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Abstract

The GÉANT Compendium provides an authoritative reference source for anyone with an interest in the development of research and education networking in Europe and beyond. Published since 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 2018, extending to 2019 and 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 2019 focused on the period from January to December 2018. It requested information relating to seven areas of interest to NRENs including: network and security, service portfolios, and budgets. The survey questions were drafted under the guidance of subject specialists from within the GN4-3 project. This same group also led the analysis of the respondents' data. The results, based on responses submitted by 38 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 2018. 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

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) 2017 to 2019; and Figure 5.5: Development of the NRENs' IRU networks 2017–2019). 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.

their variations and particularities, the European NRENs are built around delivery of the same core, interlinked 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.

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 since 2000, the GÉANT Compendium presents a comprehensive picture of the National Research and Education Networks (NRENs) in Europe. This deliverable reports on the nineteenth issue, which is based on the findings of the annual Compendium survey conducted in 2019 and focuses on the period from January to December 2018; 38 out of 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. The full Compendium is available online at [\[COMPENDIUM\]](#).

Like past Compendium surveys, the 2019 results reveal changes and continuing trends in the NREN landscape, although the changes are mostly gradual.

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.

Reflecting the continuing increase in the importance of data networks in research and education, budgets and staff numbers as a whole have expanded between 2018 and 2019 (by 17% and 6%, respectively), following a slight contraction in the year before. The growth has enabled NRENs to upgrade their networks and further develop their service portfolio.

The importance of research and education networks also manifests in the ever-increasing volume of traffic NRENs carry. About half of the NRENs responding to the survey reported a rise in traffic, and the data highlights the wide variation in traffic from GÉANT's partner NRENs. Across all NRENs, the recorded traffic grew by slightly less than 10% in 2019. NRENs expect this trend to continue into the medium term: for the years 2019–2022, more than half of the NRENs who responded to the survey forecast an average traffic growth of 50%, across all organisations within the NRENs' remit. As with last year, the highest growth is expected to come from schools, with an anticipated traffic growth of 76%, followed by universities and research institutions, estimated to grow by 64% each.

NRENs typically upgrade their network at regular intervals, which in turn typically manifests in capacity jumps of the connection to the customers and of the network backbone itself. While characteristic capacity jumps can be seen for some NRENs (which increased the average connectivity of the NRENs' backbone networks by about 10%), the typical connectivity provided to universities and research institutes has not increased on average, mirroring the results of the previous survey, which means that connectivity capacities for the research sector are currently plateauing. There have still been

increases in traffic, though, so clearly the existing capacity is able to support the needs of the sector. Average connectivity has increased for other customers, e.g. schools, probably due to this being a relatively new market sector that still needs development.

The capacity ranges from 1 Mbps up to 100 Gbps. Over half of the respondents indicate 1 Gbps as typical capacity for connected universities and research institutions. Universities and Research Institutes are the best-connected institution types and, in some countries, the typical connectivity of universities has reached 10 Gbps. Schools, where they are connected by the national NREN, normally have more modest requirements; the link capacity here is on average close to 100 Mbps.

The trend of many NRENs moving beyond their core role as connectivity providers and providing additional services continues. In doing so they are responding to technological changes and changes in the demands of the research and education community. This concerns the expansion and improvement of the authentication and authorisation infrastructures which are adapted to deal with a continuing increase of cooperation and sharing of resources across institutions and borders. Another such development is the ongoing commodification of ICT services that just a few years ago were relatively obscure, notably cloud services. Here, NRENs have moved to make their experience in procurement of such services available to their customers. 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 – NRENs that choose this path may become an important gatekeeper or mediator between content/service providers and consumers in the education sector.

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 2000, 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

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.

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](#)].
- 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

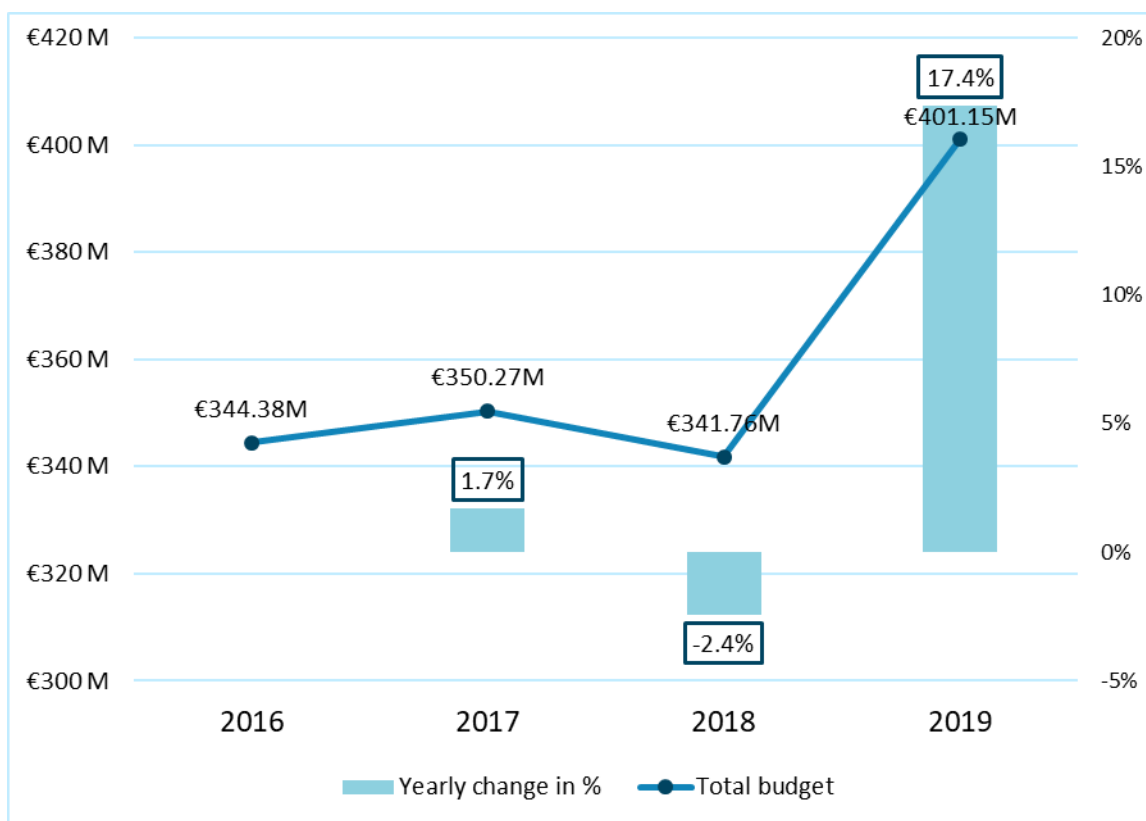
2.1 Budget

Budgets are a central factor in determining what any organisation is capable of doing. Overall, the budgets dedicated to NREN activities have increased over the last four years (Figure 2.1).

However, this does not mean that the trend is true for every individual NREN. The 2019 and 2018 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.⁵

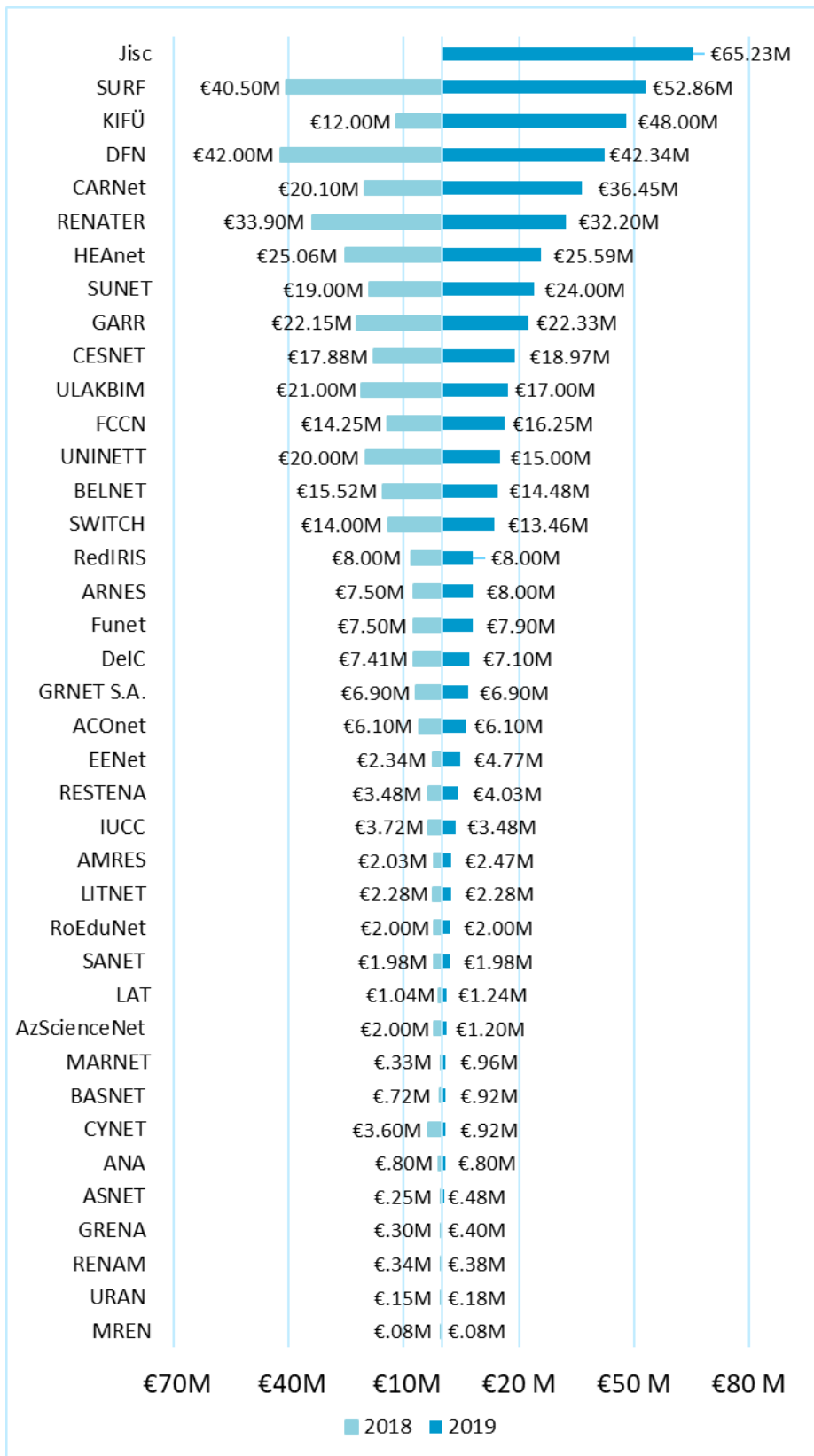
⁴ The data used in this section are mostly taken from the annual Compendium survey of NRENs. Some data come from the World Bank [[World Bank](#)].

⁵ This can be the renewal of network infrastructure (CyNet, KIFÜ), adding new business areas (CARNET, who increased their involvement in support of education, or KIFÜ, who built an HPC centre) or organisational changes (Uninett was separated into two organisations, UNIT and Uninett, in 2018, resulting in reduction of Uninett's portfolio and budget).



Note: 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 2019 survey results based on the data for all responding NRENs that year is €451 M). The percentage change is based on the earlier year's budget.

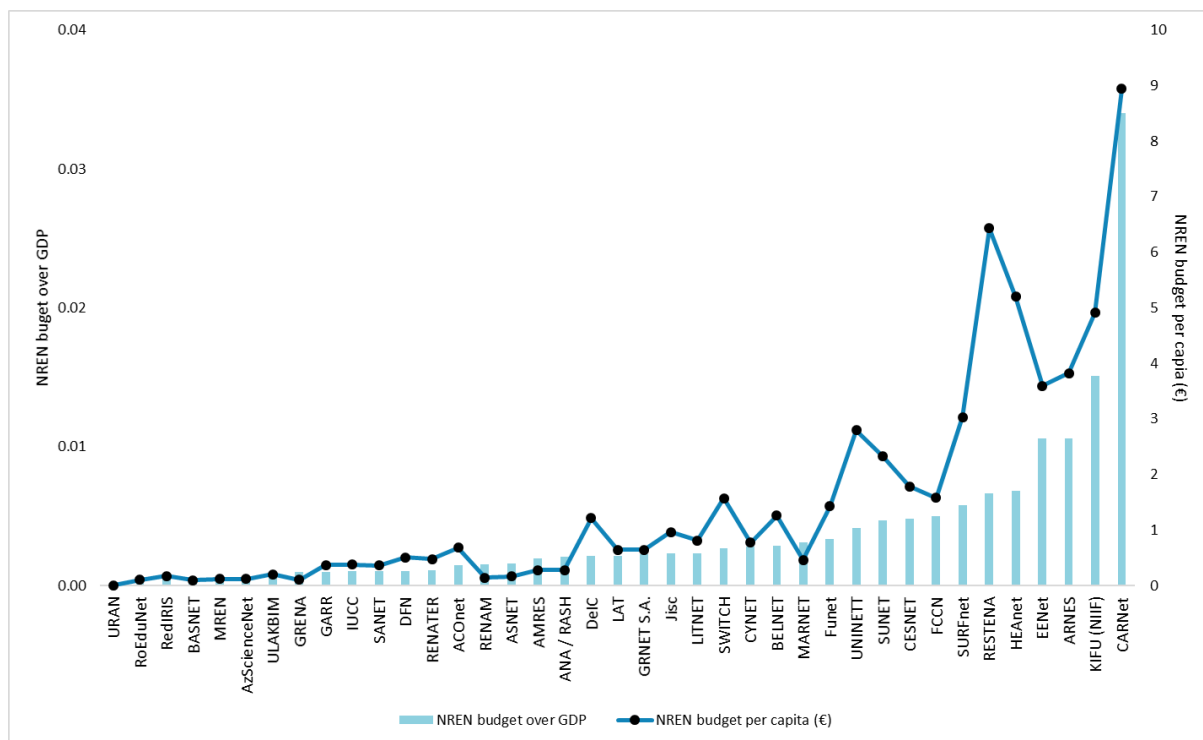
Figure 2.1: Development of total NREN budgets since 2016



Note: The figure includes NRENs that have provided budget numbers for only one of these years, hence the occasional gap. Overall, 21 NRENs reported an increase in budget, 9 no change and 9 a reduced budget.

Figure 2.2: Individual NREN budgets 2018 and 2019

Budgets reflect the size of an NREN, but this size is, of course, related to the size of its home country. Large countries have more R&E institutions, and therefore, on average, larger NRENs. This can be seen in the budget list shown in Figure 2.2, where NRENs from larger countries tend to have larger budgets – although this relationship has 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.



Note: The numbers shown here are simple indexes formed by dividing the NRENs’ budgets by the GDP (in Billion €) and population sizes. The GDP and population numbers come from the World Bank [[World Bank](#)].

