite stable in numbers. The decrease in the use of Firewall on Demand can be caused by integration of this function into DDOS mitigation solutions.

6.3.1. Upcoming services

One upcoming security service is not listed here: security operations centres. As this is a major effort and involves quite some resources, we now only see some of the larger NRENs active in this field such as JISC, Uninett, SURF and DFN. Some CSIRT services are gradually growing into SOC-services. However, only larger organisations can offer these services as they require significant manpower and financial resources.[42]

Another upcoming service is eduVPN. The pandemic has speeded up adoption of eduVPN both by NRENs and directly by universities. eduVPN gives the NREN the opportunity to offer state of the art, privacy preserving VPN services to large numbers of users.[43]

In recent discussions more interest is shown in Security intelligence sharing, DDOS mitigation, Business continuity and crisis management, as for example illustrated by the continuous attention for crisis management events like CLAW.

Some security-related services for the NREN community are provided by GEANT, importantly TCS (Trusted Certificate Service) which is currently used by 33 NRENs and Firewall on Demand (FoD), currently, used by 28 NRENs[44].

6.4 Security Community Groups

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

- **Special Interest Group on Information Security Management Special Interest Group (SIG-ISM).** SIG-ISM offers Chief Information Security Officers (CISOs) of NREN organisations the opportunity to share best practice and learn from each other's experience of safeguarding their networks against security incidents and threats. Taking part in SIG-ISM can help equip NRENs with the skills to manage information security within their research and education community. Between a third and a half of GÉANT NRENs are actively involved in SIG-ISM[45].
- **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.[46] 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

[42] Services like DDoS mitigation (or some Firewall implementations) require investments and dedicated solutions so it seems unusual to reduce it from one year to the next which is what the data in Figure 6.2 suggest. This highlights two possible problems. One is the methodology of the current survey. The questions about services don't allow for differentiation between different implementations. The second problem is the response rate to the survey. Not all NRENs respond to all questions every year which can generate anomalies in the data. We will strive to mitigate this in coming compendium surveys by improving the service questions to allow more detailed responses and by communicating to the NRENs the importance to provide consistent data.

[43] eduVPN is currently offered by 7 NRENs and piloted by 17 more.

[44] TCS is a bulk purchasing arrangement which allows participating NRENs to issue close to unlimited numbers of certificates provided by Sectigo a commercial certification authority (CA).

[45] For example, 16 NRENs were represented at the (virtual) SIG-ISM meeting on 21 April 2020: Belnet, CARNET, CESNET, CSC/Funet, DeIC, FCT|FCCN, Jisc, PSNC, RedIRIS, RENATER, RESTENA, RHnet, SUNET, SURF, SWITCH and Uninett.

[46] It is notable that members of TF-CSIRT include not only NRENs but also R&E institutions, governmental and commercial organisations.

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 for SIG-ISM, between a third and a half of GÉANT NRENs are actively involved in TF-CSIRT[47].

6.5. Summary

Guaranteeing security is an ongoing challenge involving requirements that change continuously. This change can be seen in the disappearance of some security-oriented services from a "typical" NREN portfolio, probably reflecting the commodification of some services. On the other hand, there is an increase in measures designed to prepare the NREN's organisational structure for security incidents, reflecting the crucial role of the NRENs in the security of the network and an increase in demand for sophisticated security services needed to counter the growing number of cyber-attacks. These sophisticated services require a high level of cooperation and information sharing.

[47] For example, 17 NRENs and NORDUnet were represented at the TF-CSIRT meetings in Cyprus in September 2019 and/or Spain in January 2020: ACOnet, ARNES, Belnet, CESNET, CSC/Funet, CyNet, DFN, FCT|FCCN, GARR, Jisc, LITNET, NORDUnet, RedIRIS, RoEduNet, SUNET, SURF, SWITCH and Uninett.

7. TRUST AND IDENTITY

In addition to the running of networks that connect machines to machines, trust and identity (T&I) services have become a core function of NRENs. These services enable use of identities within the research and education community, to authenticate, and authorise users 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[48].

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

- REFEDS
- eduGAIN
- eduroam
- InAcademia
- eduTEAMS
- Other T&I activities.

7.1. REFEDS

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

In 2020 there were 86 known research and education federations worldwide, a number that has increased steadily over the past years (see Figure 7.1). Most of them are operated by NRENs though at least some are brokered by other non-commercial entities. Within Europe, there are 42 REFEDS members and, except for one, they are operated by the NRENs[49].

[48] The data in this section come from the annual survey among 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 world-wide use, not just the use among the European NRENs. Differently to the rest of this report, numbers here report on global uptake and use.

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

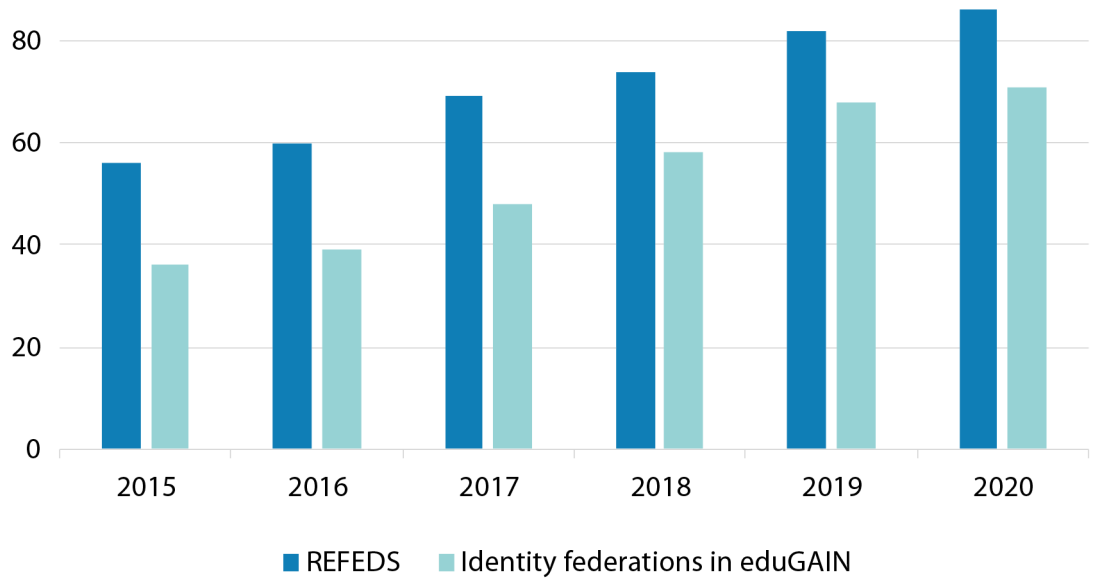


Figure 7.1: Number of known REFEDS (in blue) and number of identity federations using the eduGAIN service (orange) 2015–2020

Note that all identity federations in eduGAIN participate in REFEDS. 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. To measure the preparedness of the REFEDS to deal with actual incidents, the REFEDS survey monitors the adoption of the Security Incident Response Trust Framework for Federated Identity (Sirtfi). In order to balance the need to use relevant user information in authentications with the requirement to use this data sparsely, the survey asks about the implementation of recommended attribute release specifications for authentication. Finally, the survey monitors the use of multi-factor authentication to provide secure log-on procedures. These three aspects are explored in more detail below.

IdPs, SPs and Identity Federations

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

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

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

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

7.1.1.1. 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 in the past, but the latest REFEDS survey shows that only 17% of IdP and 10% of services in eduGAIN support it.

7.1.1.2. Attribute Release Specifications

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 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 Code.[50]

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

The release of attributes remains to date 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.

[50] A revision of CoCo started in 2020 to align it to the GDPR and to seek formal approval by the European Data Protection Board (EDPB). More information on R&S and CoCo can be found at [REFEDS_R&S] and [CoCo] respectively.