Figure 2.3: NREN budgets normalised to GDP and population

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 the top of Figure 2.3 provide a wide range of services, in addition to connectivity, to their customers (e.g. procurement support, computational resources, educational resources, etc.) and often also serve

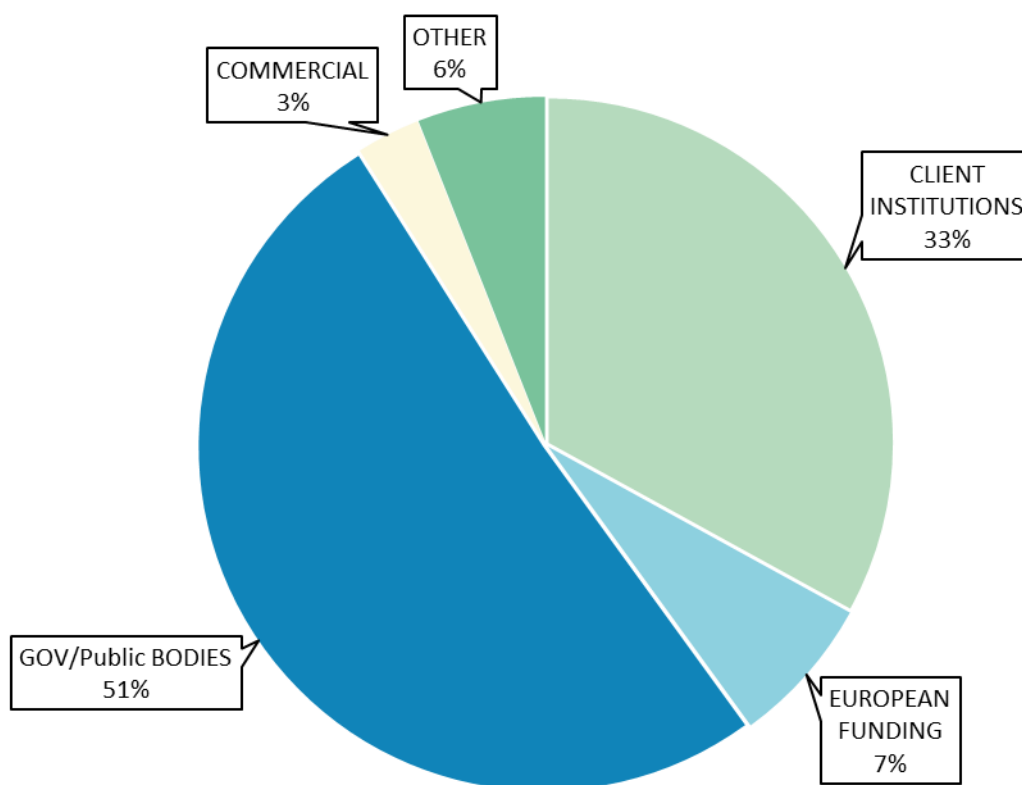
⁶ Note that the top ten budgets feature the NRENs of only four of the eight largest European countries (ULAKBIM/Turkey, RedIRIS/Spain, URAN/Ukraine are not in the top 10). NRENs from several significantly smaller countries, such as SURF (The Netherlands), CARNET (Croatia) or HEAnet (Ireland) make the 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.

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



Note: This figure shows the share of different funding sources for the total of all European NRENs’ budgets. The numbers are based on the survey responses of all NRENs that provided their budget numbers as well as their income sources (37 out of 42). 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.

Figure 2.4: Funding sources of NRENs

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.

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

	CLIENT INSTITUTIONS	EUROPEAN FUNDING	GOV/Public BODIES	COMMERCIAL	OTHER
ACOnet	100%				
AMRES			100%		
ARNES		15% (4%)	72% (84%)	13% (12%)	
BASNET	27% (34%)	64% (58%)	9% (8%)		
Belnet	38% (21%)	2%	52% (71%)	7% (6%)	
CARNET		59% (35%)	38% (62%)	2%	
CESNET	23% (22%)	4% (7%)	72% (70%)	1%	
CYNET	55% (13%)	30% (20%)	16% (63%)		
DFN	98%	2%			
EENet	3% (5%)	71% (42%)	26% (50%)		
FCCN	3%		96%		1%
Funet	60%		40%		
GARR	88%	5%	8%		
GRENA	40%	50% (45%)		5%	5% (10%)
GRNET S.A.		20% (35%)	75% (60%)		5%
HEAnet	14% (10%)	1%	84% (86%)	1%	
IUCC	86%	14%			
Jisc	23%	1%	70%	6%	
KIFÜ	3% (10%)	2% (5%)	95% (85%)		
MARnet	14% (0%)	17% (25%)	69% (42%)		
MREN		14% (20%)	66% (70%)	20% (0%)	
RedIRIS		7%	92%		1%
RENAM	39% (52%)	60% (46%)	1% (2%)		
RENATER	30%	4%	64% (65%)	1% (0%)	1%
RESTENA	5% (6%)	5% (2%)	37% (40%)	38% (37%)	15%
RoEduNet			100%		
SANET	7%		93%		
SUNET	70%		25%		5%
SURF	58% (66%)	2% (3%)	40% (31%)		
SWITCH	48% (52%)	1%	1% (3%)	50% (44%)	
ULAKBIM		0% (1%)	100% (99%)		
URAN	74% (87%)	0% (7%)	3% (2%)	23% (2%)	0% (2%)

Over 75%

25% TO 75%

LESS THAN 25%

Note: 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 2018 and are only shown when the share has changed between the years.

Table 2.1: Income sources per NREN

The majority of NRENs have a diversified income, split to varying degrees over the different categories. However, this is not true for everyone: 4 NRENs (ACOnet, DFN, GARR and IUCC) depend largely on income derived from their customer base 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 are running 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).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 Section 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 2019, the leading example here was SWITCH, but RESTENA, MREN and URAN are deriving significant income from commercial sources as well.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.

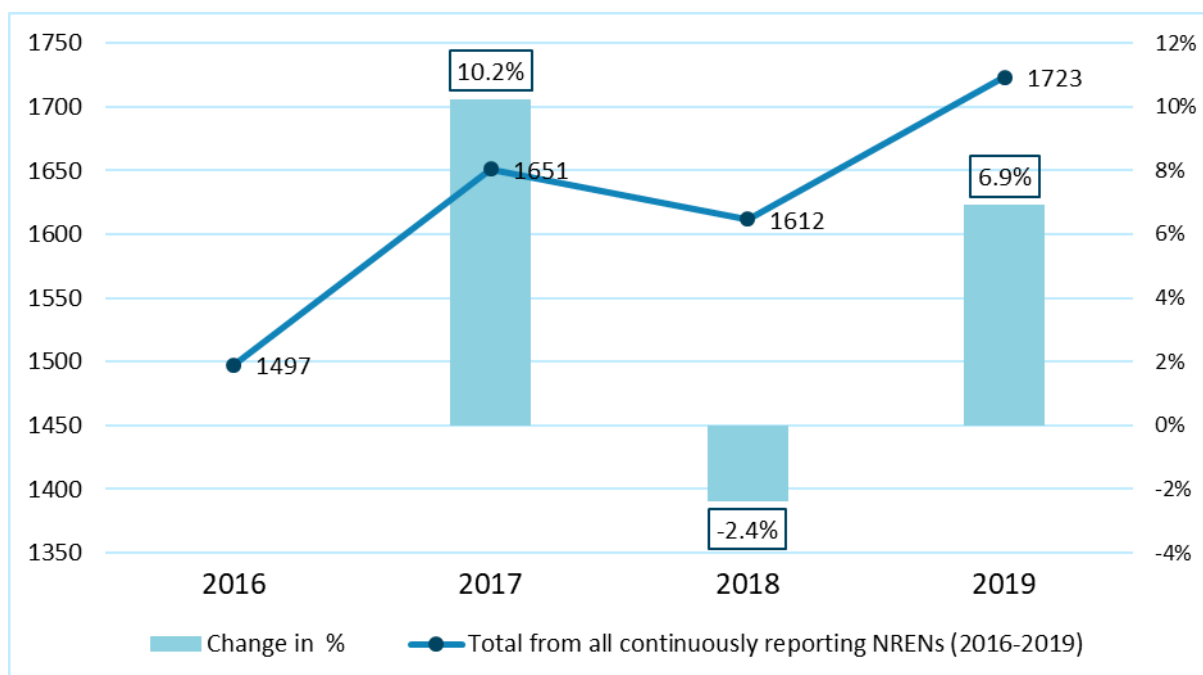
⁹ The threshold used here was 85% of the NREN’s income derived from one source. DeIC belongs to the group of customer-funded NRENs as well, though they did not provide the exact numbers in the 2019 survey (in 2018, DeIC’s customers provided 99% of the NREN’s total income).

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.

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.



Note: The percentage change is based on the earlier year’s staff numbers. While the total number of staff reported in 2019 was 1,954, 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).

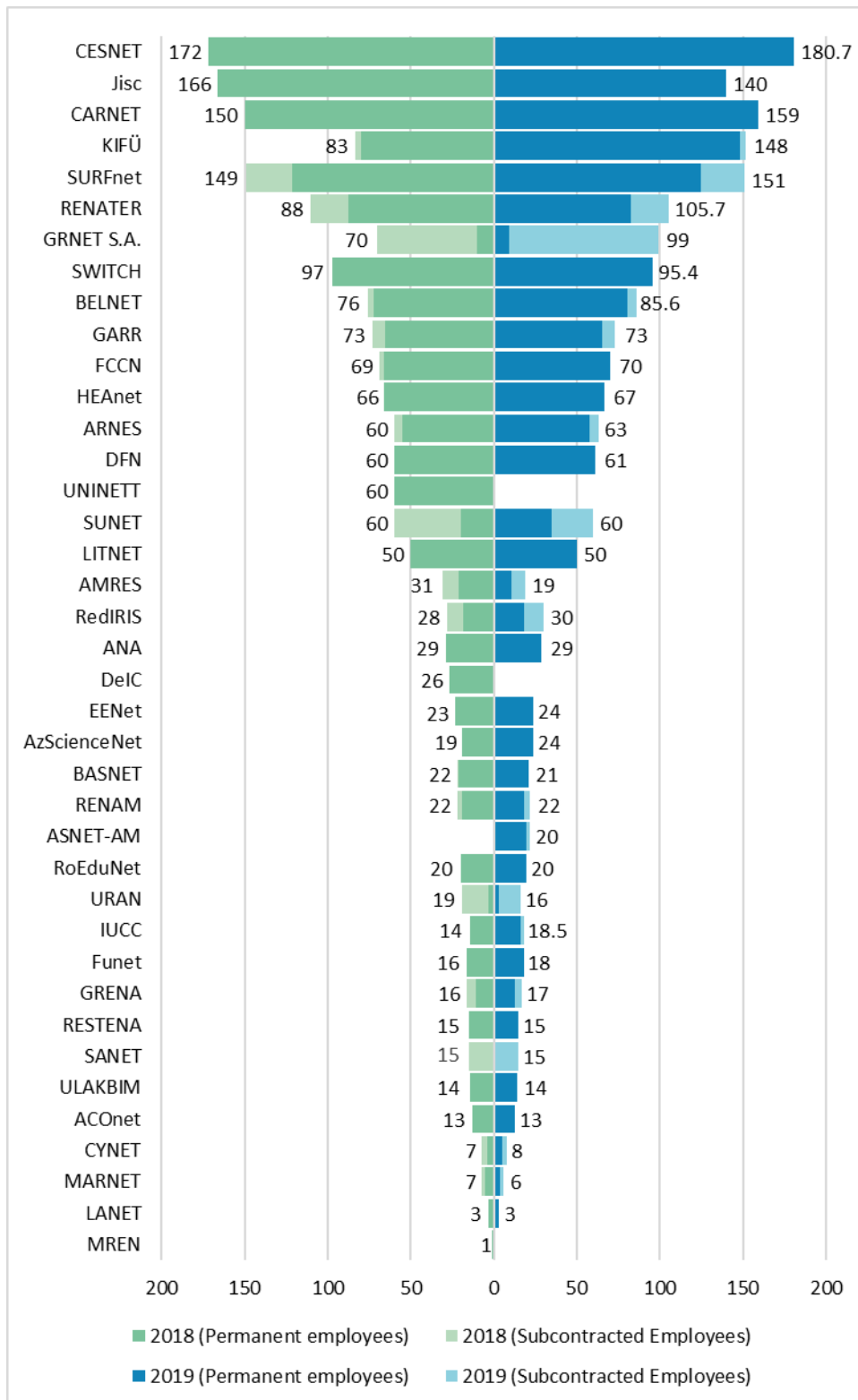
Figure 2.5: Total staff numbers of the NREN sector

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 2018 and 2019 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.¹⁴ Of course there are exceptions to this, usually correlated with organisational change.¹⁵

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 13% in 2019, this variation might be due to the noise in the data that is generated by the variability in the survey response rate.

¹⁴ A good example here is CyNet, which shows a large drop in budget, but no accompanying reduction in employees.

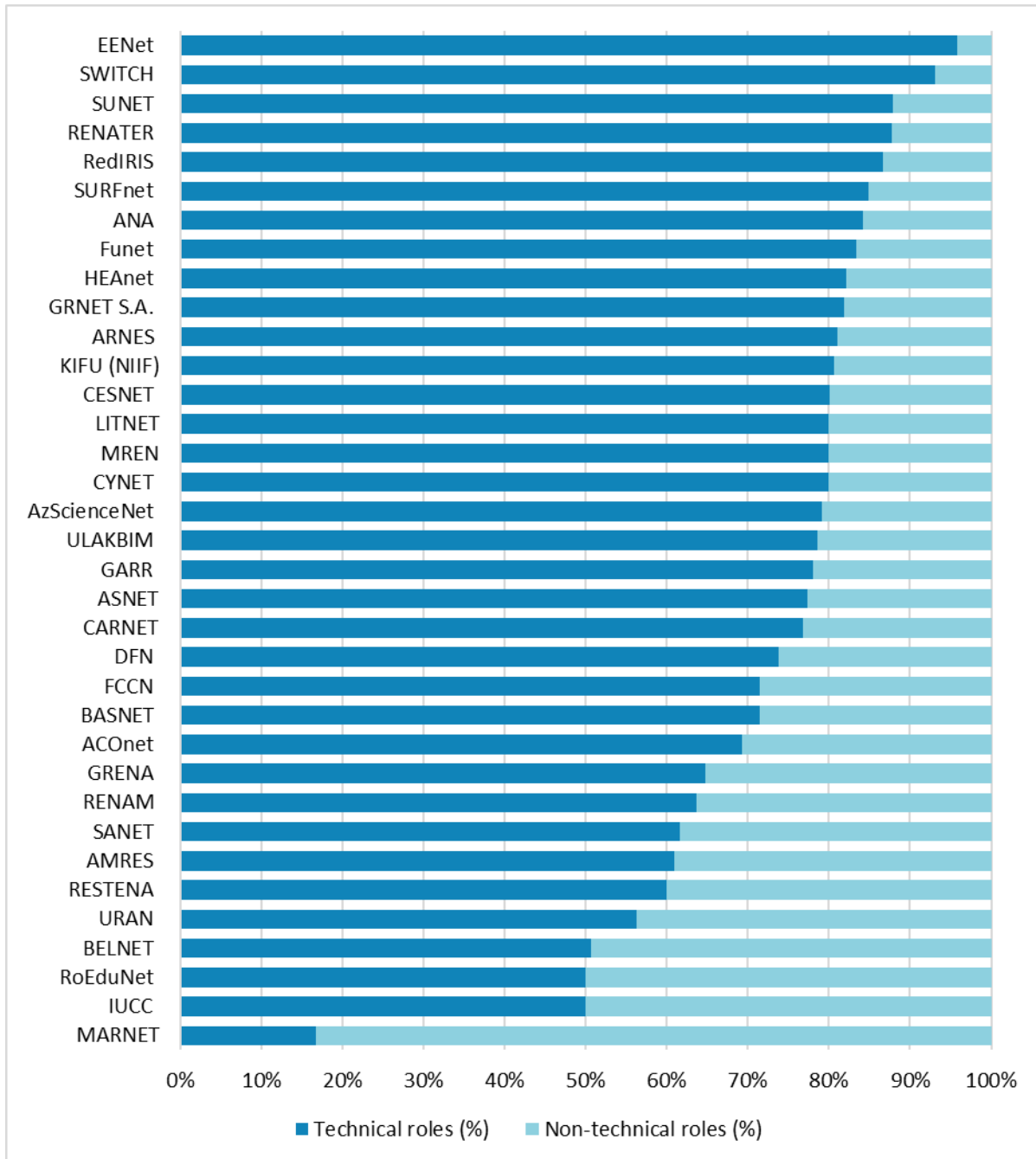
¹⁵ For example, KIFÜ started an HPC centre, which entailed of course a staff increase. On the other hand, AMRES went through a phase of business troubles, leading to a reduction in workforce. Many NRENs generally are in a challenging situation concerning staff recruitment, as public services have difficulties competing with the commercial sector for qualified staff; the reduction of AMRES’s workforce is partially due to this challenge.



Note: The figure includes NRENs that have provided staff numbers for only one of these years, hence the occasional gap.

Figure 2.6: Staff numbers of NRENs in the years 2018 and 2019

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. Not surprisingly for network providers, the majority of positions are technical roles.¹⁶ Nevertheless, there is considerable variation between NRENs, which again emphasises how different NRENs are from each other.



Note: 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.

Figure 2.7: Share of technical roles among staff numbers

¹⁶ At MARnet, the network management and operations role sits within the university, hence the lack of technical staff.

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.

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.

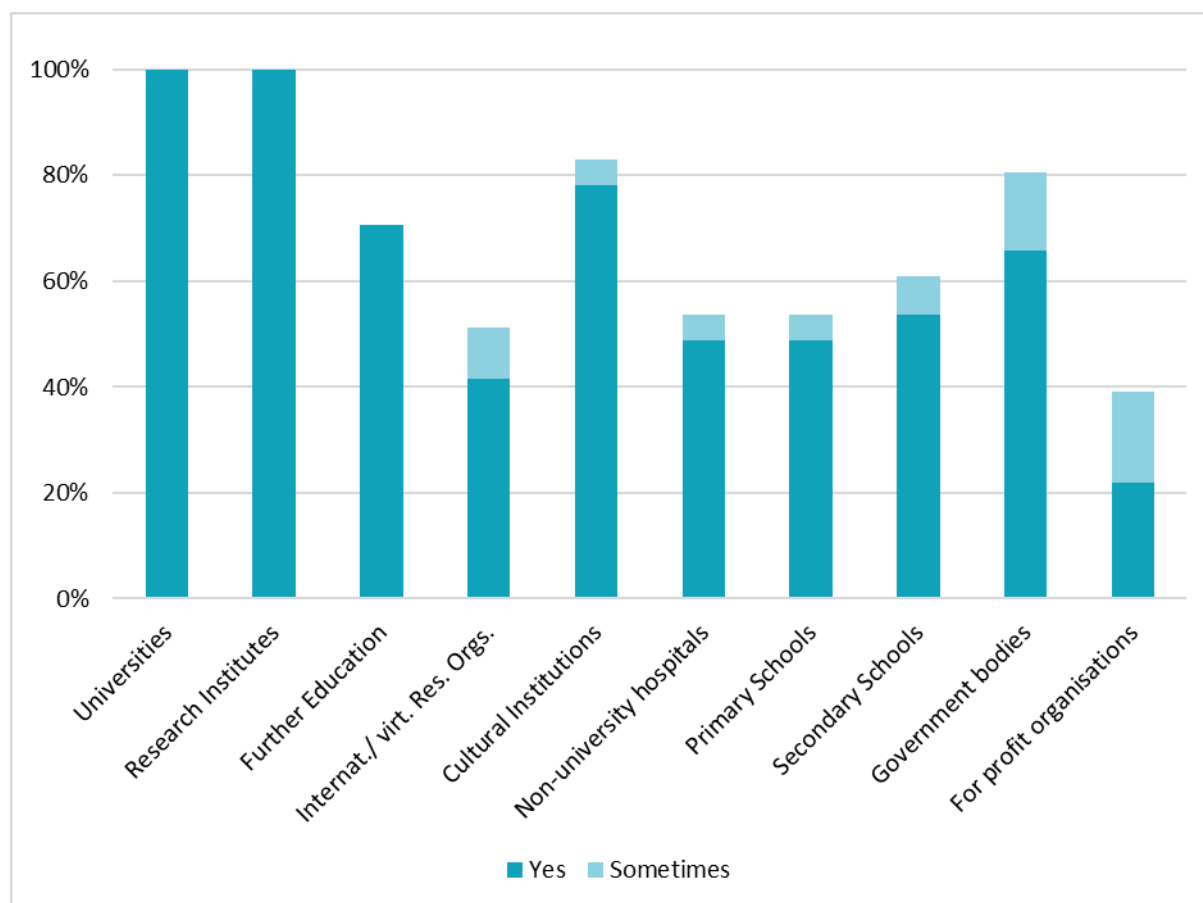
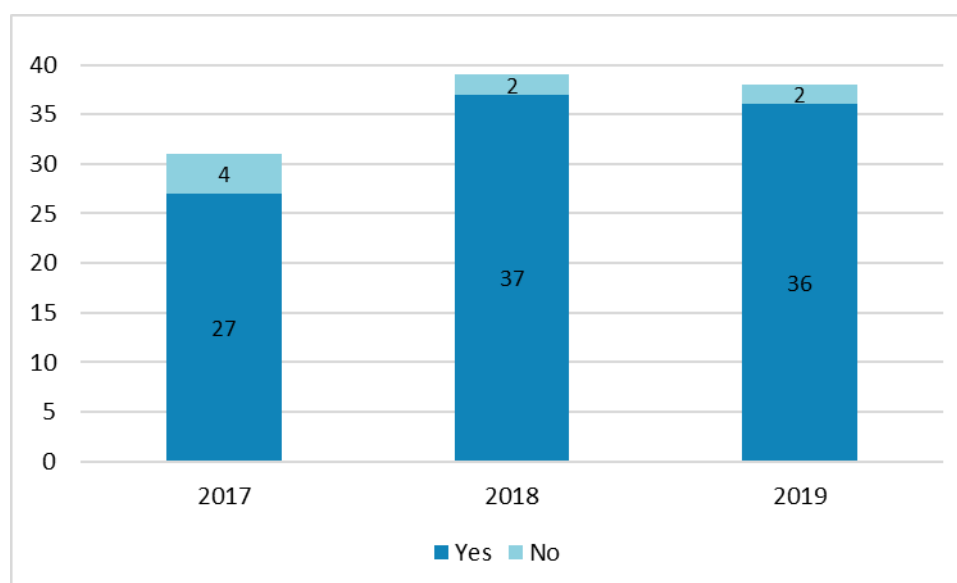


Figure 3.1: Percentage of NRENs connecting different user types

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 2019 Compendium data, there have been minimal 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 Section 6 Security Services) as well.)



Note: The slight drop in the number of AUPs from 2018 to 2019 is due to the varying response rate. Between 2017 and 2019, 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.

Figure 3.2: Number of NRENs that reported having an acceptable use policy (AUP) in place

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 2019 is comparable to that of 2018. 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.¹⁷ 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.

While overall market shares are not very dynamic, there have been notable changes in some countries. In Croatia, CARNET has expanded its coverage of governmental bodies from 16% to 80%. Such large jumps are, however, rare and in most cases noticeable changes take several years.

¹⁷ 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.

An example of where an NREN has lost market share is provided by RedIRIS, where (non-university) hospitals have increasingly opted for other ways to satisfy their connectivity needs.

	Universities	Research Ins.	Further Education	Inter'l research Inst	Libraries	Hospitals	Primary Schools	Secondary Schools	Government	For-Profit Orgs
ACOnet	80				40	60	90	90	60	
AMRES	80	80	90		50	3	97	97	2	
ANA	74	13			4				7	
ARNES		93			87		95		10	
AzScienceNet	36	90								
BELNET	90	75	1		1	5	5	5	20	
CARNet	100	98	5		1	92	98	98	80	1
CESNET	95	95	8	90	1	20	1	5	10	
CYNET	100	70	40							
EENet	68	4	66		7		10	32	5	
GARR	60	80		20	0.5	4.4	0.8	4.7		
GRENA	60	50								
GRNET S.A.	100	100	50		20	80	100	100	2	
HEAnet	100	50	5				98	100	5	
IUCC	50									
Jisc	100		100							
KIFU (NIIF)	98	99	2	100	90	5	99	99	5	
LITNET	83	100	60		19	10	11	52	9	1
MARnet	40									
RedIRIS	90					5	45	45		
RENAM	72	80	11		9	7		0.01	5	
RENATER	100	100								
RESTENA	80	96					85	100		
RoEduNet	90	80	50		60		50	30	10	
SANET	98	70	95		10	5	10	50	5	
SUNET	100		100							
SURFnet	100	90	90	20	5	6	8	8		2
SWITCH	100				5					
ULAKBIM	94		20		0.1				2	
URAN	30	13	5	10	4	5			2	1

Over 75%	25% TO 75%	LESS THAN 25%
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Note: The table shows only NRENs that gave an estimate of their market share in at least one category; missing NRENs and 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 within its connectivity remit but not connect a single one.

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

3.3 Typical and Highest Capacity of Connected Institutions

Typical capacity of 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. Interestingly, throughout this period the most common link capacity has been around 1,000 Mbps; the number of NRENs and the absolute numbers have not changed much during this time. Only in the last year has there been an uptick in the number of NRENs providing their users with link capacities in excess of 1,500 Mbps. The decrease in the 500–1,500 Mbps range (by far the most common capacity in this category is 1,000 Mbps) is actually due to some NRENs having upgraded their offers.

Interestingly, though link capacities seem to have reached a plateau for the time being, there have still been increases in traffic (for details, see Section 5 Network), so clearly the existing capacity is still sufficient for the needs of the sector. Although not shown in the figures, the average connectivity for other customers has increased, in particular for schools, probably due to this being a relatively new market sector that is still being developed.

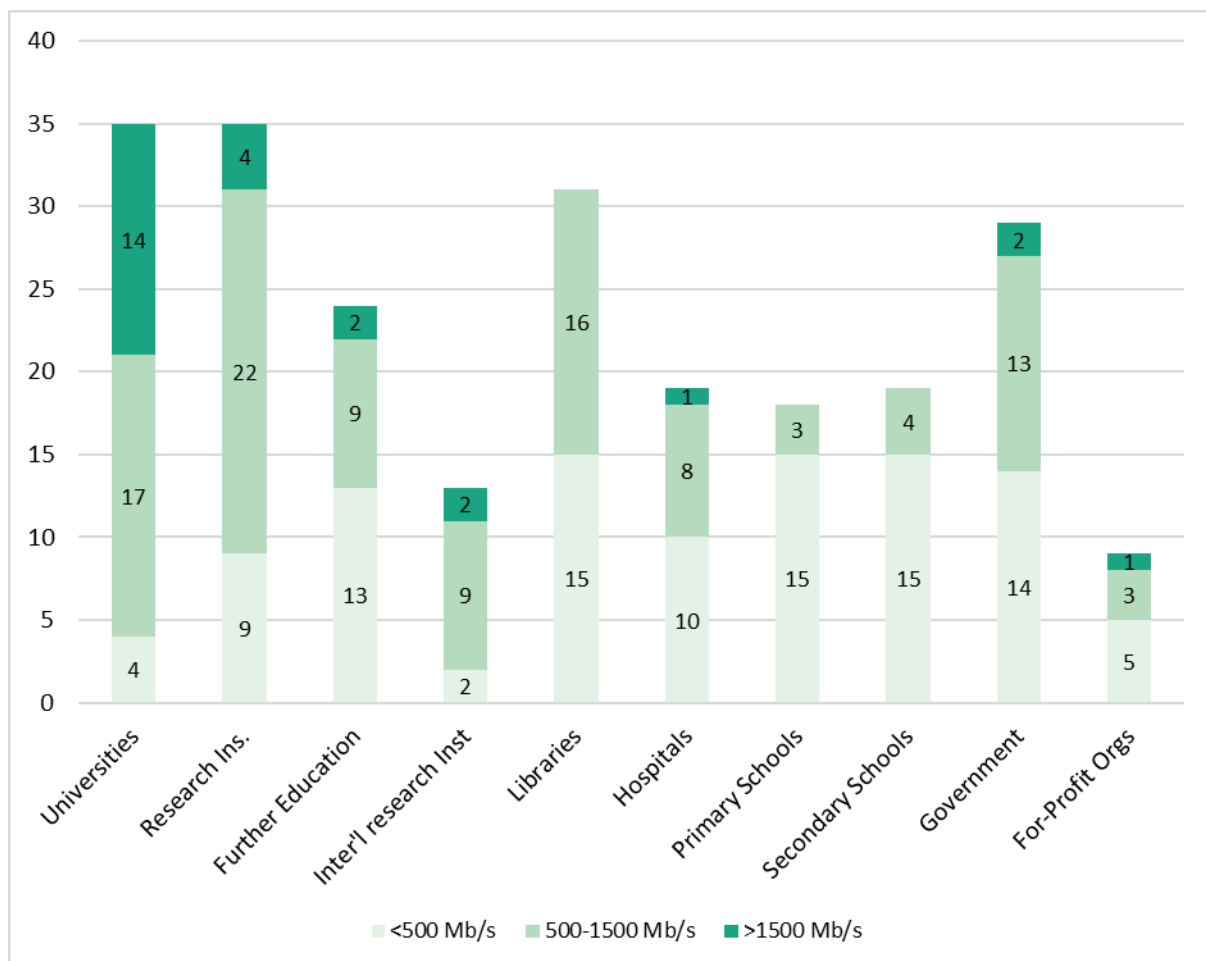


Figure 3.3: Typical link capacities provided to different types of connected institutions

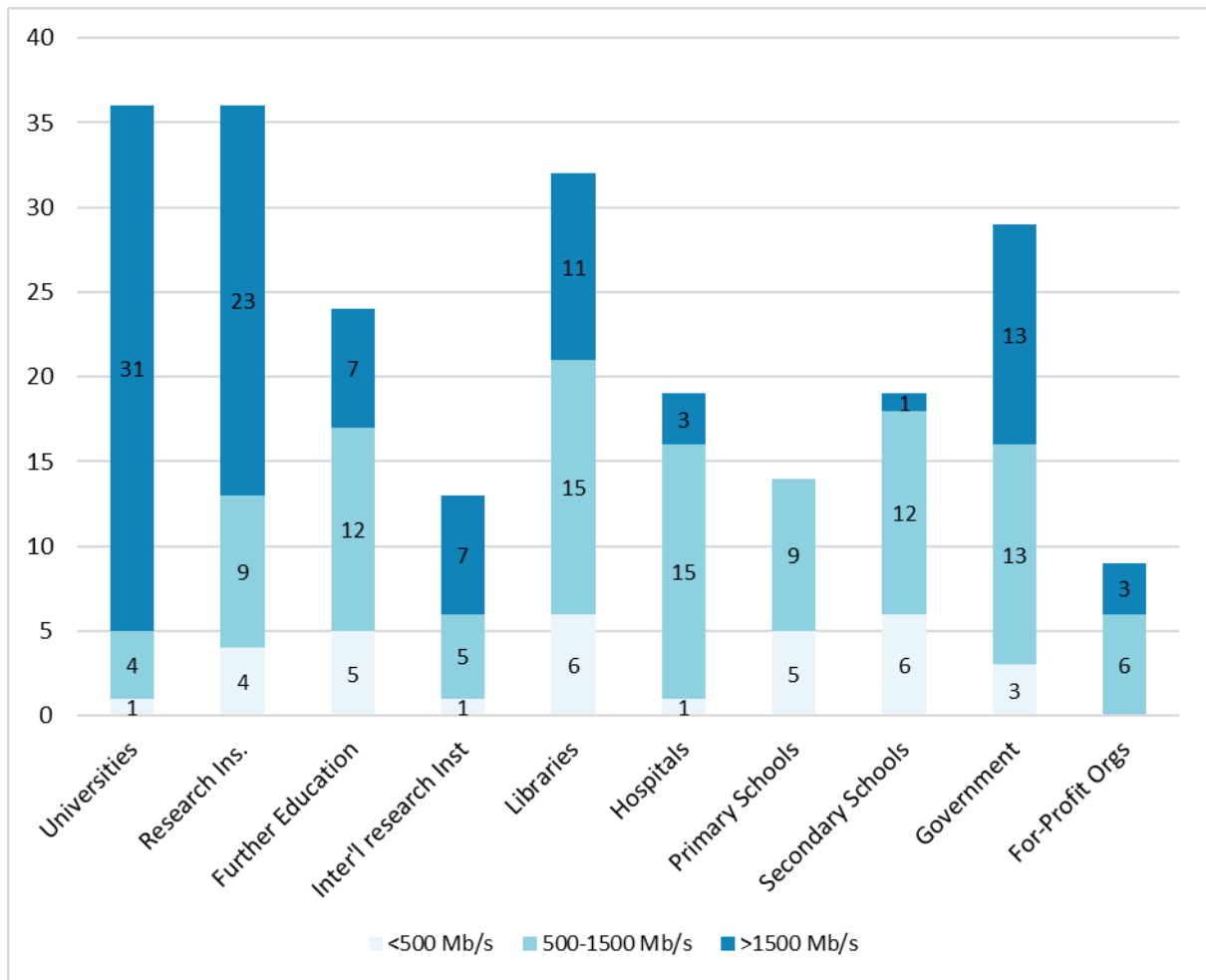
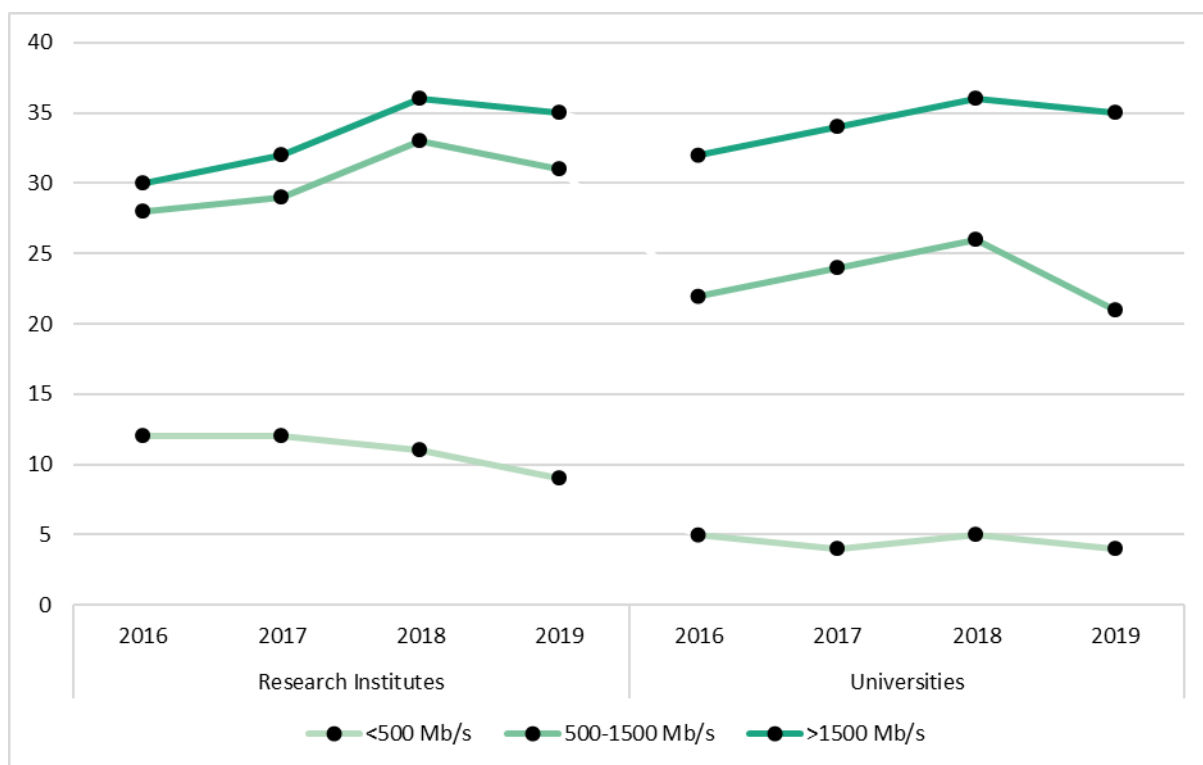