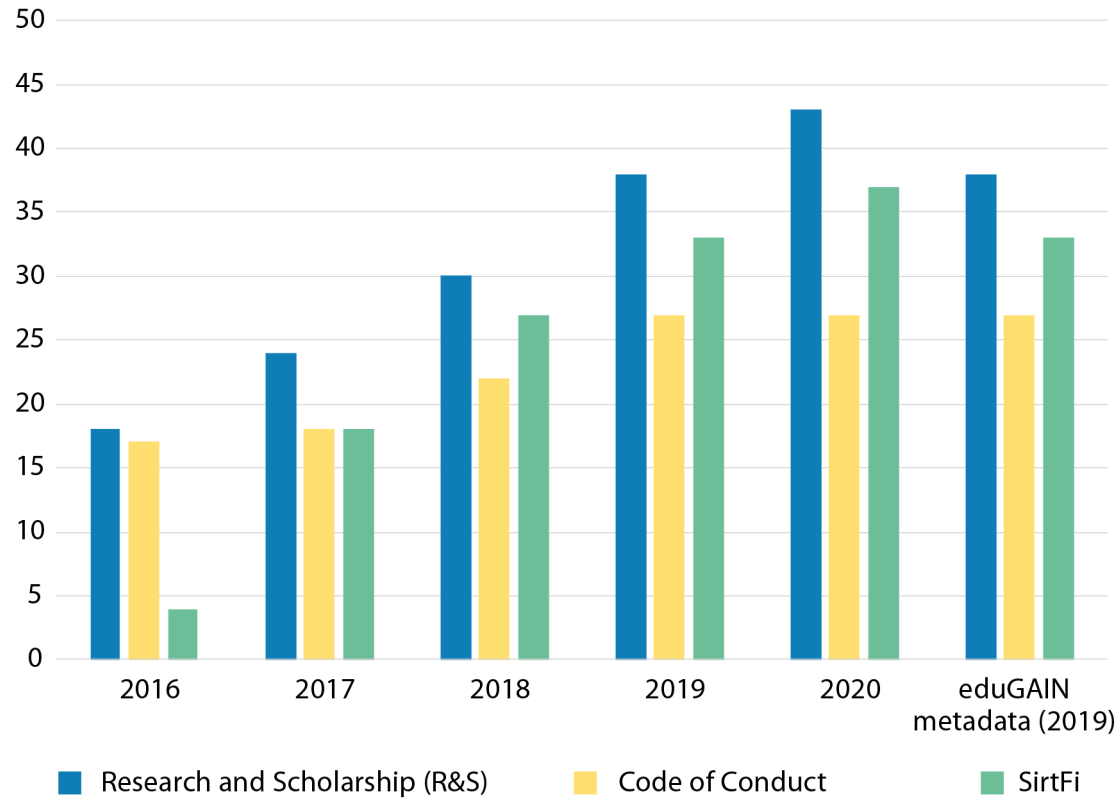


Figure 7.2: Compliance of REFEDS to policies

Shown are adherence to the Research and Scholarship attribute release schema, the Code of Conduct data protection requirements and the implementation of the Sirtfi security incident response framework. The numbers are the eduGAIN service. The response rates to the REFEDS surveys are less than 100%.

7.1.2. Identity Federation Budgets

Despite the core role that identity federations play, the budget allocated to them is still rather limited. Only 24% of federations answering the survey had a dedicated budget of 100K or more and there has been a downward trend in budget allocation. This is also reflected in staff allocated to the federations. The majority of the responding federations have only 2-3 people that are dedicated to the federation.

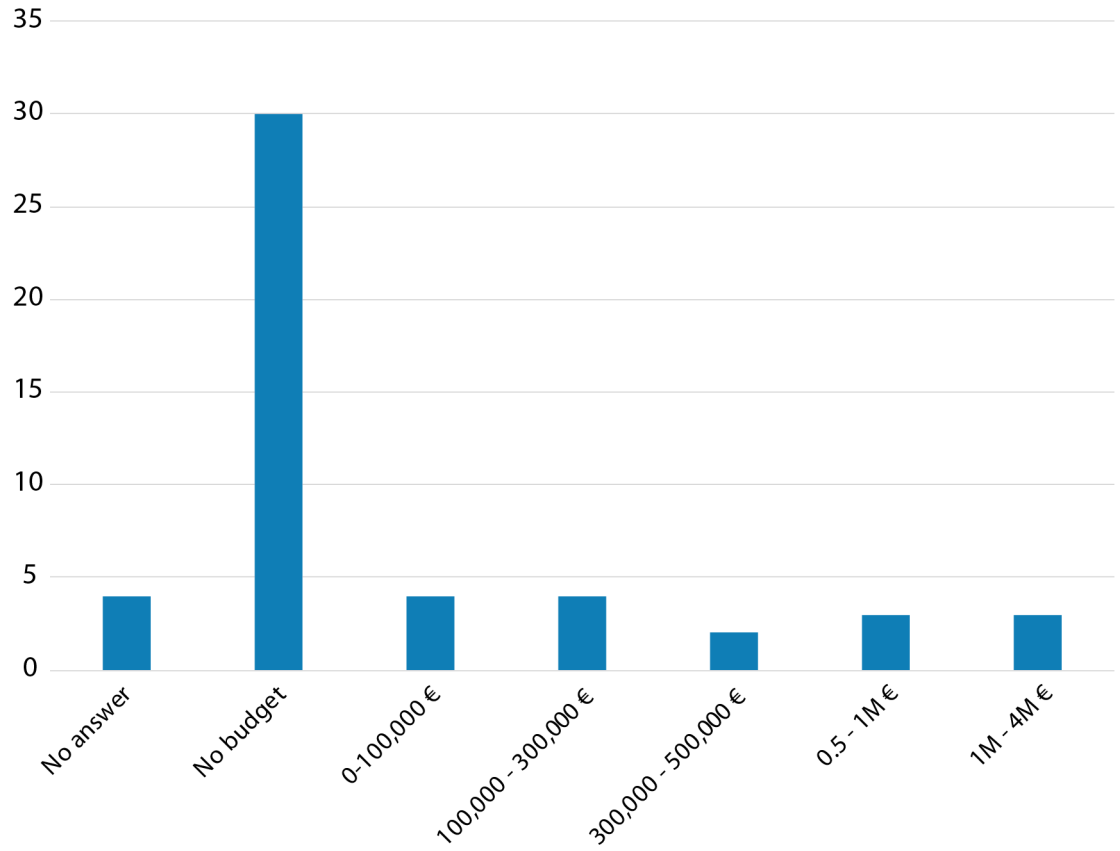


Figure 7.3: Budgets allocated to REFEDS according to the REFEDS survey
From the responses, it is clear that in many cases this core function has no budget of its own.

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 of participating federations. This allows institutions to offer a wider portfolio of services (those in eduGAIN): 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 7.4; 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 7,000 in 2020 (Figure 7.5). The service continues to mature and expand its core competencies by creating dedicated teams: in 2020 the eduGAIN security team was established with the aim to raise the eduGAIN overall security; a dedicated eduGAIN training team was established to curate the training material and deliver training as needed and the eduGAIN secretariat function (operating for several years) was formally defined. These complement the work done by the existing eduGAIN Support team.

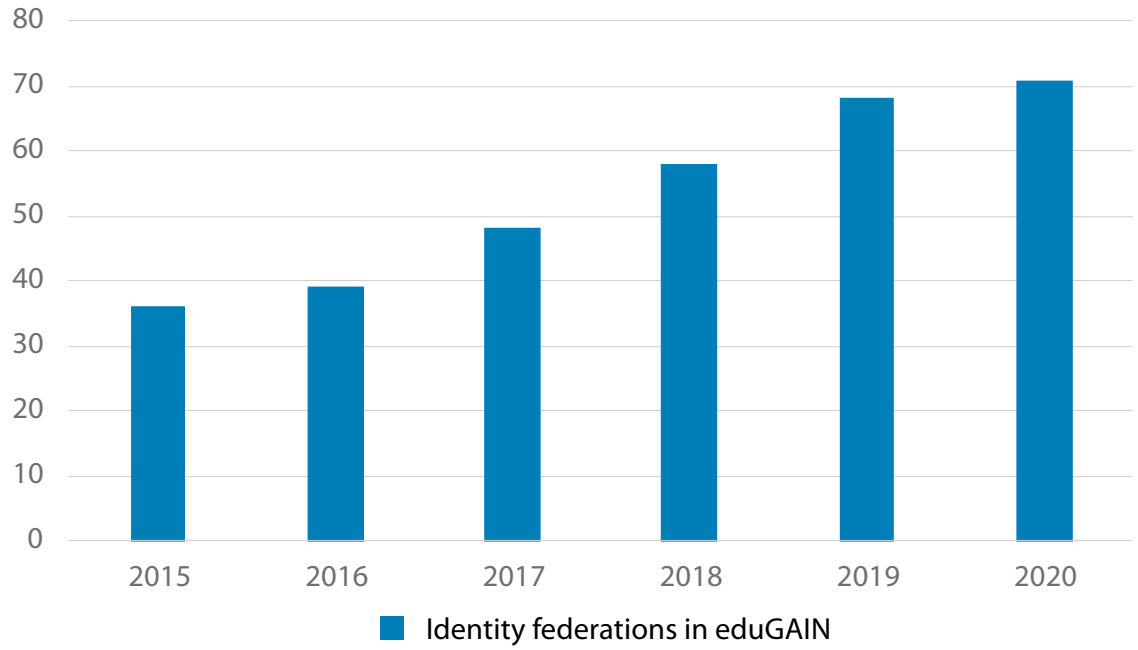


Figure 7.4: Number of identity federations using the eduGAIN interfederation service 2015–2020