Figure 3.4: Highest link capacities provided to different types of connected institutions



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

Figure 3.5: Development of link capacities for universities and research institutes 2016 to 2019

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	Inter'l research Inst	Cultural Institutions	Hospitals	Primary Schools	Secondary Schools	Government	For profit orgs
AzScienceNet	80,000	7,000			1,200					
BELNET	530,282	36,309	900	375	2,672	21,341		62,196	145,312	1,200
CARNet	200,000	5,000	50	100	500	10,000	400,000	200,000	50,000	500
CESNET	380,000	50,000	3,000	500	600	3,000	2,600	22,000		
CYNET	24,700	580	2,000							
FCCN	343,600						542,600	634,200		
Funet	355,000	13,000			1,000				5,000	
GARR	1,500,000	30,000		2,700	1,000	8,000	36,500	125,000		
GRENA	81,500	2,500								
GRNET S.A.	300,000	40,000	20,000		10,000	20,000	100,000	100,000	1,000	1,000
HEAnet	230,000						450,000	350,000		
IUCC	140,000									
Jisc	2,500,000		2,500,000							
KIFU	100,000	50,000	1,000	200	200,000	5,000	800,000	1,000,000	100	
MARNET	60,000									
RENAM	74,500	2,900	850					208		
SURFnet		120,000	430,000	10,000	20,000	30,000	60,000	60,000		10,000
SWITCH		3,977	754						300	
ULAKBIM		5,500	14,800						3,000	
URAN		1,600	1,000	200		1,000			170	250

Table 3.2: Estimates of the number of individual users per institution type

While there are many gaps in the data that NRENs can provide about the number of end users, it is possible to estimate the number of end users using the market share estimates provided by NRENs (Table 3.1) and the number of students in Europe in schools and universities, as these make up by far the largest user group in terms of headcount. A smaller, but still significant, contribution comes from the staff of universities and schools. Using publicly available numbers of students and an assumed staff-student ratio of 1:12.5, the number of end users of NREN networks and services in Europe in 2018 amounted to about 38 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).

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 of 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.

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.

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 a number of projects in this field. NRENs are uniquely well placed to support these EC projects to build or improve this 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 29 individual NRENs participated in a total of 78 unique projects (up from 28 NRENs and 56 projects in 2018). The number of projects is bound to fluctuate over the years but 7 of the additional projects in 2019 are EOSC-related, underlining the importance of the developments in this area to the NREN community. 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, but also requires 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. 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.

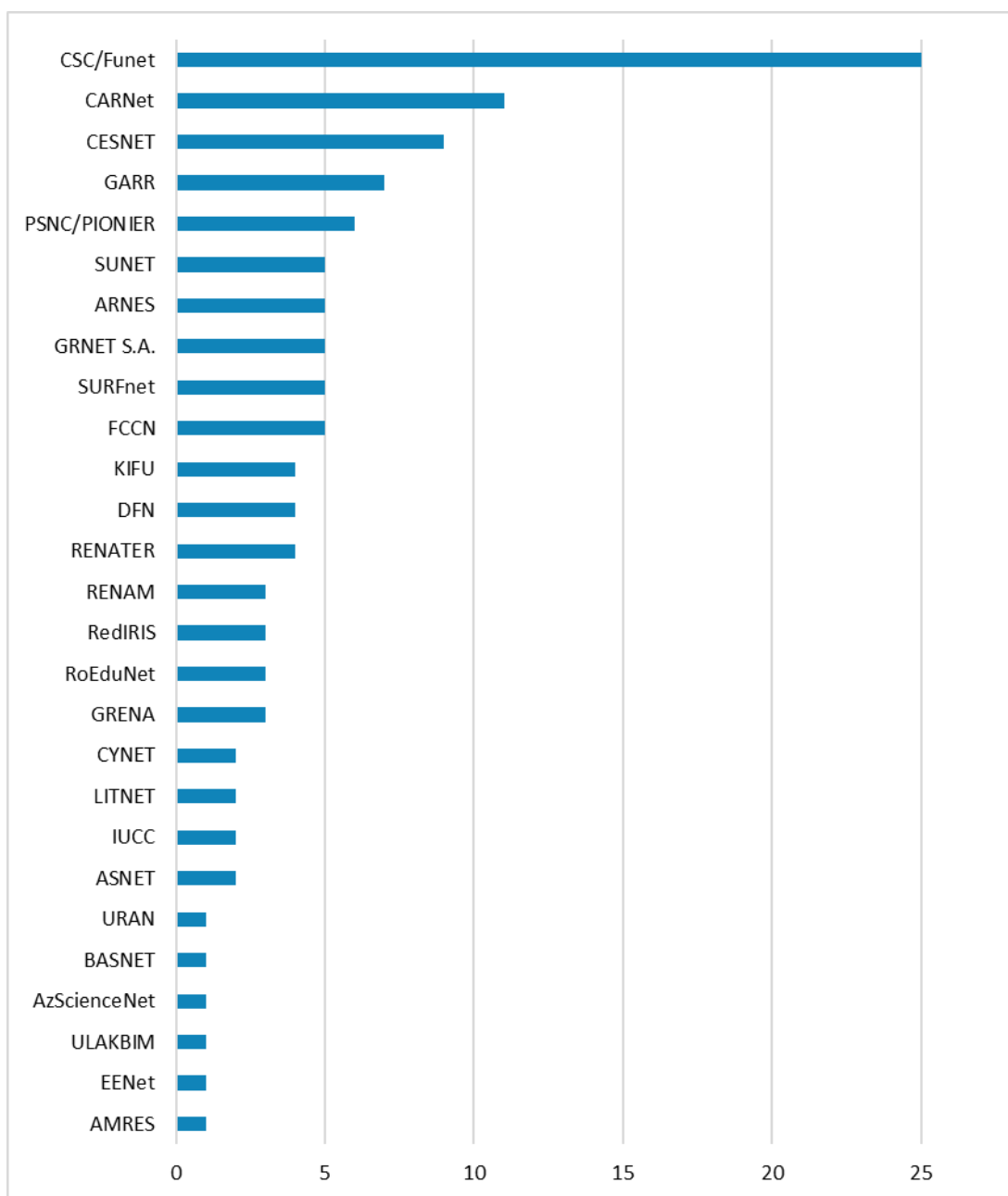


Figure 4.1: NRENs’ participation in EC-funded projects – total number of projects per NREN

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.

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 Secretariat [EOSC_Sec]	The preparation of the future EOSC Governance Structure and setting up of the post H2020 structure for EOSC (i.e. the legal entity that will support EOSC in the future).	CSC/Funet ²¹
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 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	CSC/Funet, DeIC, SUNET, Uninett
EOSC-Pillar [EOSC-Pillar]	Bundling initiatives from Austria, Belgium, France, Germany, and Italy	GARR
EOSC Synergy [EOSC_Synergy]	Bundling initiatives from Spain, Portugal, UK, Czech Republic, Slovakia, Poland, the Netherlands, and Germany	CESNET, FCCN, Jisc, PSNC, 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
Subject-specific resources		
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)	CSC/Funet

Table 4.1: Overview of EOSC-connected projects and NRENs participating in them

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

²¹ Funet as a network is part of the Finnish Centre for Scientific Computing (CSC), which provides ICT support, computing and information services for academia, research institutes and companies in Finland. The two organisations are closely intertwined. A similar relationship exists between the Polish network, PIONIER, and its mother organisation PSNC (Poznan Supercomputing and Networking Centre).

More and more NRENs are getting involved in national EOSC initiatives as well as in European ones; GÉANT NRENs are also involved in the EOSC authentication and authorisation infrastructure (see Section 7.4.2). In addition to the participation of individual NRENs, GÉANT is active in the EOSC Executive Board, helping to shape the strategic research and innovation agenda, working groups and stakeholder engagement. This common effort has recently led to the creation of the EOSC Association.²²

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.

AARC2

Authentication and Authorisation for Research and Collaboration (AARC2) [[AARC2](#)] aims to design a framework of policies and technical guidelines which allow research collaborations to enable federated access to their services, and to interoperate with each other. This includes the development of training modules to support setting up and operating authentication and authorisation infrastructure (AAI) procedures based on the AARC Blueprint Architecture (BPA) for interoperable and secure AAls. The NRENs DFN, GARR and SURF are partners in AARC2.

AARC2 (like its predecessor AARC) was funded by the European Union's Horizon 2020 programme from 2016–2019.

PROTECTIVE

Proactive Risk Management through Improved Cyber Situational Awareness (PROTECTIVE) [[PROTECTIVE](#)] was a project to improve ICT security. It aimed to develop policies and tools to raise organisational cyber situational awareness (CSA) which would aid security teams in their work. The solution is based on (1) improving the processing of security alerts, (2) mapping the security criticality of the organisation's parts/assets, and (3) establishing structures to share security information between security teams.

PSNC/PIONIER, CESNET and RoEduNet were partners in PROTECTIVE.

PROTECTIVE ran from 2016 to 2019 and received funding from the European Union's Horizon 2020 programme.

²² The EOSC Association was founded in Brussels on 29 July 2020 as an international non-profit association (AISBL). Involving research and innovation stakeholders across the EU and beyond who wish to formalise their role in EOSC, 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.

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.

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 and LITNET are partners in Up2U.

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

EaPConnect

Eastern Partnership Connect (EaPConnect) [[EaPConnect](#)] 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 partners – in addition to the NRENs of the six partner countries (ASNET, AzScienceNet, BASNET, GRENA, RENAM, URAN) – are AMRES, CyNet, GARR, DFN, LITNET, who provide extra support and expertise.

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.

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.

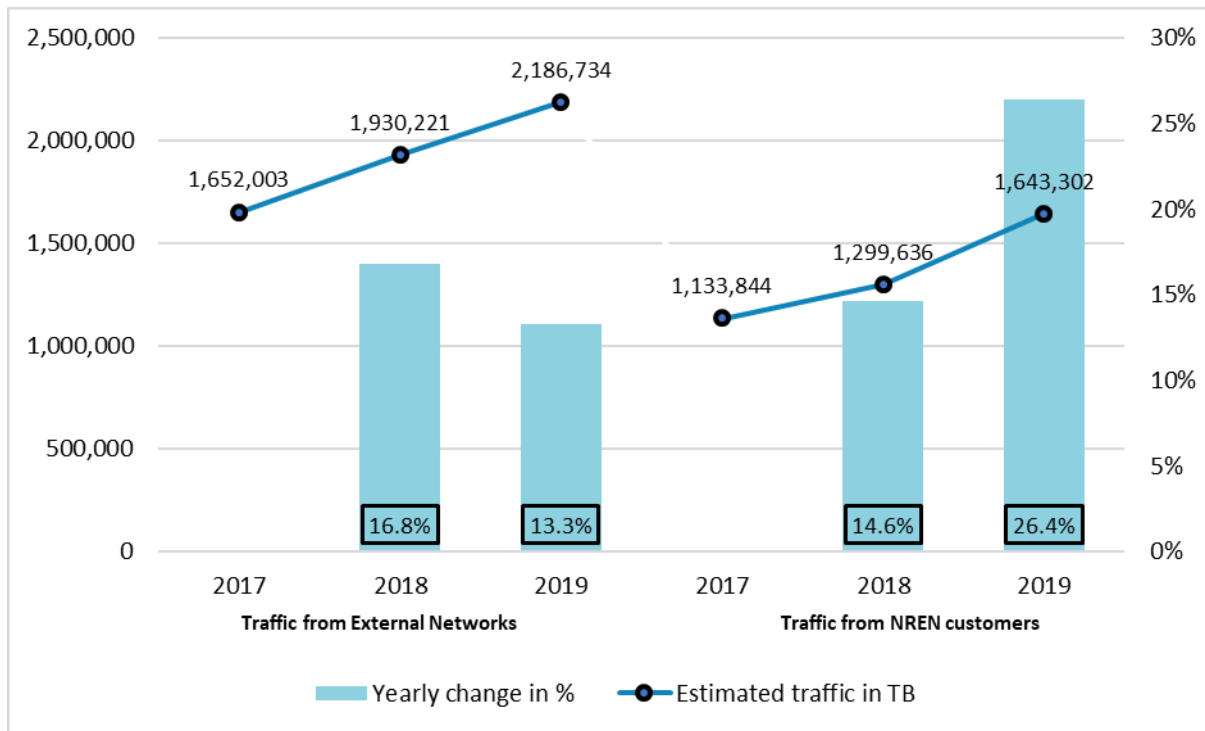
NREN networks, like the countries in which they reside, are unique and tailored to fit the community they serve, within the limits of the resources at their disposal. This section presents an overview of NREN network traffic, infrastructure and services.

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 2017 to 2019. 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.

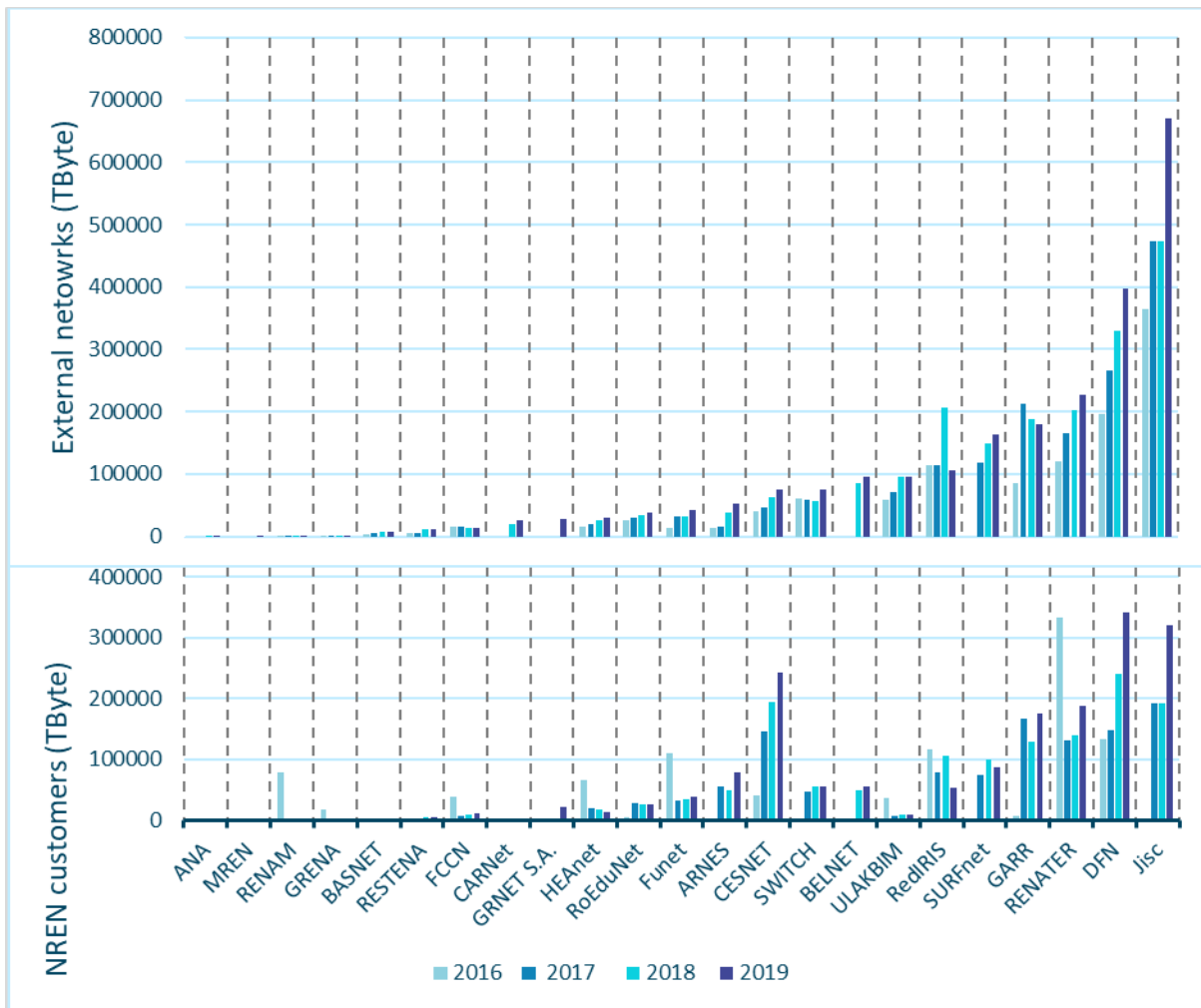
Naturally, the absolute contributions to these figures differ considerably between NRENs, as can be seen in Figure 5.2. At the extremes are Jisc, with more than 670,000 Tbytes of data from outside the NREN, and ANA/RASH, with just 65 Tbytes. The volume of traffic is driven by several factors, including 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 (18) reported an increase in traffic (again, at the top here was Jisc, reporting an increase of traffic from outside of 41%) and only two NRENs (BASNET and RedIRIS) reported decreases.



Note: “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 18 NRENS for which there are continuous traffic records from 2017–2019 (RENAM, GRENA, BASNET, RESTENA, FCCN, HEAnet, RoEduNet, Funet, ARNES, CESNET, SWITCH, ULAKBIM, RedIRIS, SURF, GARR, RENATER, DFN, Jisc).

Figure 5.1: Increase of traffic into the NRENS from external networks (left-hand graph) and NREN end users (right-hand graph) 2017 to 2019



Note: Where available, data from 2016 were added to illustrate the increase in traffic within this 4-year period. As in the previous figure, “External networks” 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.

Figure 5.2: Traffic per NREN from external networks (upper panel) and NREN end users (lower panel) 2016 to 2019

5.2 Traffic Growth Forecast

Since 2017 the Compendium survey has asked NRENs what they anticipate the growth in their traffic will be, by institution type, over the next three years.

NRENs expect traffic to grow in the medium term: more than half (15) of the NRENs who responded to the survey forecast an average traffic growth of 50% over the three years 2019 to 2022, across all organisations within their remit. The highest growth is expected to come from schools, with an anticipated traffic growth of 79% and 76% for primary and secondary schools respectively, followed by universities and research institutions, estimated to grow by 64% each.

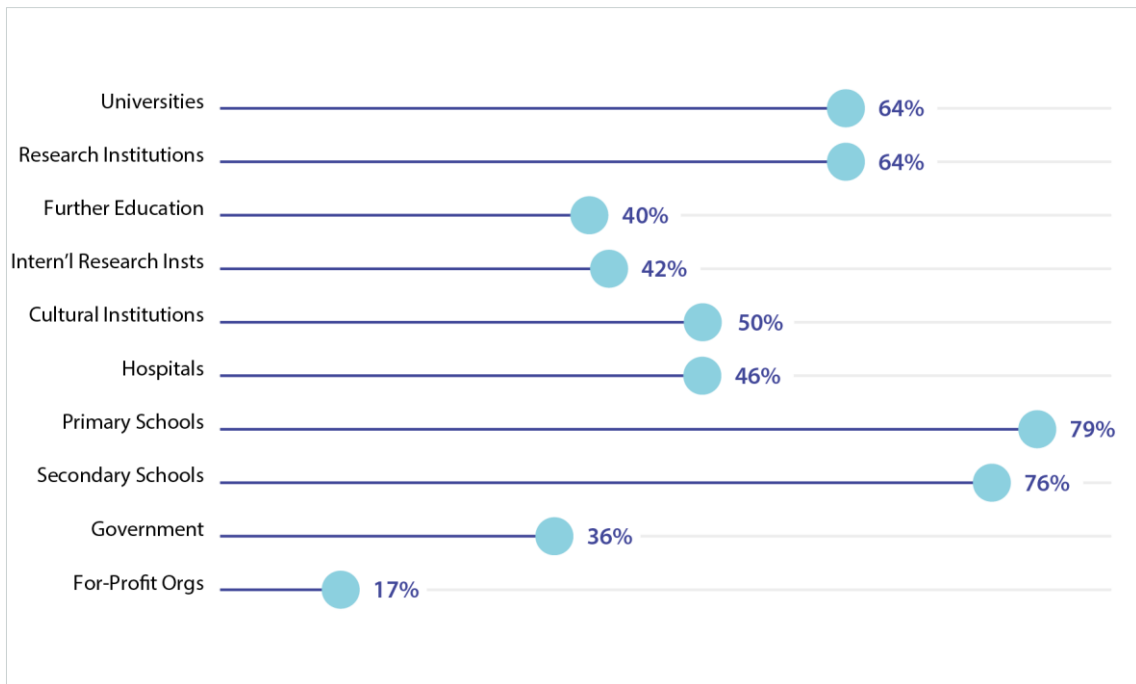


Figure 5.3: NRENs’ forecast traffic growth by institution type (based on 27 responses)

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 2019 to 2022, by NREN, and by institution type.

	Universities	Research Ins.	Further Education	Inter'l research Inst	Cultural Institutions	Hospitals	Primary Schools	Secondary Schools	Government	For-Profit Orgs
ACOnet	50	75	50		50	50	100	100	50	
AMRES	30	30	30		30	30	50	50	30	
ANA	40	30	20		10				10	
AzScienceNet	300	300			300					
Belnet	172		72							
CESNET	10	10	5	10	5	5	5	5	5	
CYNET	20									
EENet	10	50	10		5		10	10	10	
FCCN	50	50		20				20	50	
Funet	30	50			30				100	
GARR	100	100		100	20	100	100	100	20	
GRENA	100	100		100	100	100			80	
GRNET S.A.	30	30	40		10	40	500	500	10	
HEAnet	20	20	20				40	41		
IUCC	50	30			30					
Jisc	50	50	50	50	50	50	50	50	50	50
KIFU (NIIF)	100	100	100	20	100	100	100	100		
LAT	30	30			30				30	
MREN	100	50			50				50	
RedIRIS	60	60	60		40	40	70	60	40	
RENAM	20		10							
RESTENA	80	80					30	50		
RoEduNet	30	100	20		30		20	20		
SUNET	98	99	90		99	1				
SWITCH	35	35	35	35	35	35	35	35	35	35
ULAKBIM	60	50	30		30				50	
URAN	55	80		55	40	55			55	70

LESS = 40	OVER 40-100	OVER 100
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Table 5.1: Forecast traffic growth by NREN and institution type 2019 to 2022

5.3 IPv6

IPv6 became a draft RFC in 1998 and is still the most recent version of the internet protocol (IP) [IPv6]. Its continued take-up is important to network evolution as IPv6 supports further growth in the number of connected hosts, as well as transmitted data traffic, and simplifies routing.

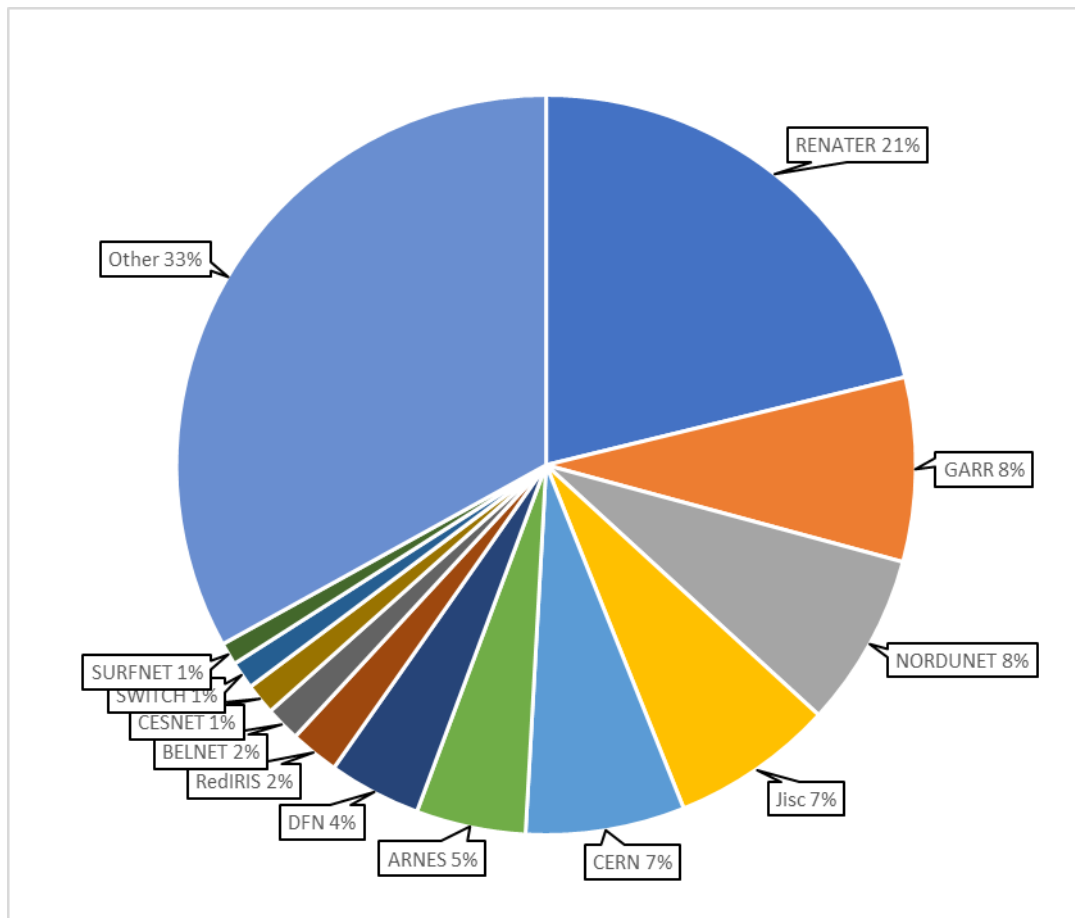
While overall adoption has initially been slow, the deployment of IPv6 among network providers in general has reached an estimated 80–90% within their networks (usually running in parallel with “traditional” IPv4 networking). R&E networks are no exception, with close to 80% of NRENs offering

IPv6, while GÉANT has implemented IPv6 across the whole network, with 100% of the network now fully IPv6-enabled.

However, the data volumes using IPv6 over commercial networks are still quite low. As an example, the Amsterdam Internet Exchange (IX) transfers an average of 5.1 Terabits per second of which only about 2.5 % is IPv6 traffic (numbers for 2020).

By contrast, R&E networks showed 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 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 CERN. This large share of IPv6 of the total traffic means that the R&E community is leading the field in IPv6 adoption. GÉANT believes that this will bring benefits to the community and ensure sustainability and robustness of the networking infrastructure.



Note: The total IPv6 traffic in September 2020 was 119 Gbps, which represented 27.6% of all traffic in September [Source: GÉANT Kentik tool].

Figure 5.4: Top 12 GÉANT IPv6 traffic sources in September 2020

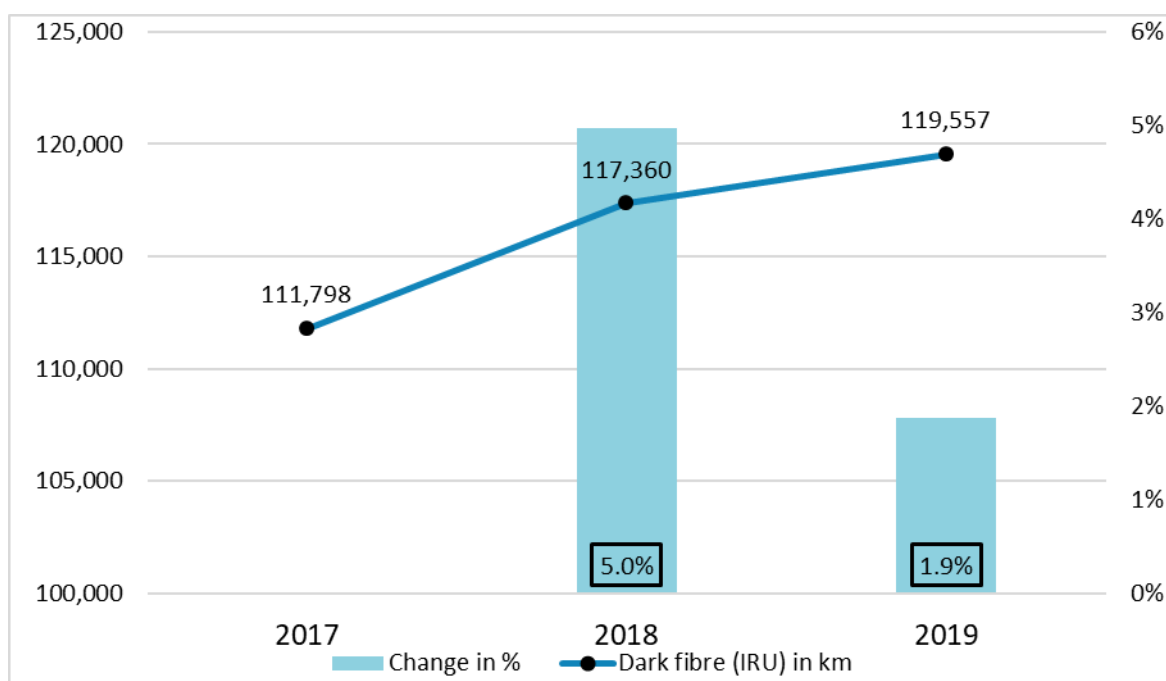
5.4 Network Infrastructure: Dark Fibre

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 dense wavelength division multiplexing (DWDM) transponders and amplifiers. This term is used mostly interchangeably (if not fully accurately) with Indefeasible Rights of Use (IRU) (see textbox).

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. The increase is documented in Figure 5.5. In 2019, the NRENs reported a total of around 150,000 km of dark fibre. Figure 5.6 below shows the number of kilometres of fibre each NREN reported in its own network. This NREN-operated fibre interconnects with GÉANT’s 11,000 km of intercity dark fibre, forming a strong community infrastructure (see Section 5.8 GÉANT Network Updates).