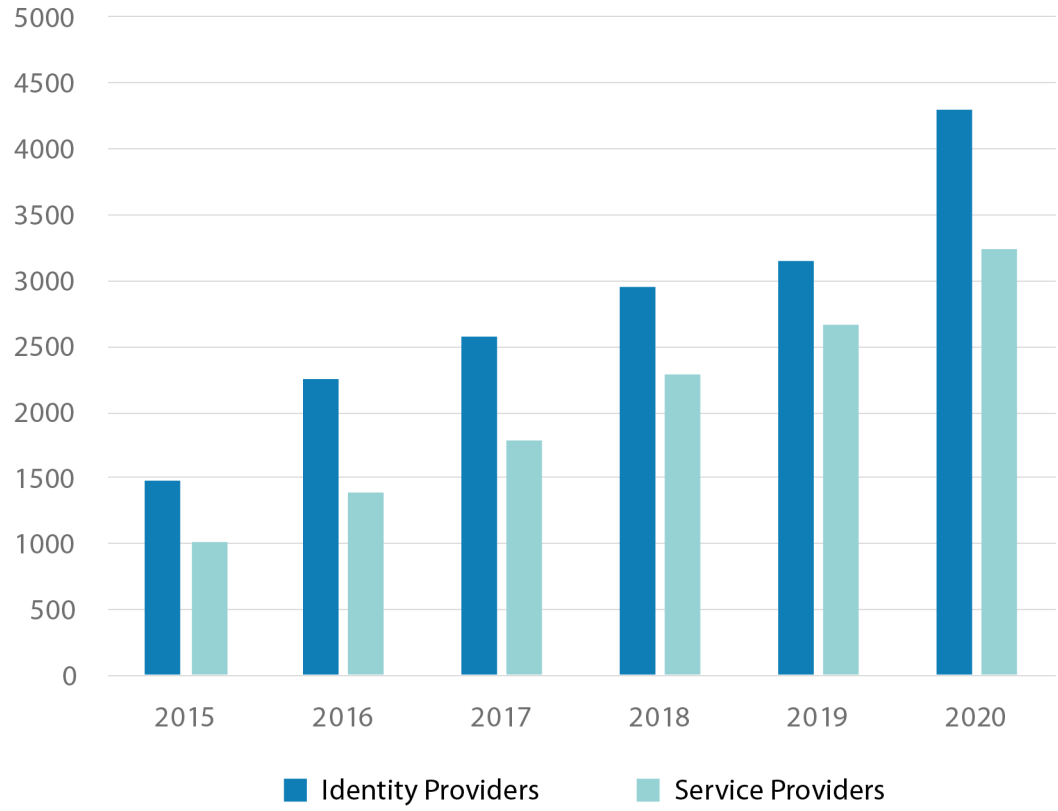


Figure 7.5: IdPs and SPs that are part of the eduGAIN service. *The numbers have increased considerably over the years, with varying but impressive growth rates (increase of IdPs 2015/16: 52%; 2016/17: 15%; 2017/18: 14%; 2018/19: 7%; increase of SPs 2015/16: 37%; 2016/17: 28%; 2017/18: 29%; 2018/19: 17%; , 2019/2020: 22%).*

To better address the service providers' expectations as to which attributes they will receive from the various identity providers, discussions have started in REFEDS about defining a baseline of requirements for identity federations; once this work is concluded, eduGAIN will require participating federations to comply with the baseline.

7.3. eduroam

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

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

eduroam is present in almost all European countries (exception: Bosnia Herzegovina), and its usage is growing. However, , the international traffic dropped significantly in 2020 for the first time since the start of the service, as illustrated by Figure 7.6. This clearly is an effect to the COVID-19 situation.

In 2020, eduroam continued engagement with OpenRoaming that is aimed to widen the footprint of eduroam access locations to spaces other than academic institutions and positively influence eduroam usage and traffic.

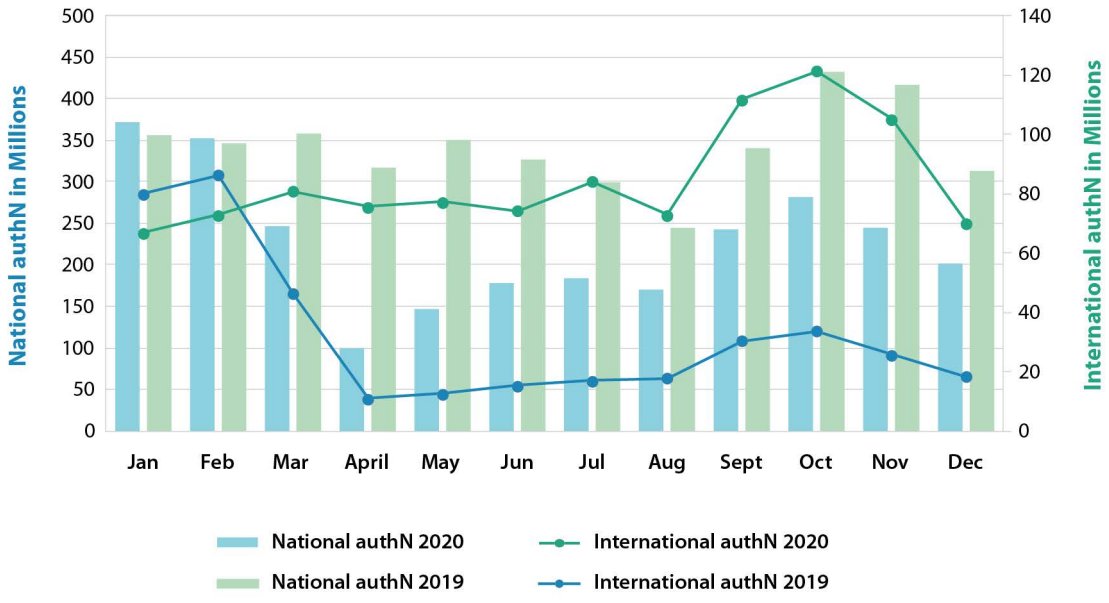


Figure 7.6: Authentications by eduroam month on month for the years 2019–2020
Comparing the two years is interesting as 2020 clearly illustrates the effect of COVID-19 on the use of campus networks. With universities moving much of their teaching activities online, much less physical presence of students and staff is reflected in reduced authentications via eduroam. The majority of authentications happens nationally while international authentications (e.g. visiting scholars, exchange students, etc.) make up about 20% of authentications in both years.

7.4. eduTEAMS

eduTEAMS [eduTEAMS] is GÉANT's implementation of the 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. The adoption of eduTEAMS grew significantly in 2020, 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 the picture below. The table shows the adoption of eduTEAMS by the end of 2020; in addition, eduTEAMS technology is also used by the GEANT Association.

3 out of 5 EOSC Clusters	High Performance Computing	Research infrastructures	NRENs
EOSC-Life panosc SSHOC	FENIX RESEARCH INFRASTRUCTURE LUMI eneic PUHURI	NEXTGEOSS EUROfusion europlanet LAGO	SURF

7.5. InAcademia

GÉANT and NRENs have worked together to launch InAcademia [InAcademia] , a service that validates only whether or not a user is a student. The aim is to better support service providers like merchants that have student-specific offers while still allowing users to protect their privacy. InAcademia leverages federated access to validate a user's identity. The result of the validation is transferred to the connected merchants that use this information to determine whether a user is entitled to a discount or offer. Since its launch at the beginning of 2020, InAcademia was launched in 2020 and by the end of that year was supported by 4 NRENs in Europe (RedIRIS, DFN, SURF, SUNET) so the service available through identity federations in Spain, Germany, the Netherlands and Sweden.

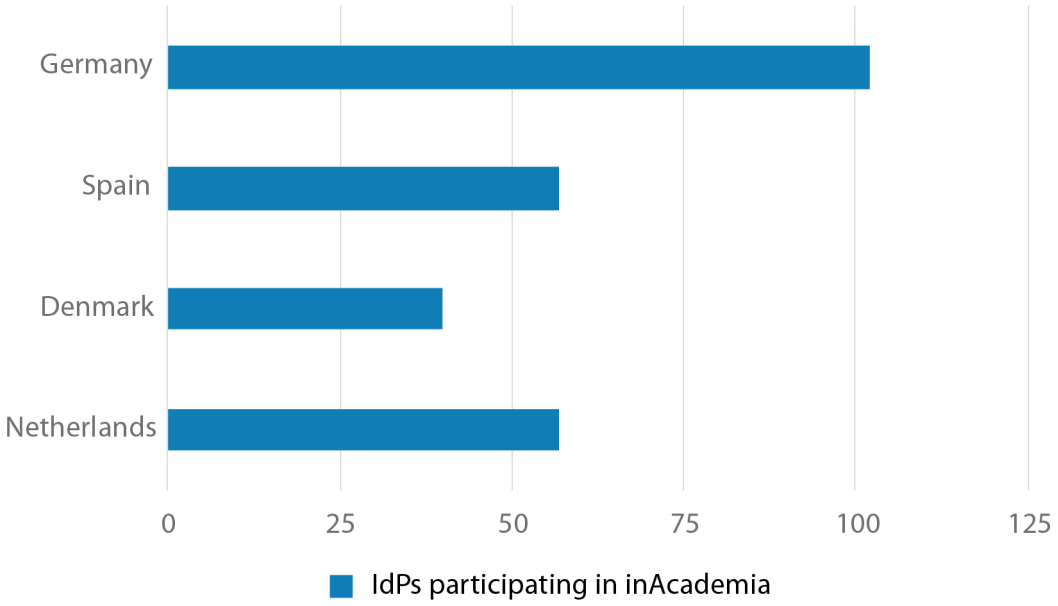


Figure 7.7: Numbers of institutions that participate in inAcademia
In 2020, InAcademia was used in 4 countries. The usefulness of the service depends on the number of IdPs (e.g. the home universities of students) that participate and in all participating countries, significant numbers of IdPs do so. Total number of institutions participating in InAcademia in 2020: 256.

It is anticipated that the number of participating countries/NRENs and institutions will increase in 2021 as the service grows.

7.6. Other Trust and Identity Activities

The numbers presented in the previous sections document a remarkable growth and maturation of the authentication and authorisation infrastructure in the research and education sector over the last five years. This increased deployment of federated access and national identity federations has enabled NRENs to explore a number of opportunities to build on these foundations, some of which are presented below.

7.6.1. AARC and eduTEAMS

The AARC Blueprint Architecture (BPA) [https://aarc-project.eu/architecture/] provides a set of building blocks for software architects and technical decision makers who are designing and implementing access management solutions for international research collaborations. The AARC BPA is maintained and updated via the AEGIS group [https://aarc-project.eu/about/aegis/], a spin off of the AARC project. AEGIS brings together representatives from research and e-infrastructures and operators of AAI services to share experiences in deploying an AAI that follows the AARC BPA and oversees the further evolution of technical and policy guidelines.

The AARC BPA, paved the way for the European Open Science Cloud (EOSC) AAI, which is being developed in specific groups and EC-funded projects. During 2020, GÉANT and the NRENs engaged significantly in the preparation of the EOSC-Future project, which started in 2021.

The EOSC Future project is a major undertaking with an ambitious goal, where Trust and Identity plays an important role. GÉANT leads the AAI Operations task and the Architecture Interoperability Work Package. eduTEAMS is one of the components of the EOSC AAI.

7.6.2. Student Mobility

Student mobility has always been an area of interest in the NREN community, namely the universities. The European Commission is supporting the digital transformation of the Erasmus programme via the European Student Card Initiative and via dedicated projects funded under the Connecting Europe Facility Programmes. GEANT and the European NRENs were particularly active in this space in 2020

GEANT and the NRENs participated in the MyAcademicID project [MyAcademicID] , which aimed to design and deploy a platform to enable electronic identification 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 and the European Student Identifier.

The project ended in 2020 and delivered MyAcademicID Identity and Access Platform (MyAID IAM), which is a production service as of November 2020. Such a quick approach was possible thanks to eduTEAMS technology that was used for MyAID IAM. The platform provides a single integration point to connect Erasmus+ services as well as 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.

A follow up project, the European Digital Student Services Infrastructure (EDSSI), started in September 2020. The EDSSI Project will work for two years to further evolve the MyAcademicID platform into the core production platform for student mobility with the aim to connect more relevant services.

7.7. Summary

All of the projects and initiatives discussed in this section have resulted in NRENs expanding their boundaries to think about wider trust and identity strategies, and to make their service offers more sustainable and attractive to researchers and students.

The trend shows that trust and identity is becoming a strategic area for the NRENs, particularly concerning engagement with the research infrastructure and the Erasmus community.

GÉANT supports the work in these areas in collaboration with the NRENs and via different frameworks, such as the GN4-3 project, MyAcademicID, other EC-funded projects to support eduroam and eduGAIN deployments to other regions, EOSC-related activities, REFEDS and Task Forces.

8. CLOUD SERVICES

8.1. Introduction

The Research and Education community is seeing a continuing digitalisation of work and life, mirroring the trends in the wider society these days. One cornerstone of digitalisation is an increased use of location-independent digital services, Cloud Services, which are enabled by the availability of ubiquitous, reliable, and high-performance network connectivity such as those offered by the NRENs, but also wireless and soon satellite networks. The advent of additional ingredients such as virtualisation and innovative business models like the "as-a-Service"[51] paradigm allow the securely partitioned and yet flexible sharing of remote IT resources by many independent users.

Cloud Services
There are three "flavours" of cloud service delivery:

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

Community Cloud, offered to a wider target "community", allows resource-sharing 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. Typically operated in large datacentres that benefit from economies 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.

8.2. Opportunities offered by Cloud Services

Location-independent usability of cloud services is a benefit to individuals and teams, not only during the COVID-19 pandemic. In addition, cloud-based services benefit from economies of scale as they are generally developed and operated by providers that can offer the same service to a large customer base. This makes it easier to optimise performance, reliability, and develop features for these services. Adopting cloud services benefits organisations by reducing the need to run local IT services and focussing 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 with shorter reaction times and at improved value for money.

8.3. Opportunities for NRENs

While institutions will surely continue to deliver specialised or sensitive services to their staff on their own, e.g., via a private cloud model, many individual users see a strong incentive to use available public cloud services for their work in an individual and ad hoc way. This may not be in the best interest of the home institutions, but these may also not feel in a position to

[51] Infrastructure-as-a-Service (IaaS); Platform-as-a-Service (PaaS); Software-as-a-Service (SaaS).

offer viable alternative services from within their own resources. By filling the role of the cloud competency centres, NRENs can play a valuable role in enabling and easing access to community cloud and public cloud services for their institutions.

8.3.1. Supply or facilitate Community Cloud Services

The NREN community members across Europe have a close affinity with infrastructure operation, like networks and datacentres. The community therefore has the expertise to build and offer community cloud services to cover a larger target audience than simply the staff of one institution. This may either take the form of an NREN or a key partner supplying a community data infrastructure centrally, or an NREN may create a marketplace for individual community cloud offerings from institutions willing to offer the use of their resources to peers. NRENs have joined their efforts and developed the first cross-border joint NREN-based containerised cloud software appliance (GÉANT Cloud Flow) from November 2020 as a common basis to build community cloud offerings on top of.

8.3.2. Brokerage or procurement support for Public Cloud

NRENs are also well placed to facilitate centralised, and therefore efficient, procurement activities for commercial Public Cloud services on behalf of their community. The pan-European cloud tenders performed by GEANT in 2016 and 2020 (OCRE) take this approach one level further and provide NRENs with ready-made Frameworks available in their respective countries. This activity allows participating NRENs to supply their institutions with framework contracts for in-demand cloud offerings with improved conditions. This in turn empowers central IT at institutions to offer the exact services that are being asked for at their institutions, but in a centrally managed and compliant way that also reduces the problems around shadow-IT.[52]

8.3.3. Be a Centre of Cloud Competence for Institutions

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

In total, the NRENs together with their IT partners at institutions can evolve their role from IT resource operators, to more full-service solution facilitators, and thereby keep their value visible to their user communities in an increasingly digitalised environment.[53]

8.4. NRENs' Cloud Service Portfolios

The cloud service portfolios fall into four categories: cloud storage, Infrastructure as a Service (IaaS), Software as a Service (SaaS) and Grid. Overall, 40 NRENs responded out of a possible 43, however not all of them answered all the questions. NREN responses about providing cloud storage, IaaS and Grid in 2020 were the same or mostly the same as in 2019 but varied in the previous years.

[52] Shadow IT refers to IT systems deployed by departments other than the central IT department of larger organizations (like Universities or Research Institutes), which has become very easy with the commodification of cloud services.

[53] This strategy, which NRENs agreed on in May 2019, implies to expand the scope of tenders beyond Infrastructure-as-a-Service type offers. Mainly this concerns SaaS type applications specific for Research and Education, but also general collaborative tools (e.g. Microsoft Office 365, Adobe, Zoom).

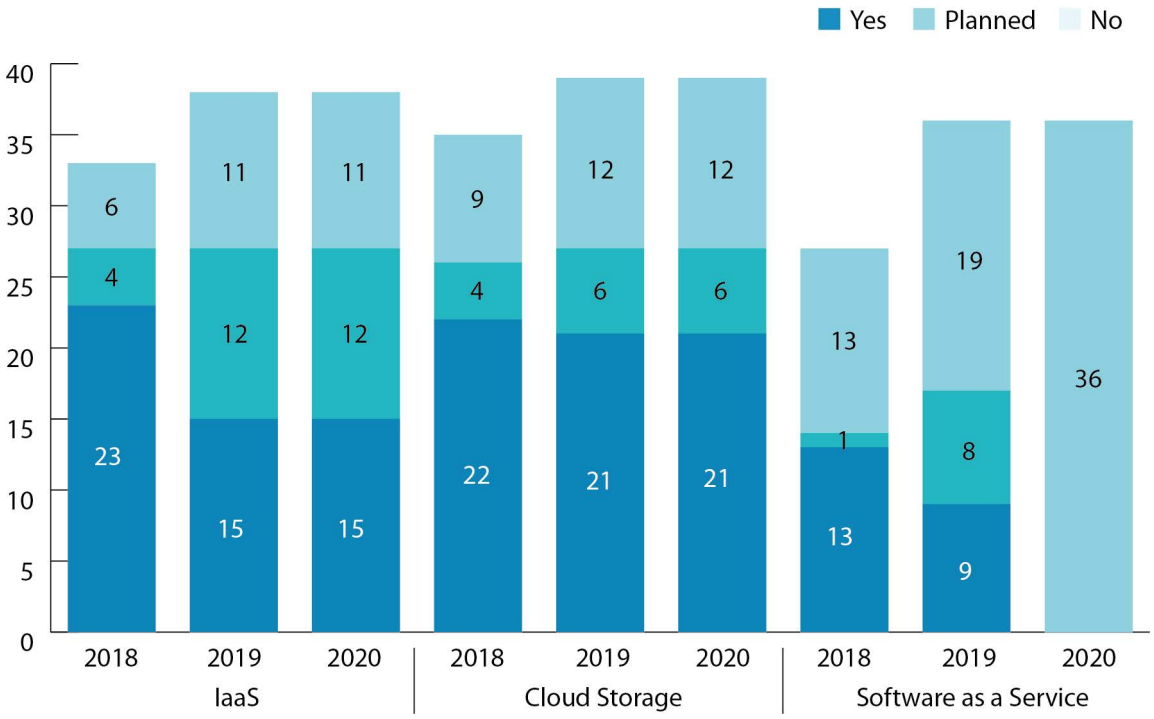


Figure 8.1: Availability of cloud services from NRENs. *The number of NRENs in the survey is 43. However, not all NRENs provide all information, therefore numbers not adding up to 43 indicate missing responses in the survey.*

8.4.1. Cloud storage

Cloud storage services are provided by the majority of North-Western[54]. NRENs and little less than half of the South-Eastern NRENs. 39 respondents from all 43 NRENs answered this question. From the respondents, 17 NRENs were from North-Western Europe and 22 from the South-East. Armenia and Belarus both planned cloud storage services in 2018, Georgia did not provide storage in 2018, but there are no later responses.