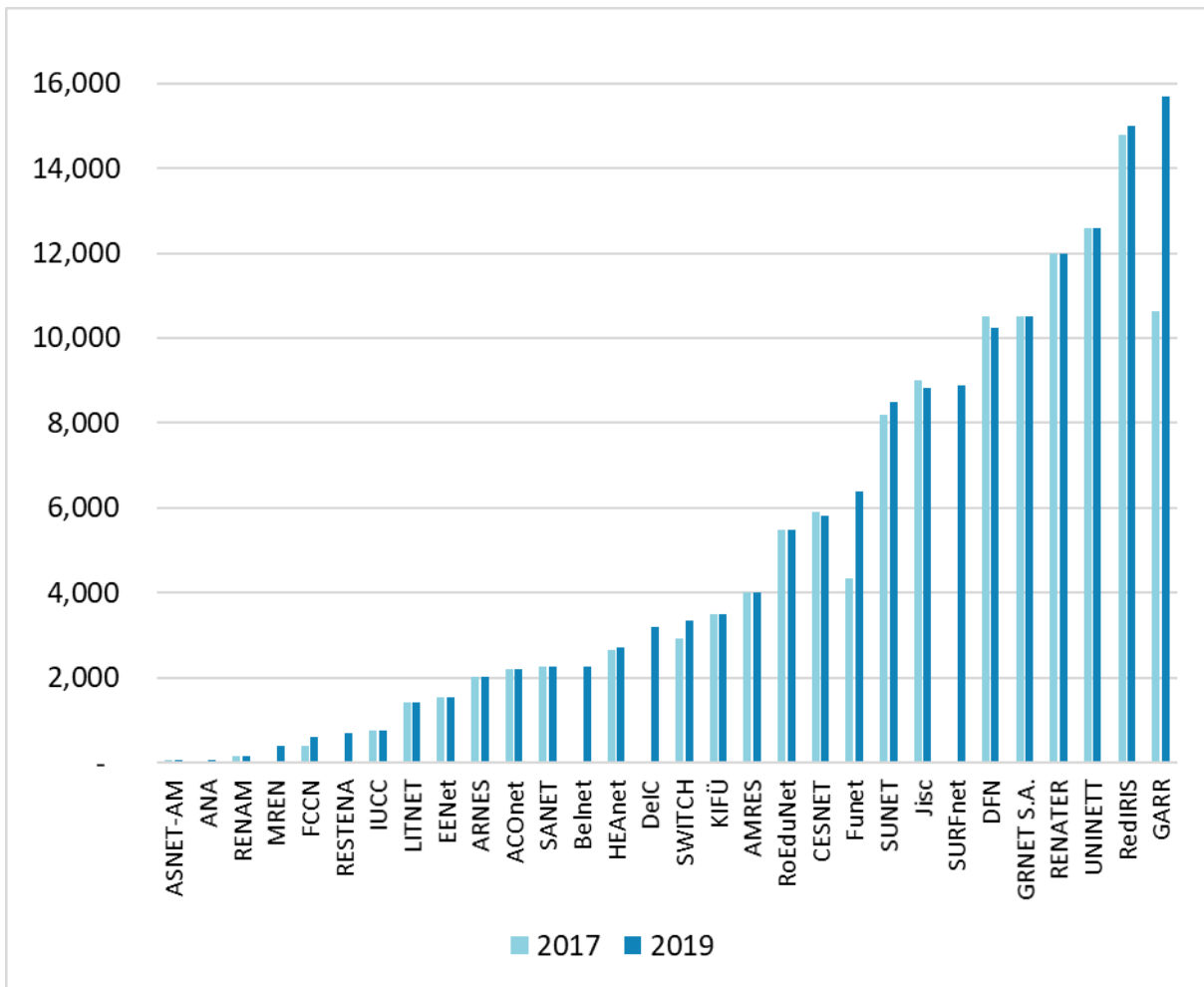
IRU

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.



Note: 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 2017 to 2019. Therefore, the total length here (ca. 120,000 km) differs from the 150,000 km mentioned in the main text, which represents the sum of all responses in the 2019 survey.

Figure 5.5: Development of the NRENs’ IRU networks 2017–2019



Note: The figure shows numbers for all NRENs that reported on their IRU network in the 2019 Compendium survey. For visual clarity, 2018 has been omitted from the graph. Even so, it is clear that overall, only small changes have taken place, though GARR and Funet reported significant additions to their networks.

Figure 5.6: Number of kilometres of IRU network per NREN 2017 to 2019

5.5 Alien Waves

In the optical transport world, the term “alien wavelength” or “alien wave” (AW) is used to describe wavelengths in a DWDM line system that traverse the network but are not sourced/terminated by the line-system operator’s equipment. 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.²³

According to the survey results, the number of NRENs making use of alien waves within their network has not changed, and in 2019 was still the same as in 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:

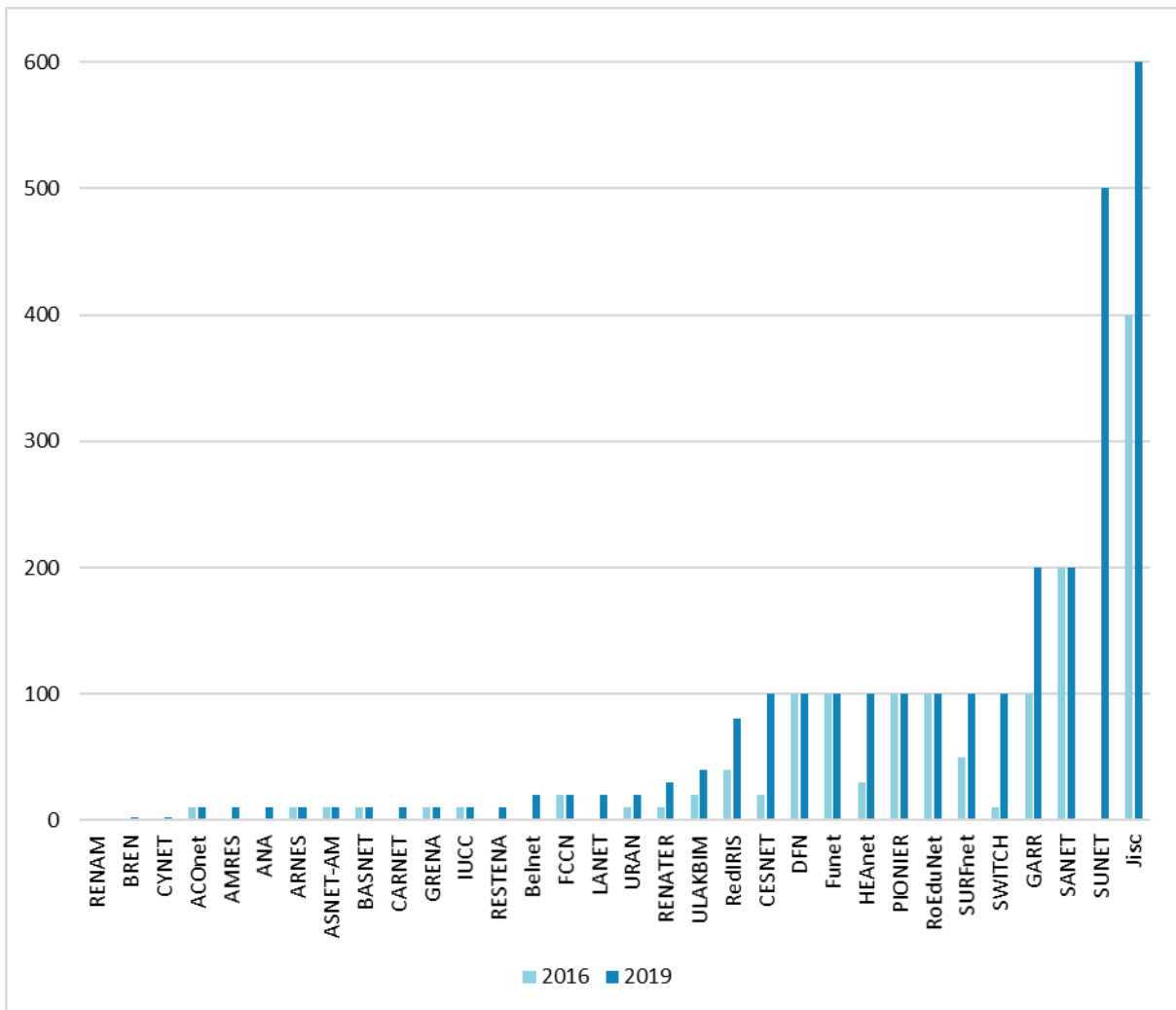
- NORDUnet has taken steps towards building its entire network using spectrum provided by its local NREN members.
- GÉANT will offer a new service in GN4-3 called the Spectrum Connection Service. This service will allow NRENs to inject coloured DWDM light directly into the GÉANT network without the cost of optical–electrical–optical (OEO) conversion at the GÉANT/NREN interface.
- GÉANT will make use of as much NREN spectrum as possible when building the new network in 2020–2022. 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. As such, the capacity of the network has to fit the needs of a country's research and education sector. As a consequence, the different capacities of the NRENs' backbones reflect the size of this sector – as well, of course, as factors such as the funding that is available. An overview of the typical backbone capacity of individual NRENs is shown in Figure 5.7.

NRENs that serve a large research and education sector are increasingly using 100G technology to light their fibre. Twelve NRENs have reported having backbone capacities of 100G or more. Overall, the average capacity of backbones has increased over the years (as can also be seen in Figure 5.7). It is interesting to note, however, that the median capacity has remained at 20G for the past three years. This stability 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), and that increases of the typical capacity result from network renewals, which are undertaken only in intervals of several years.

²³ 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.



Note: The figure shows all NRENs that provided data on their trunk capacity in the 2019 survey. For visual clarity, the years 2017 and 2018 have been omitted from the graph. There have been significant increases for a number of NRENs over four years (URAN, RENATER, ULAKBIM, RedIRIS, CESNET, HEAnet, SURFnet, SWITCH, GARR and Jisc).

Figure 5.7: NRENs’ typical core usable backbone IP trunk in Gbps 2016 to 2019

5.7 Network Peering

“Network peering” refers to the direct exchange of internet traffic between two networks. Settlement-free peering offers the possibility of saving fees for upstream traffic but has the added cost of a presence in an internet exchange.

Most NRENs have at least some direct peering with commercial networks and content providers. The number of peering networks will also vary according to particular needs. Many NRENs aim to cover general internet use with their peering agreements and will therefore limit them to 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.²⁴

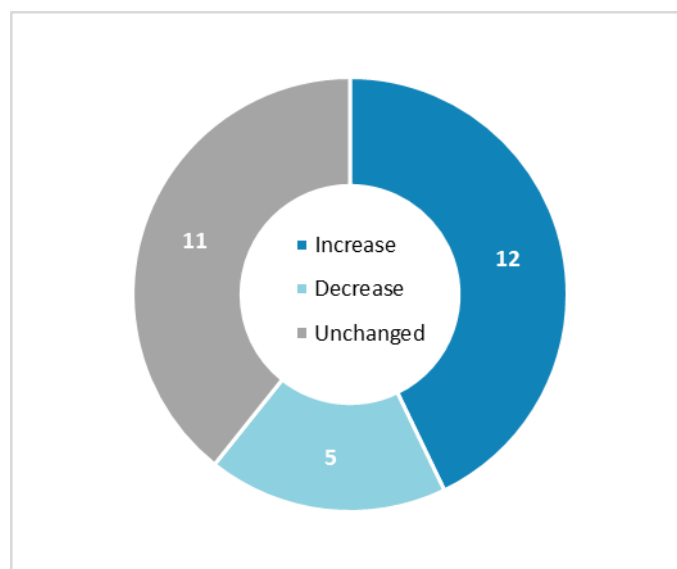
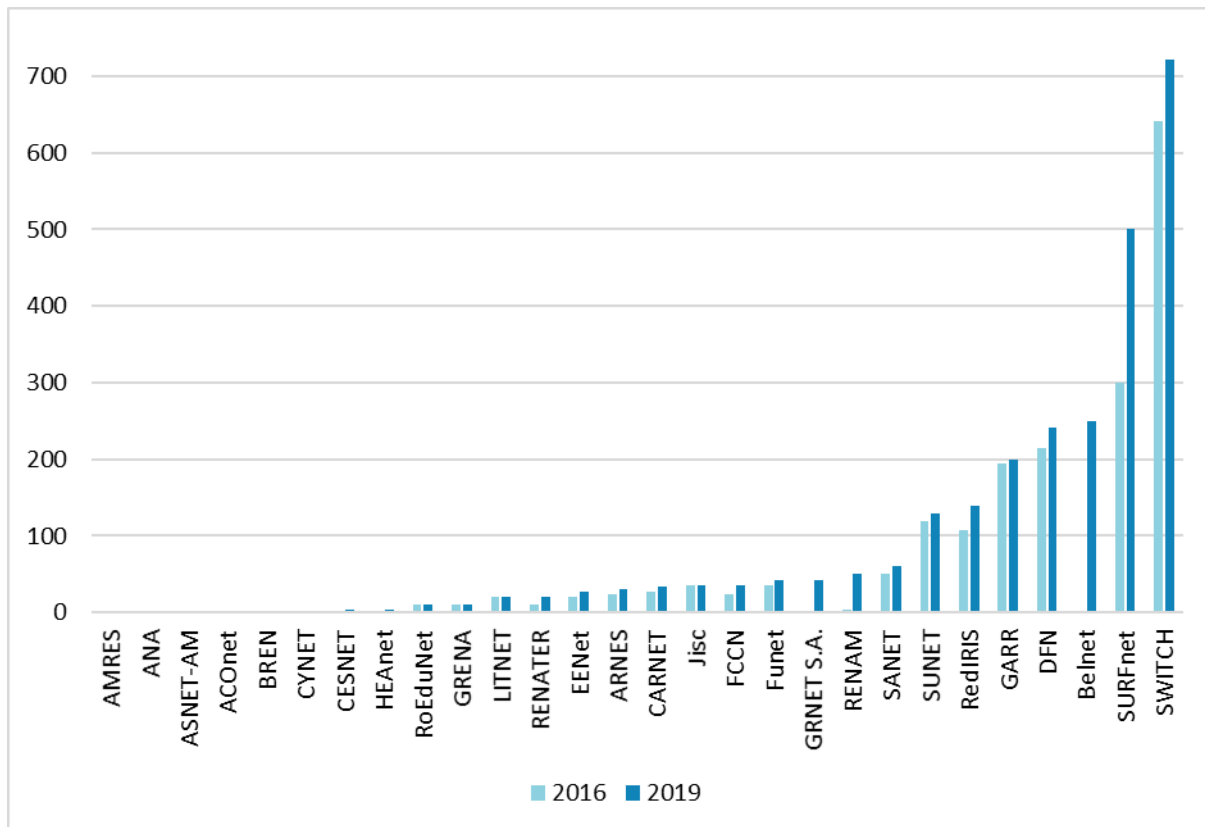


Figure 5.8: Non-R&E network peering development of NRENs 2018 to 2019

In the 2019 survey, of the 30 NRENs responding to this question, 12 reported an increase in the number of non-R&E peering networks, 5 reported a drop, while the remaining 11 NRENs did not see a change in the number of peering agreements (see Figure 5.8). The number of peering agreements per NREN is shown in Figure 5.9.

²⁴ NRENs can negotiate peering agreements with any number of networks and some NRENs maintain a large number of such agreements. Another solution that is available to NRENs is peering services provided by GÉANT. In this case, GÉANT has negotiated peering agreements with a number of commercial networks for its members. Some NRENs make use of both options, possibly complementing the more internationally oriented peering possibilities of the GÉANT services with local peering agreements.



Note: The figure shows numbers for all NRENs that reported on their peering agreements in the 2019 Compendium survey. For visual clarity, the years 2017 and 2018 have been omitted from the graph. Generally, the number of peering agreements has increased for most NRENs between 2016 and 2019, but in most cases only modestly.

Figure 5.9: Number of non-R&E peering networks 2016 to 2019

5.8 GÉANT Network Updates

5.8.1 GÉANT Network and Statistics

The GÉANT network interconnects 43 networks in Europe and has 36 active routers and 19 Infinera transmission nodes. This section presents a snapshot of the GÉANT network, including statistics such as IP/MPLS traffic growth.