8.4.2. Iaas

Less than half of the respondents (15 out of 38) reported providing IaaS services to their connected institutions in 2020.[55] About a third of North-Western respondents (7 out of 17 respondents to this question) are planning to offer such services to their connected institutions, while a quarter already provide IaaS to their users. In contrast, half of all the South-Eastern respondents do provide IaaS services to their institutions. This appears as a mirror opposite of the digital divide for commercial public IaaS services so far described between North-Western

[54] The European sub-regions used here are based on the United Nations geoscheme system which divides the countries of the world into regional and sub-regional groups. North-Western means the western (Austria, Belgium, France, Germany, Luxembourg, Netherlands, Switzerland) and northern (Denmark, Estonia, Finland, Iceland, Ireland, Latvia, Lithuania, Norway, Sweden, United Kingdom) European countries, the South-Eastern means the Southern (Albania, Armenia, Croatia, Cyprus, Greece, Italy, Malta, Montenegro, North Macedonia, Portugal, Serbia, Slovenia, Spain) and Eastern (Belarus, Bulgaria, Czech Rep., Georgia, Hungary, Moldova, Poland, Romania, Slovakia, Ukraine) European countries.

[55] The Compendium questionnaire did not allow to differentiate between in-house developed services and brokered services. However, the responses very likely did not refer to brokered IaaS services as there has been a steady increase of the pan-European IaaS Framework consumption throughout the years 2017-2020 while the compendium survey suggests a decrease in cloud service offers over that time period.

and South-Eastern NRENs in the GÉANT 2016 IaaS Framework. The South-Eastern NRENs are more likely to provide their own in-house IaaS services instead of public cloud services.[56]

Another quarter of the respondents from the South-East were planning to introduce IaaS services for their users, which would continue this trend.

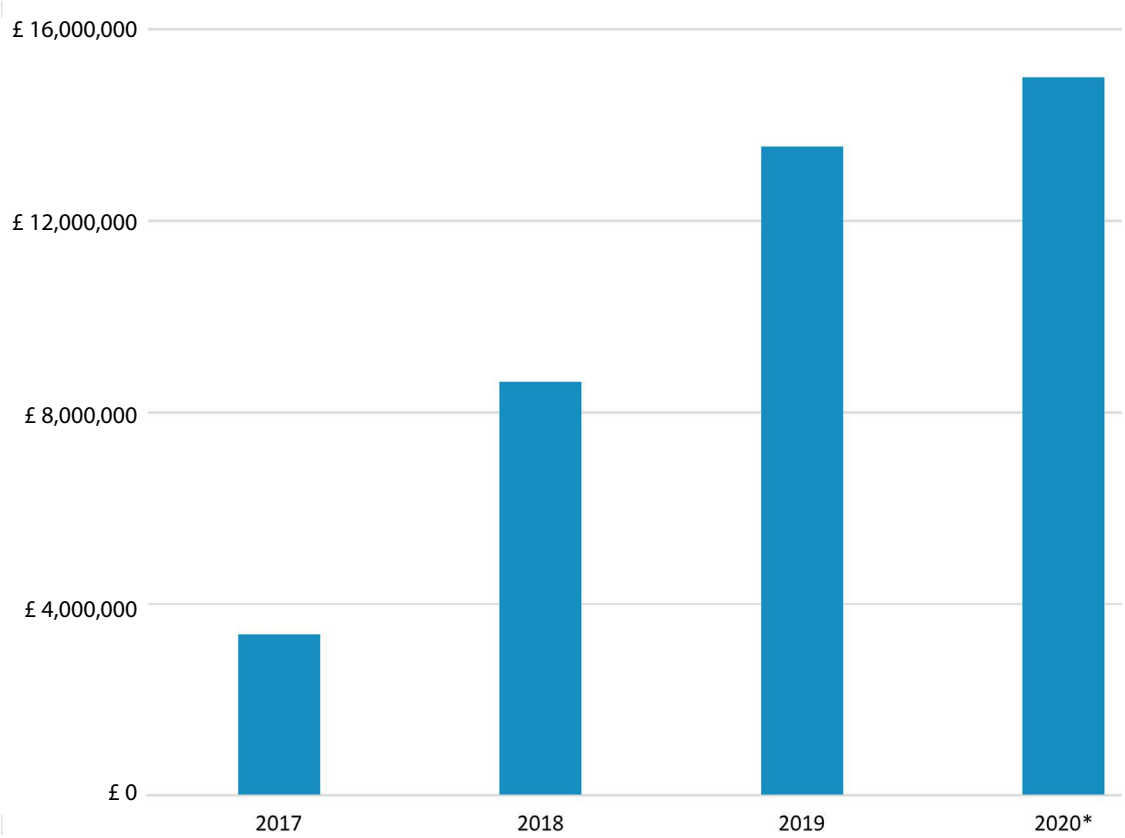


Figure 8.2: Cloud service consumption through the IaaS Framework
Note that the numbers for 2020 are not yet 100% verified.

8.4.3. SaaS

16 NRENs claimed to provide SaaS services to their users or planned to do so in 2019, while no NREN did so in 2020[57] This complete withdrawal from such services It seems likely to reflect the commodification of such services to a degree that there is no point in competing with commercial providers unless it adds value on top of the NREN services. Likely the focus of NREN in-house development has changed from SaaS to other services.[58]

8.4.4. Grid

Only about a quarter of the responding NRENs provide Grid (or High-Performance) computing services to their users and just 6 of the NRENs were planning to add such services to their portfolio in 2020. Compared to 2017 (the question was not asked in 2018), the overall

[56] ARNES, CESNET, CARNET, EENet, GRNET, IUCC, JISC, KIFÜ, MREN, PIONIER, RENAM, RENATER, SUNET, SURF, SWITCH and UNINETT.
[57] Many countries have national frameworks available, in some cases also created by the local NREN. For example, the Irish NREN HEANet has created a procurement framework for learning management systems (LMS).
[58] While some NRENs that in past years invested in building infrastructure to provide cloud services up to and including SaaS level have seen moderate uptake, several of these NRENs have recently moved to end in-house provision of generic community cloud services because of insufficient economic viability.

picture has drastically changed. In 2017 all of the responding NRENs (18) provided Grid services to their connected institutions, whereas in 2020 less than one third of them still do (10 out of 36 responding NRENs). It seems likely that this change is due to the paradigm change from Grid Computing to HPC plus Cloud Computing today and the trend of moving from in-house developments to brokered public IaaS services.

8.4.5. Cloud services by the NREN Service Matrix

The following four categories connected to clouds were found in the NREN service matrix 2020 that describe the service portfolios of NRENs:

- Storage & hosting - IaaS, SaaS, housing & co-location, hosting content delivery and email servers, cloud & grid storage, disaster recovery.
- Collaboration - mailing lists, web-hosting, project collaboration, Virtual Learning Environments (VLE) & plagiarism detection, Content Management System (CMS), database and e-portfolio services; scheduling, polling, survey and registration tools.
- Multimedia – web & desktop conferencing, event recording & TV/radio and event streaming.
- Some professional services – training & consultancy, procurement & brokerage, user portals

The most used (and planned) of these categories in 2020 were storage & hosting services - IaaS services, co-location & hosting services (email servers, content delivery), storage and disaster recovery; but also web-hosting and user portals (that belong to other matrix categories), as well as training and consultations, web and desktop conferencing, Filesender, mailing lists and VLE.

8.5. Conditions determining Cloud Services adoption

Despite the overall growth in interest, and rates of adoption, European research and education institutions are still somewhat reluctant to adopt cloud services centrally, and are often lagging behind other sectors, something that is also apparent in the very uneven usage of the IaaS Framework. There are several factors affecting this:

8.5.1. Driving Factors:

- End-user demand. The capability to quickly and flexibly deliver these digital experiences is becoming a competitive playing field for universities and research institutes looking to recruit top-level talent and to increase the excellence of their graduates and research output.
- Value In-house IT facilities would be billed as capital expenses (CAPEX) while funding for public cloud services usually are billed as operational costs (OPEX). A transition from CAPEX to OPEX allows a more flexible cost/value optimisation.
- Legislation and Regulations. The requirements of the GDPR 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 (see also the chapter on Security Services). This changes the value-calculation of on-premises versus cloud, especially when existing local datacentres reach their end-of-life and the necessary investment decisions for replacement are made.

- Multi-cloud. Data 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 functionality of multi-cloud-management solutions allows a model of central management and de-central use of diverse cloud services across an institution that matches the lived reality at a typical university.
- Scalability. As the gap between locally operated cloud services and hyperscale platforms widens, operators of local resources increasingly face scalability issues

8.5.2. Delaying Factors:

- Legislation and Regulations (GDPR).
  - There is still a perception that the risks of internal solutions are lower. Externally sourced services also require additional work to assure compliance - contracts must be checked and revised, and processes on the supply and demand side might have to be changed. This will reduce as similar requirements are placed on in-house services.
  - Shrems-II: The ECJ ruling invalidating the US-EU Privacy Shield agreement casts doubt on whether US Cloud Suppliers can refuse to deliver EU users' data to US authorities under search warrants under the US Cloud Act. To continue to abide by GDPR, EU users of US Cloud Providers now need to take additional measures to minimise the data-protection exposure of their data. This additional effort should be best practice in any IT environment, but the associated public uncertainty and doubt over the issue is slowing adoption of all cloud services, even in clearly legal use cases.
- Uncertainty and Risk Aversion. Many institutions are adopting a "me second" approach to cloud adoption – waiting for other institutions to be the leaders. The NREN community will continue to share user experiences and coordinate best practice examples to reduce the uncertainty of cloud adoption.
- Data-sovereignty concerns

8.6. Summary

The Compendium 2020 asked about cloud storage, Infrastructure as a Service (IaaS), Software as a Service (SaaS) and Grid services. Longitudinal data of the GÉANT Compendia (2017-2020) shows three trends in cloud services.

1. Virtual Machines/IaaS services are a very popular, and are comparable to other areas of NREN innovation such as DDoS protection, Identity inter-federation, or SDN. This is attested by a majority of NRENs either offering or planning to offer IaaS services.
2. Software as a Service has disappeared from the NRENs' service portfolios in 2020. In 2020 none of the respondents (36 altogether) provided these services anymore.
3. Grid services have decreased by half in the NREN service portfolios since 2017. It does not mean that these services are completely disappearing, however. More likely they have transformed into other forms and/or are labelled differently today, e.g., HPC.

9. EDUCATION

9.1. Introduction

A number of NRENs are offering services that are specifically designed to serve education. This is a development that reflects the increasing use of ICT tools in the teaching and learning communities. Educational institutions use a wide range of such education services supported or provided by NRENs, some of which are of strategic importance to them, ranging from learning management platforms, student administration systems to learning analytics and online assessment systems. As ICT experts, NRENs are well placed to support these needs in various ways. Over the last three years, GÉANT has created an overview of such activities among European NRENs in this domain.

Due to the corona pandemic, the demand for offering and developing educational services has increased, and the NRENs has become an important player in the accelerated digitalization puzzle.

This section gives an overview of the activities of NRENs in supporting education, detailing how many and which services they offer, on what maturity level those services are and also gives a brief overview of the services. This section is based on the work of the Task Force on Educational Technologies (TF-EDU)[59], in particular on two surveys among NRENs about their activities in education, carried out in 2020 and 2021.

9.2. Methodology

The latest surveys carried out by TF-EDU defined twelve service types (see Educational Services below) and asked the NRENs whether their service offering included any of these education-related services. They also asked about the maturity level of the services on offer. In this section, these data have been condensed into mature service-level services (on offer) and new services in initiative or project phase (in development). The mature service-level[60] also includes services that are being phased out but are still being offered in a reduced version.

Among other questions, NRENs were asked which services are provided to the different levels of education. In the compendium we only present a condensed version of the complete survey implemented.

This section seeks to give an overview of the current state of the educational activities among NRENs, however it also presents a comparison of their results from the previous year to reflect on the effect of the COVID-19 pandemic.

We have approached the dedicated person at the NRENs where there was such a distinct function available.

[59] The Task Force on Educational Technologies (TF-EDU) is formed of members of the NREN community across Europe. It aims to gather information, discuss and develop tools and best practices to address the common issues faced by NRENs with regard to their educational services and activities. It serves as a strategic platform for the creation of an overview of the educational technologies landscape in the NREN community and beyond.

[60] A "service level" or "on offer" service refers to an integrated service offered by the NREN which is available to all customers. The label "in development" fuses two categories: the surveys distinguished between "initiative level" and "project level" services. Initiative level meant an informal joint exploration of an idea by an expert group. In most cases, there is some investment to explore the initiative further, supporting the NREN's participation in the initiative. Project level meant a formal joint follow-up of an initiative with a project owner and a budget.

9.3. Education Services

Figure 9.1 provides an overview of the different services during 2021 and how common they are.

Video conferencing tools offering is the most common service. This is probably not very surprising, as for many NRENs it is a service that has been offered for a long time, and can therefore be repurposed for the specific needs of the education sector, making this a relatively easy service to establish and to scale up to meet the demand. The need for video conferencing has also increased tremendously during the past year due to the COVID-19 pandemic. Another relatively common service is digital learning environments (DLE), and the large number of DLE services in development suggest there might be more to come. T&I services for education is also offered by many NRENs, and it's maturity by NRENs has grown over the last year, more NRENs are providing it as part of their offering. The other services are less common but catching up.

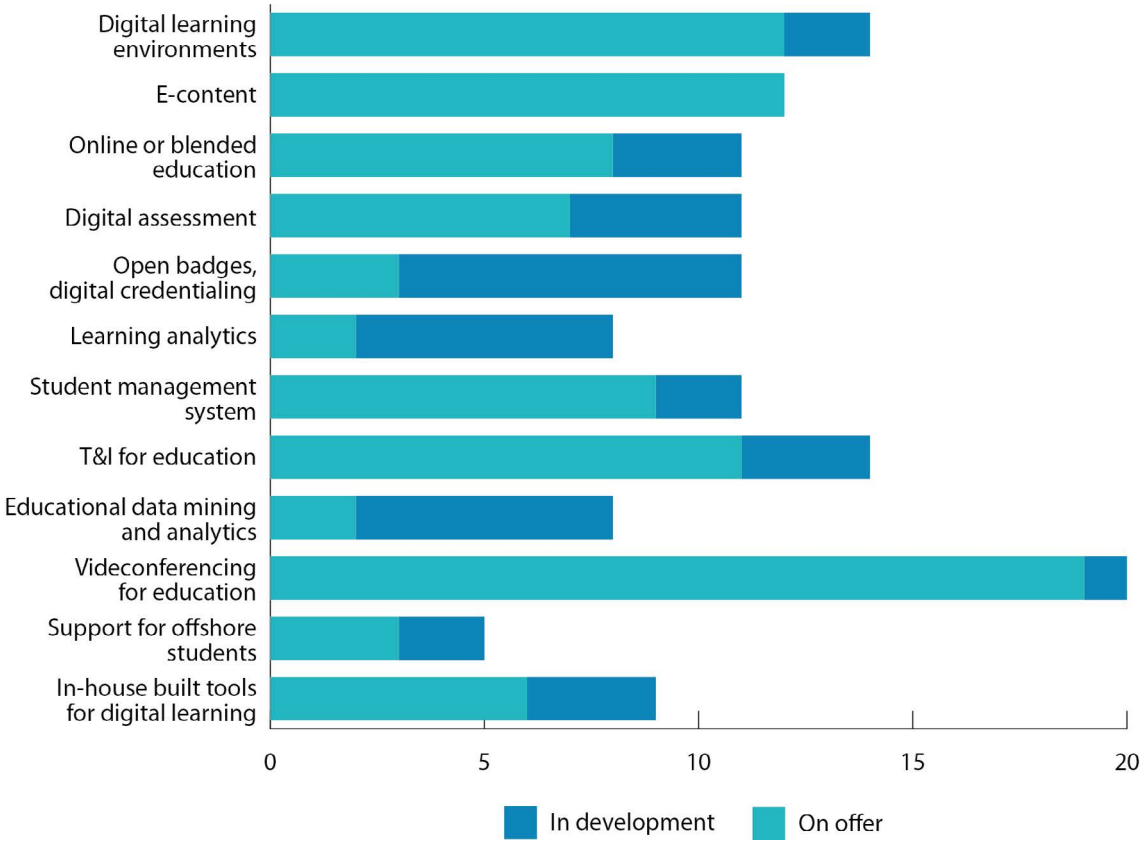


Figure 9.1: Education services provided by NRENs as well as services in development

9.4. NRENs' Education Portfolio

Figure 9.2 shows that the majority of NRENs offer services that specifically target education, though the extent of their commitment differs. Those NRENs who responded that they do not provide educational services provided the reasoning of either not having it in the remit or mandate of the NREN or they lack the capacity to introduce them.