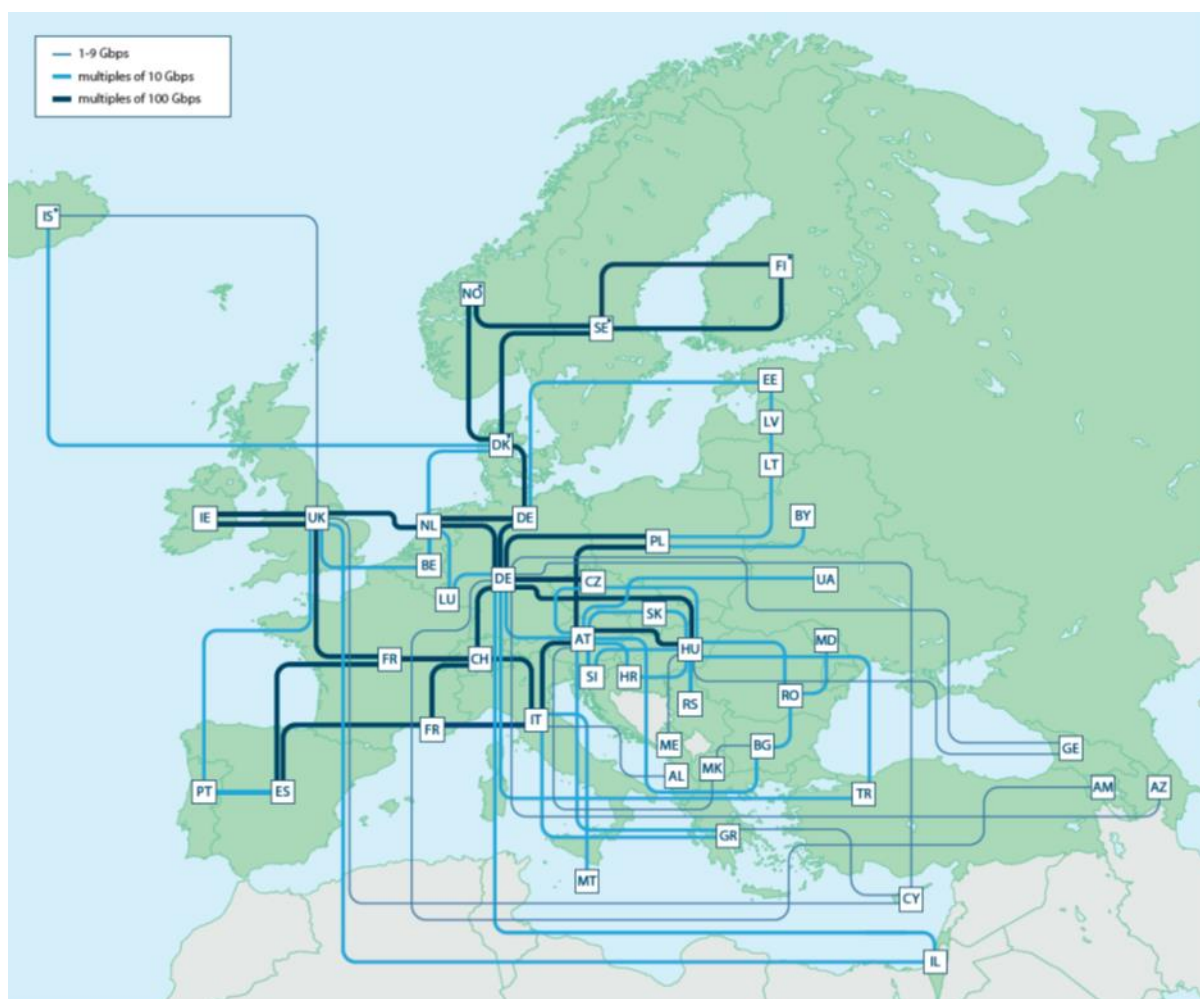
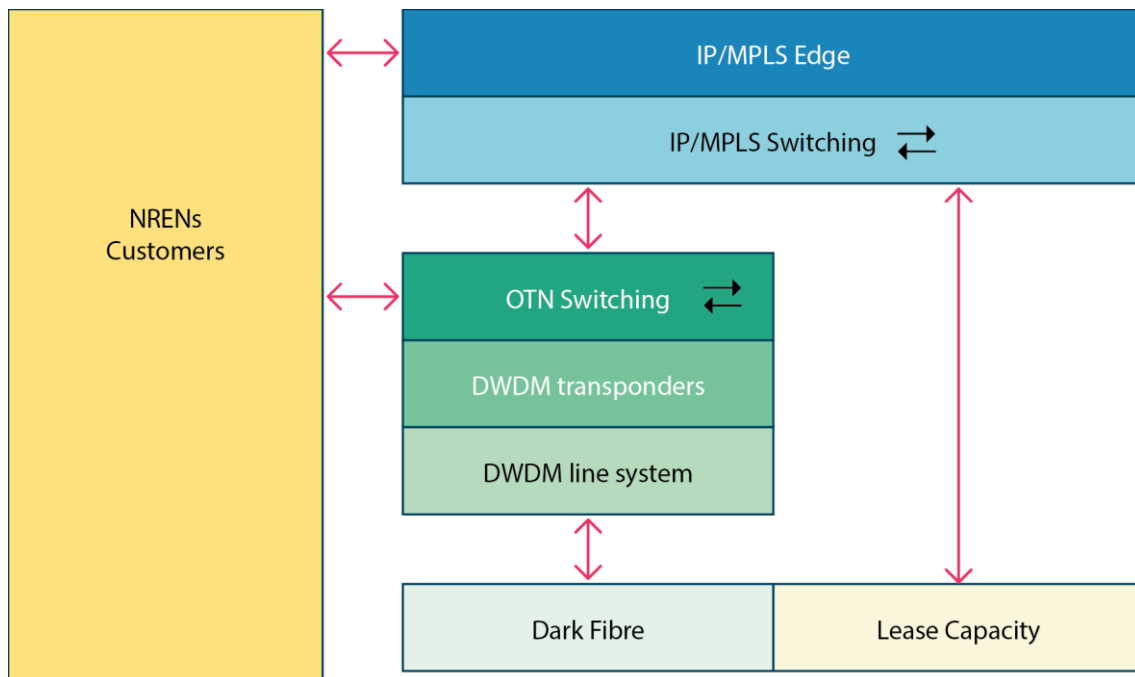


Figure 5.10: GÉANT pan-European network topology map (December 2018).

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 on 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.



Note: 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.

Figure 5.11: The current layered structure of the GÉANT network

5.8.1.2 GÉANT Network Statistics

In 2019 the GÉANT network received over 2.8 Exabytes of traffic, with a daily peak on the IP/MPLS side of more than 1 Tbps. Figure 5.12 shows the year-on-year traffic growth from 2015 to 2019. While growth has been continuous, the growth rate for the whole of GÉANT (IP/MPLS and Lambdas) has slowed down to 17% over the period 2018 to 2019 compared with 26.5% over the period 2017 to 2018.

The picture is different, however, when looking at the two main parts of the network individually. The year-on-year growth for the IP/MPLS network accelerated from about 30% (2017 to 2018) to more than 42% (2018 to 2019), while the Lambda service faced a decline of more than 22%, in contrast with a growth of 21% in the previous period (see Figure 5.12).²⁵

²⁵ This particular decline is mainly caused by the planned decommissioning of the 200 Gbps Lambdas between Geneva and Budapest previously used by CERN to connect to its backup site, which has now moved to a separate location in Geneva. It should be noted, however, that the proportion of traffic accounted for by Lambdas has been decreasing for the past few years, compared to the overall GÉANT traffic as growth rate of Lambda services has been less than for IP/MPLS.

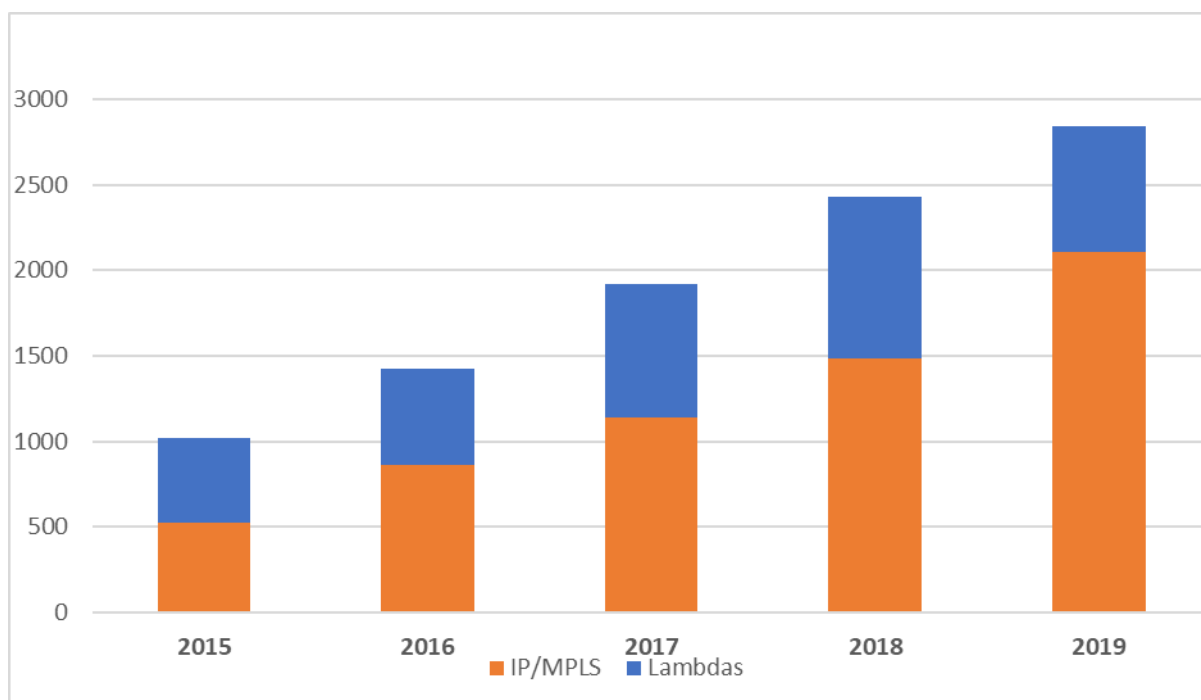


Figure 5.12: Overall volumes of traffic (IP/MPLS and Lambdas) received by GÉANT (in Petabytes) 2015 to 2019

5.8.2 Evolution of the GÉANT Network

5.8.2.1 Network Topology

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

The new, 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).

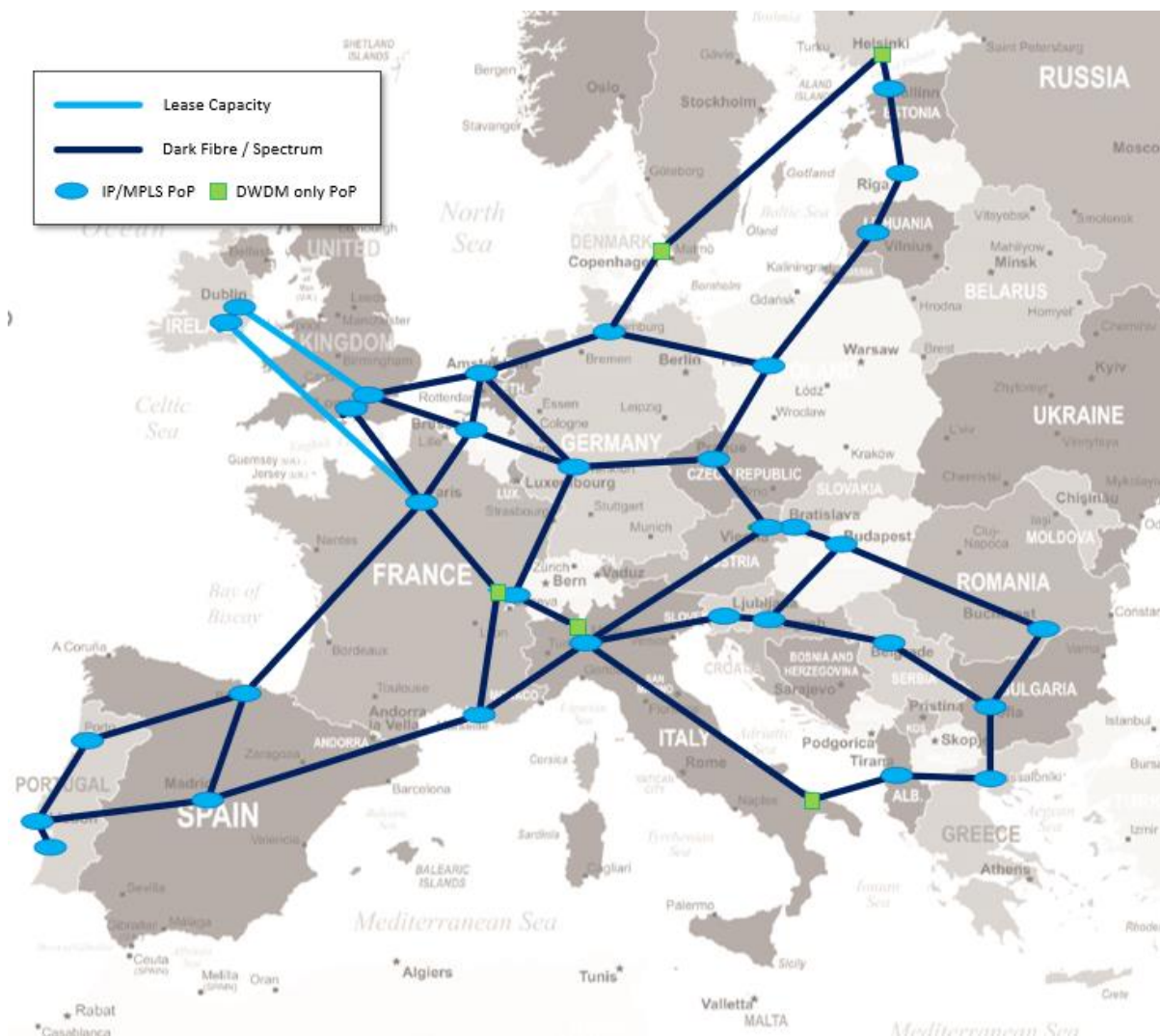
The number of countries connected directly via GÉANT fibre is planned to increase from 14 to 25+ with dark fibre / spectrum routes doubling in number and tripling in length (see Figure 5.13 for details).

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

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.

GN4-3N funding can be directed towards places where it is most needed and infrastructure duplication is minimised.²⁶ Full details can be found in the GÉANT Network Evolution Plan [D7.1].



Note: 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.

Figure 5.13: A view of the current reference topology for GN4-3N

²⁶ 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.

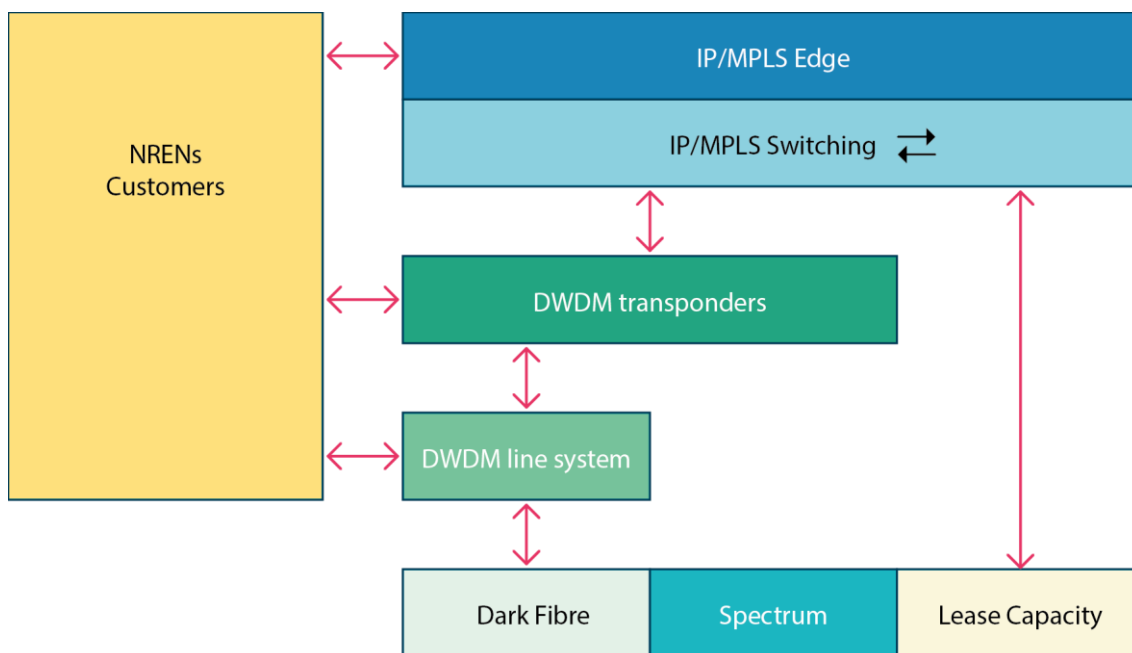
5.8.2.2 Transmission/DWDM

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.