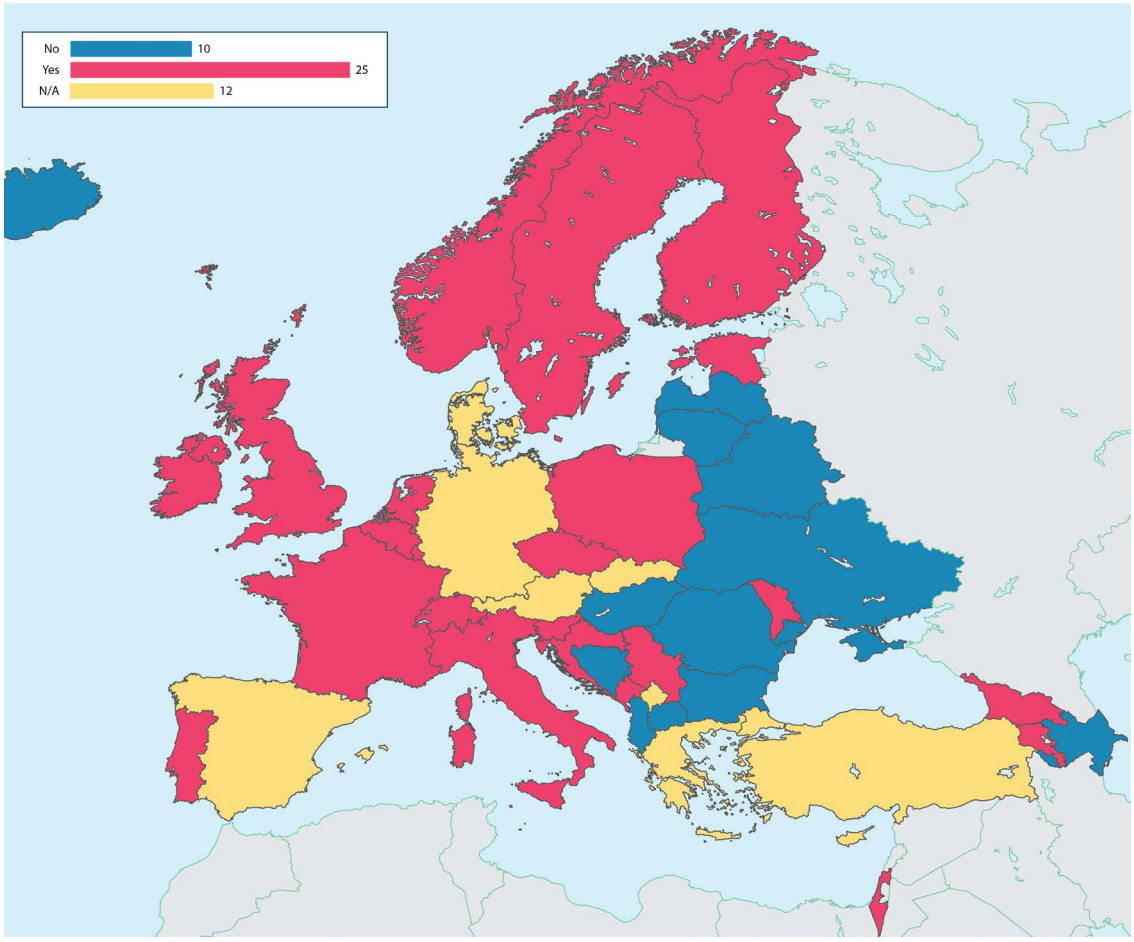


Figure 9.2: Map of Europe with NRENs that show which NRENs offer at least one service that specifically aims to support education. *The inset shows a summary of how many NRENs offer at least one education service (N/A mean that the NREN in question did not respond to the survey).*

The number of such services offered varies considerably between NRENs, as is shown in Figure 9.3.

These numbers make it clear that this is a well-established area of activity for many NRENs.

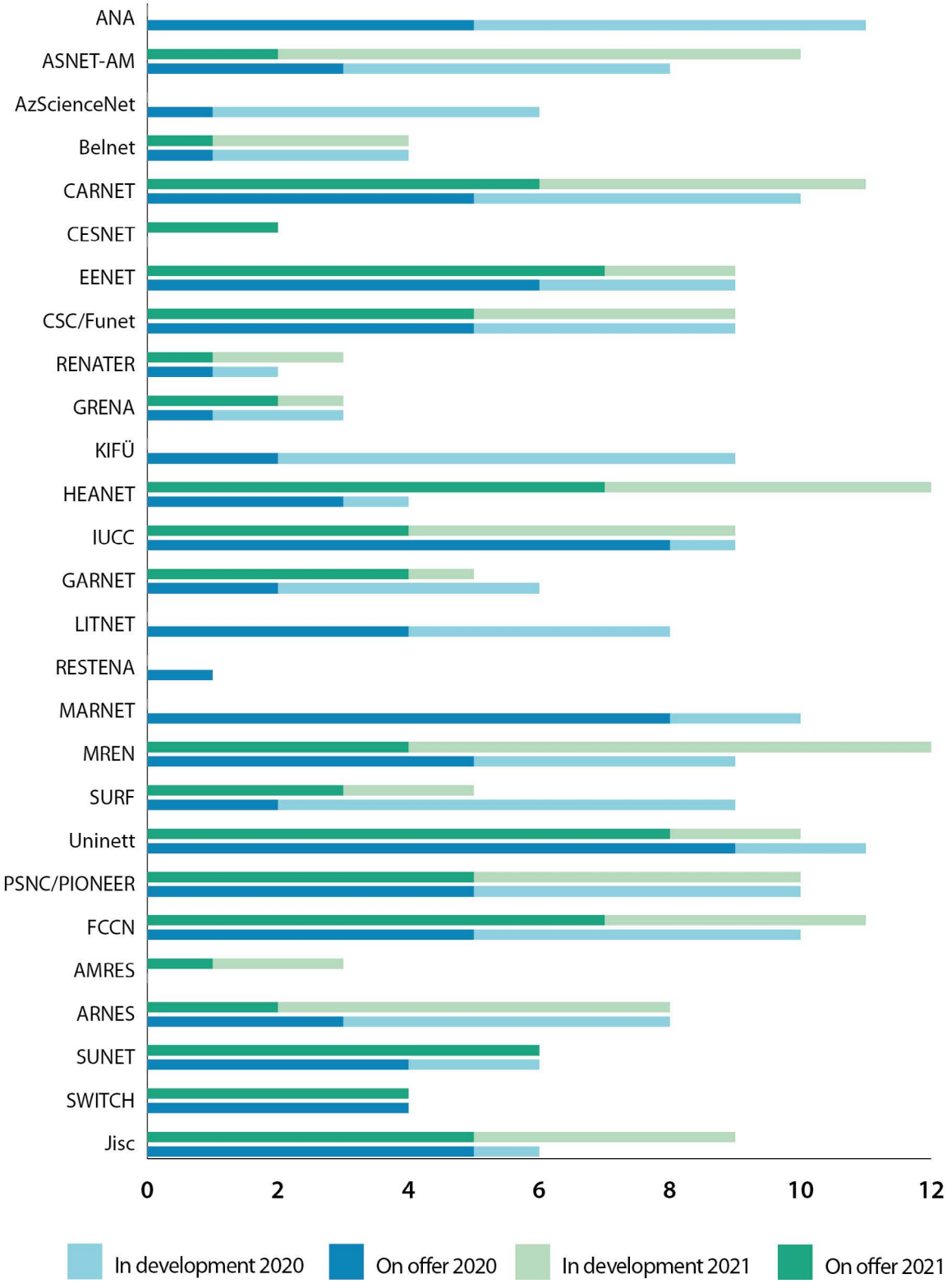


Figure 9.3: Number of education services provided and in development, by NREN

This is further enforced by the large number of NRENs that are developing new services for the sector, as shown in Figure 9.3, which might become part of the NRENs' service portfolio in the near future. We have extended the geographic area for this year's survey to invite global NREN partners to respond.[61]

Finally, Table 9.1 gives an overview of the service portfolio of the individual NRENs.

	Digital learning Invironments	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
ASNET-AM	X									X		
Belnet										X		
CARNET	X	X	X				X	X		X		
CESNET								X		X		
EENET	X	X		X	X		X	X		X		
CSC/Funet		X		X			X	X		X		
RENATER												X
GRENA				X						X		
HEANET	X	X					X	X		X	X	X
IUCC	X	X	X							X		
GARNET		X	X				X			X		
RESTENA												
MREN	X	X		X						X		
SURF		X			X			X				
Uninett	X	X	X	X			X		X	X		X
PSNC/PIONEER	X	X	X							X		X
FCCN	X	X	X				X	X		X		X
RENAM												
AMRES										X		
ARNES	X									X		
SUNET	X			X			X	X		X	X	
SWITCH		X			X			X		X		X
Jisc		X	X			X		X	X	X		

Table 9.1: NREN portfolios of currently provided education services

[61] Participation from non-European NRENs 2020; Belize, Benin, Bhutan, Cote D'Ivoire, Ghana, Nigeria and for 2021; Bangladesh, Brazil, China, Ecuador, Jordan, Malaysia, Mexico, Lebanon, Morocco, Pakistan, Tanzania, Somalia. Participation from non-European NRENs were not included in this overview.

9.5. Summary

The responses to the 2021 survey reflect the effect of the COVID-19 pandemic and how rapidly the education service portfolio of the NRENs evolved in the past year. The rapid increase in demand for remote learning has resulted in a significant increase and scale up of video conferencing services by NRENs to their educational institutions. Many NRENs also expanded and scaled up their offer of Digital Learning Environment solutions as a service and even some NRENs that last year considered to phase out these services maintained them in response to the increase in remote education needs. Another similarly growing and maturing area is e-Content where a number of development projects turned into service offerings and initiative level activities have been promoted to projects.

In summary, 2020 has seen a large expansion of the educational service portfolio as many planned services have gone into production, very likely driven by the demands created by the rapid increase of online teaching that has taken place over the past year. With so many supporting services in production, there is now probably a need to consider how to shape education going forward, both nationally and globally, as the world resets itself.

The developments in the area of educational IT services are part of the continuing and important process to critically re-examine the role of NRENs – how much can and should they expand beyond their core business of connectivity and related services [NRENs functions and organisational practice, 2014]. Education-specific IT support is clearly both a need of many NREN customers and close to the NRENs' area of expertise so NRENs need to evaluate and reflect whether to expand their focus correspondingly. However, as this chapter shows, NRENs take different approaches toward educational services – very much depending on their circumstances.

Finally, it should also be mentioned, that the scaled up conversion towards digitalized education creates technological and legal issues that this chapter hasn't touched upon, namely that the enormous increases in the amount of data handling require an increased focus on Trust & Identity, privacy and security for education services.

10. OUTLOOK

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

As the NRENs' business is providing infrastructure, many changes are slow. Nonetheless, changes do happen, and to track and present them the right parameters need to be assessed. Therefore, a project such as the Compendium needs to expand its scope when necessary, to document developments that shape and alter the ways NRENs are serving their user base. Currently, educational services see a rapid development. This has certainly been accelerated by the COVID-19 pandemic with required IT tools to support remote education but was a recognizable trend before that. Another trend is the increasing involvement of NRENs in pan-European research infrastructure projects like EOSC, PRACE or EuroCC. As providers of national research and education networks, NRENs are natural partners for such initiatives that facilitate international collaboration in science continues to grow and the EC aims to create pan-European research structures. EC involvement. In a third example T&I services which have long been core service provided by NRENs allowing users within the research and education community to authenticate and access resources see use beyond their original domain. Increasingly, T&I infrastructure is leveraged to be used in adjacent areas like student discounts or study credentials. Both developments are reflected in the Compendium.

Two out of the three trends presented above are documented by using data that come from outside the compendium survey itself and complement the latter. This approach that has been used throughout the compendium and future iterations of the Compendium report will be similarly consider to include any kind data that will be useful to understand the NREN community – and useful for the community to know about.

This means, of course, that the annual Compendium survey will develop over time to gather relevant data; for example, more effort will be dedicated to documenting the service portfolio of NRENs which means that the corresponding section of the survey will see a reorganization to allow a more differentiated response. To further future-proof the relevance of the Compendium, while still being based on the annual Compendium survey, future issues will likely draw on additional data from more non-core data sources, both internal GÉANT project sources (as has always been the case) and publicly available external sources. The current Compendium has already drawn on socio-economic data to provide more context, and on the results of two service-specific surveys; where this approach promises to provide additional insights, it will be continued.

APPENDIX A
CONTACT LIST

Table A.1 below lists the NRENs that responded to the 2019 Compendium survey, and contains links to their respective websites.

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	www.uiip.bas-net.by
Belnet	Belgium	www.belnet.be
BREN Bulgarian Research and Education Network	Bulgaria	www.bren.bg
CARNet Hrvatska akademska I istrazivacka mreza	Croatia	www.carnet.hr
CESNET CESNET, zajmove sdruzeni pravnickych osob	Czech Republic	www.ces.net

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

MREN Javna Ustanova Univerziteta Crne Gore Podgorica	Montenegro	www.mren.ac.me
KIFÜ (formerly NIIFI) Kormányzati Informatikai Fejlesztési ÜgynökségNemzeti	Hungary	http://kifu.gov.hu/kifu/
NORDUnet (Representative Member)	Denmark, Finland, Sweden, Norway, Iceland	www.nordu.net
PSNC Poznan Supercomputing and Networking	Poland	www.man.poznan.pl
RedIRIS/RED.ES Entidad pública empresarial RED.ES	Spain	www.rediris.es
RENAM Research and Educational Networking Association of Moldova	Moldova	www.renam.md
RENATER Groupement d'Intérêt Public Réseau National de Télécommunications pour la Technologie, l'Enseignement et la Recherche	France	www.renater.fr
RESTENA Réseau Téléinformatique de l'Education Nationale et de la Recherche	Luxembourg	www.restena.lu
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
SURFnet[1]	Netherlands	www.surfnet.nl
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 2019 Compendium survey respondents

[1] In 2020, SURFnet began a series of organisational and name changes, and is now known as "SURF".

APPENDIX B
COMPENDIUM AUTHORS

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

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

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

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

Tom Fryer, Head of International Relations (GÉANT), joined GÉANT as a member of the International Relations Team in 2008. He leads the team that support GÉANT's relationships with R&E networking partners in other world regions and manage 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.

Nataša Glavor, Assistant Director of the Croation National CERT (CARNET) works on data analytics, data lakes and databases, and learning analytics system in the data management team at CARNET. During her career at CARNET, she fulfilled a number of roles, starting in the in the computer security incident handling team where she became Assistant Director for Computer Security in 2004 and helped to develop the CARNET security program 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 program 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.

Gyöngyi Horváth, Community Support Officer (GÉANT). Gyöngyi was born in Hungary and graduated from the University of Miskolc in 2002, with a Masters Degree in Sociology. Working with the community for over a decade and being responsible for organizing the community's annual conference TNC she gained view on many future initiatives. GÉANT recognized the importance for our community to address the needs of students and educators with it 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.

Birgitta Hemmingsson, educational developer at Mid Sweden University (MIUN). Birgitta is engaged in educational development within higher education, and has been working with educational services and technology development, as well as community building for 10 years. She also was the chair of the Swedish Network for IT in Higher Education (ITHU) for four years. She is also a developer of sustainable digital conferences. Birgitta worked as Product Owner of media services for the Swedish NREN, Sunet, for several years, and it was within that work she became a member of the NREN educational expert group, that later transformed to TF-EDU.

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

Sylvia Kuijpers, community manager for research at SURFnet (SURF), Sylvia is involved in research engagement for the Dutch research community in collaboration with SURF and the SURF organizations SURFsara and the Netherlands eScience Center. Previously she has worked at Utrecht University as a PhD Candidate on cancer research.

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

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

János Mohács, Head of Research and Development (KIFÜ). At KIFÜ, János Mohács 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 involveed in major projects like 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 GEANT 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.

Maria Ristkok, Work Package Leader for the GN4-3 project cloud activity (WP4) (EENet), Maria has ca 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 member of SIG-Marcomms Steering Committee. Maria has a MA in Social Sciences with a focus on Communication Management. Maria's great grandpa was announced the holy hieromartyr (saint) of the Greek Orthodox Church in 2012, establishing a spiritual cloud connection as well.

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

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

Daniel Wustenberg, 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.

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GLOSSARY

AAI
Authentication and Authorisation Infrastructure

AARC
Authentication and Authorisation for Research and Collaboration

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

AUP
Acceptable Use Policy

AW
Alien Wave

BPA
Blueprint Architecture

CCNP
Cisco Certified Network Professional

CERN
European Organisation for Nuclear Research

CISO
Chief Information Security Officer

CoCo
Code of Conduct

Compendium Advisory Board
The Compendium Advisory Board shapes the compendium initiative by reviewing and updating the survey and publication process. It meets regularly to discuss issues around the compendium. Its members are recruited from the NREN community and the GEANT compendium team.

CSIRT
Computer Security Incident Response Team

DCI
Data Centre Interconnect

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

DG DEVCO
EC Directorate-General for International Cooperation and Development

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

DTN
Data Transmission Network

DWDM
Dense Wavelength Division Multiplexing

EaPConnect
Eastern Partnership Connect

EB
Exabyte (1018 bytes of data)

EC
European Commission

eduID
Educational ID

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

ENISA
European Union Agency for Cybersecurity

EO
Earth Observation

ESFRI
European Strategy Forum on Research Infrastructures

ExPaNDS
European Open Science Cloud Photon and Neutron Data Services

FTE
Full-time equivalent

Gbps
Gigabits per second

GDP
Gross Domestic Product

GDPR
General Data Protection Regulation

GN4-2
GÉANT Network 4 Phase 2 project, part-funded from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No.731122

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

H2020
Horizon 2020

IaaS
Infrastructure as a Service

IdP
Identity Provider

IETF
Internet Engineering Task Force

IP
Internet Protocol

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

ISP
Internet Service Provider

IX
Internet Exchange

LMS
Learning Management System

MEF
(formerly) Metro Ethernet Forum

MEF-CECP
MEF Carrier Ethernet Certification Program

MFA
Multi-Factor Authentication

MIUN
Mid Sweden University

MPLS
Multiprotocol Label Switching

NREN
National Research and Education Network

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

OEO
Optical to Electrical to Optical

OLS
Open Line System

OTN
Optical Transport Network

PaaS
Platform as a Service

PaNOSC
Photon and Neutron Open Science Cloud

PB
Petabyte (1015 bytes of data)

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

R&E
Research and Education

R&S
Research and Scholarship

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

RO
Roaming Operator

SaaS
Software as a Service

SIG
Special Interest Group

SIG-ISM
Special Interest Group on Information Security Management

Sirtfi
Security Incident Response Trust Framework for Federated Identity

SLA
Service Level Agreement

SP
Service Provider

T
Task

T&I
Trust and Identity

TB
Terabyte (1012 bytes of data)

TF
Task Force

TF-CSIRT
Task Force on Computer Security Incident Response Teams

TF-EDU
Task Force on Educational Technologies

VPN
Virtual Private Network

WP
Work Package

WP3
GN4-3 Work Package 3 User and Stakeholder Engagement

WP3 T3
WP3 Task 3 Stakeholder Insights

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