Infinera will deploy its most recent open line system (OLS), FlexILS, combined with transponders in data centre interconnect (DCI) form factor.

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

The new system (shown in Figure 5.14) will also enable GÉANT to share spectrum with NRENs. An activity in GN4-3 is working on defining the parameters of this new service.



Note: 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).

Figure 5.14: Layers of the network as it will be after the transition to a partly disaggregated DWDM 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 Figure 5.11 and Figure 5.14) 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 router (or combination of routers) will be needed by 2022 to support the connectivity requirements of the largest sites. A clear candidate is still not available, as much of the industry is still yet to move to 400G Ethernet at scale.

5.9 Summary

Reflecting the ever-increasing importance of digital services in the R&E world, network traffic keeps growing. At the same time, network capacity is seeing only modest increases – this is valid for the capacity provided for individual customers as well as for the backbone. This is evidence that the 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. The modest overall increase of network capacity is due to some significant updates of individual networks, 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.

6 Security Services

6.1 Introduction

Cyber security is an ever-present 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.

This has two aspects:

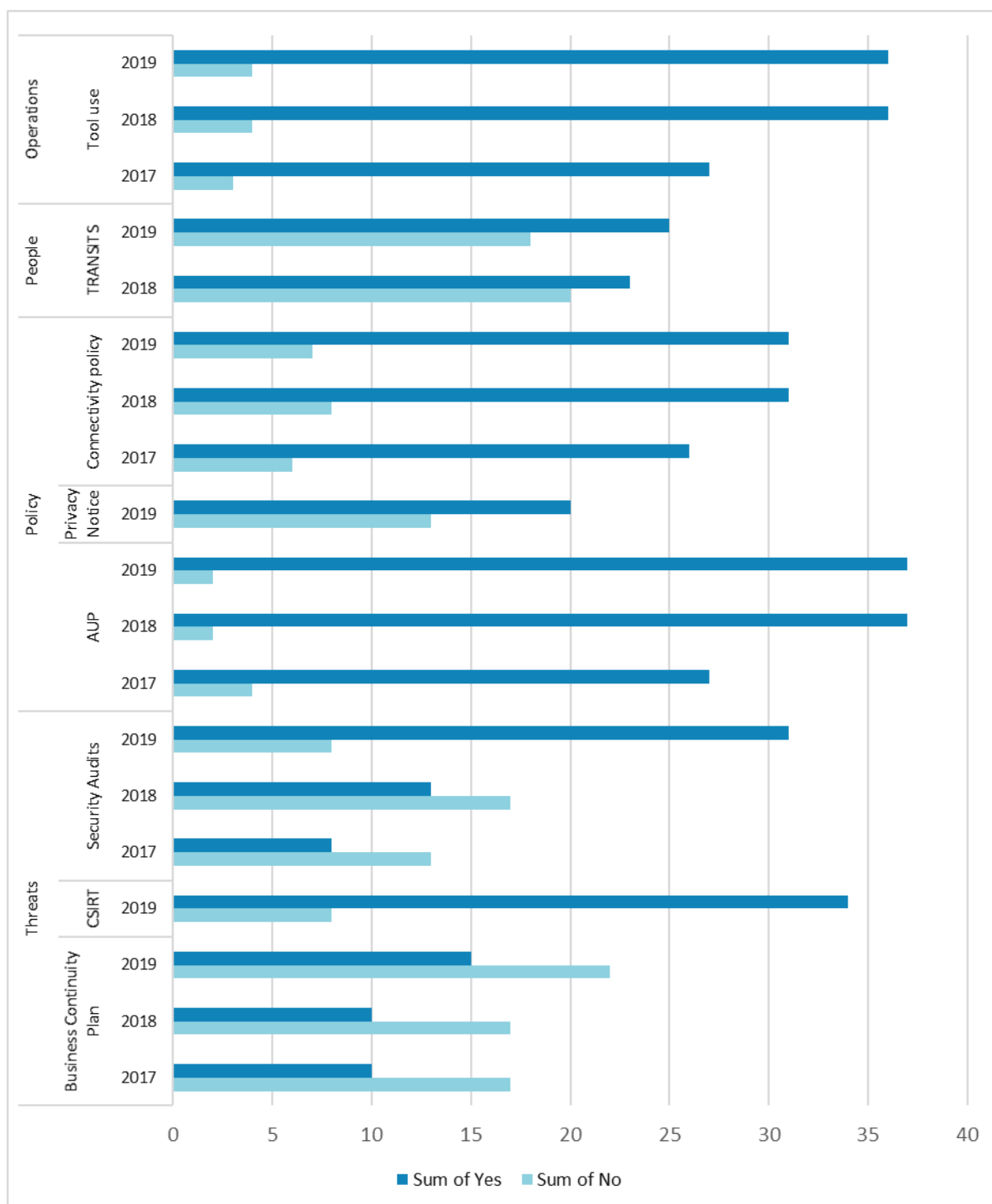
1. Organisational security. The NREN sits in a hub position among many users. These users could potentially be affected by any lapse in cyber security by the NREN.
2. Security services. As service provider and ICT experts, NRENs are also well placed to provide cyber security services to their customers.

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. Also included are externally sourced data from the European Union Agency for Cybersecurity (ENISA) [[ENISA](#)].

6.2 Organisational security

The data on the organisational security of NRENs are presented by area – policy, people, threats and operations – in alignment with the security framework laid out in the *Security Baseline for NRENs* document [[D8.2](#)].²⁷

²⁷ Only some of the sub-topics defined in *Security Baseline for NRENs* can be assessed via the data available to the Compendium and only at a limited level of detail, so a full evaluation of NREN security competence is not within the scope of this report.



Note: Not all data are available for all years.²⁸

Figure 6.1: Development of the adoption of organisational security features by security area

²⁸ 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. The number of surveyed NRENs was 43 for all years. Numbers missing from that count are due to non-responding NRENs.

Policy

An Acceptable Use Policy (AUP) and a Connectivity Policy are important security-related policies. The number of NRENs with such policies has increased since 2017 (see also Section 3.1.2 NRENs' Acceptable Use Policy).

Another important policy area is the adherence to the General Data Protection Regulation (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 2019 only about half of the NRENs stated having a privacy notice and 13 explicitly stated a lack thereof.

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

People

The number of GÉANT NRENs that participate in TRANSITS training (courses designed for computer security incident response team (CSIRT) personnel) is well above 50% (25 in 2019 and 23 in 2018), indicating the NREN community's serious commitment to this aspect of security policy.

Threats

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 CSIRT team. Those NRENs that do not have a CSIRT team usually have this function covered by closely associated organisations. 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.

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 6.2 below.

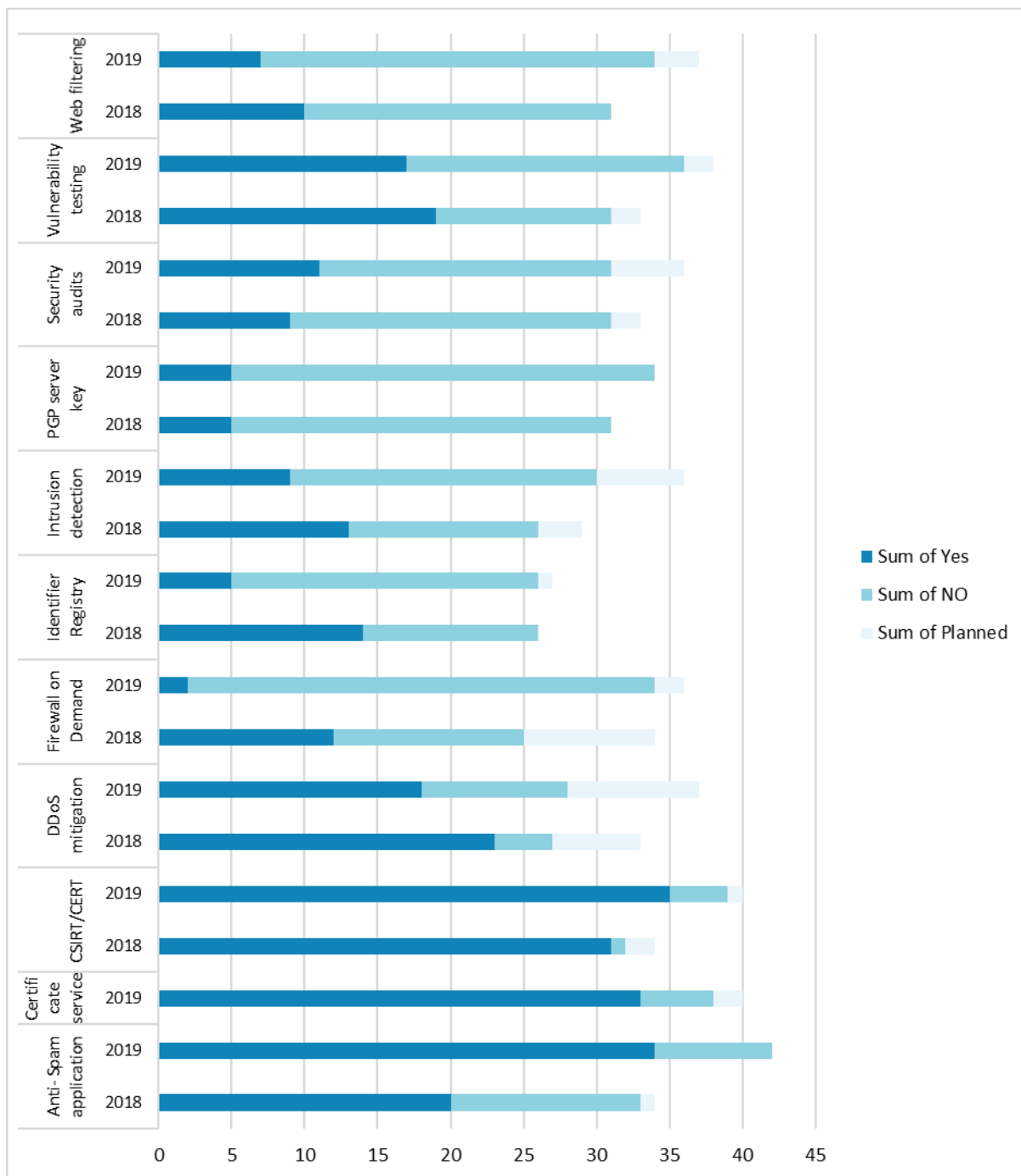


Figure 6.2: Security services offered by NRENs

It is interesting that some of the most basic services (such as Firewall on Demand and web filtering) have apparently disappeared from many NRENs’ portfolio. This might reflect the trend that many fundamental services such as these have become a commodity on the market, so there is not really a need for NRENs to provide such services specifically. The provision of more complex, high-level services such as security incident/emergency handling (CSIRT/CERT) or security audits is either

constant or has increased. However, only larger organisations can offer these services as they require significant manpower and financial resources.²⁹

6.4 Security Community Groups

As with others areas of general interest to the community, the 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.³⁰

- **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.³¹ It maintains a system for registering and accrediting CSIRTs, as well as certifying service standards. The Task Force also develops and provides services for CSIRTs, promotes the use of common standards and procedures for handling security incidents, and coordinates joint initiatives where appropriate. This includes the training of CSIRT staff and assisting in the establishment and development of new CSIRTs.

As for SIG-ISM, between a third and a half of GÉANT NRENs are actively involved in TF-CSIRT.³²

6.5 Summary

Guaranteeing network 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

²⁹ Services such as DDoS mitigation (or some Firewall implementations) require investments and dedicated solutions, so it seems unusual to reduce the service offering 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 do not 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 future Compendium surveys by improving the service questions to allow more detailed responses and by communicating to the NRENs the importance of providing consistent data.

³⁰ 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.

³¹ It is notable that members of TF-CSIRT include not only NRENs but also R&E institutions and commercial organisations.

³² 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.

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.

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 “middleware” services are needed in the management of user identities within the research and education community, to authenticate users, and to authorise access to resources. This is delivered by specific authentication and authorisation infrastructures (AAIs), such as identity federations and eduroam.³³

This section outlines the NRENs’ involvement in the following aspects of T&I:

- REFEDS.
- eduGAIN.
- eduroam.
- Further T&I activities.

7.1 REFEDS

In the R&E community, identity federations (Research and Education Federations or REFEDS) are an important component, enabling access to much of the digital infrastructure of universities and research institutions. REFEDS are usually delivered using a combination of self-built or self-integrated systems, reflecting the organic manner in which these systems have developed as well as the specific requirements of research and education that are not easily met by solutions obtainable on the commercial market.

As of October 2019, there were 82 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 and, except for one, they are operated by the NRENs.³⁴

³³ 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.

³⁴ 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 [\[REFEDS\]](#).

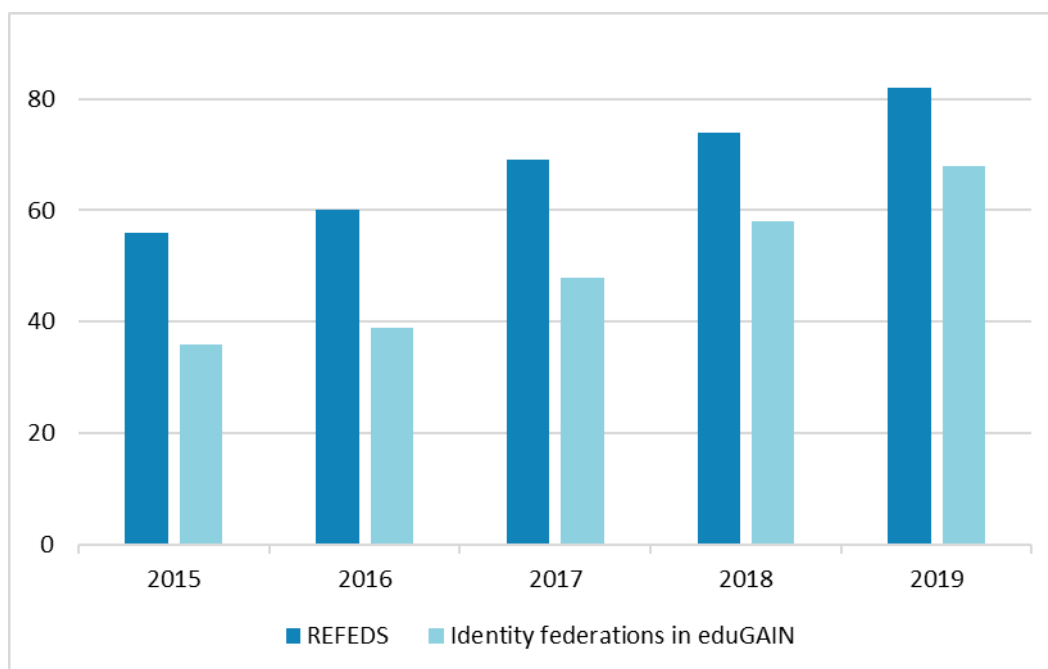
IdPs, SPs and Identity Federations

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

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

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

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



Note: All identity federations in eduGAIN are REFEDS.

Figure 7.1: Number of known REFEDS and number of identity federations using the eduGAIN service 2015–2019

7.1.1 Security 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 authentications to provide secure log-on procedures. These three aspects are explored in more detail below.

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 (and NRENs – see Section 6), but still less than half of the REFEDS (33) in the survey are fully compliant (Figure 7.2).

7.1.1.2 Attribute Release Specifications

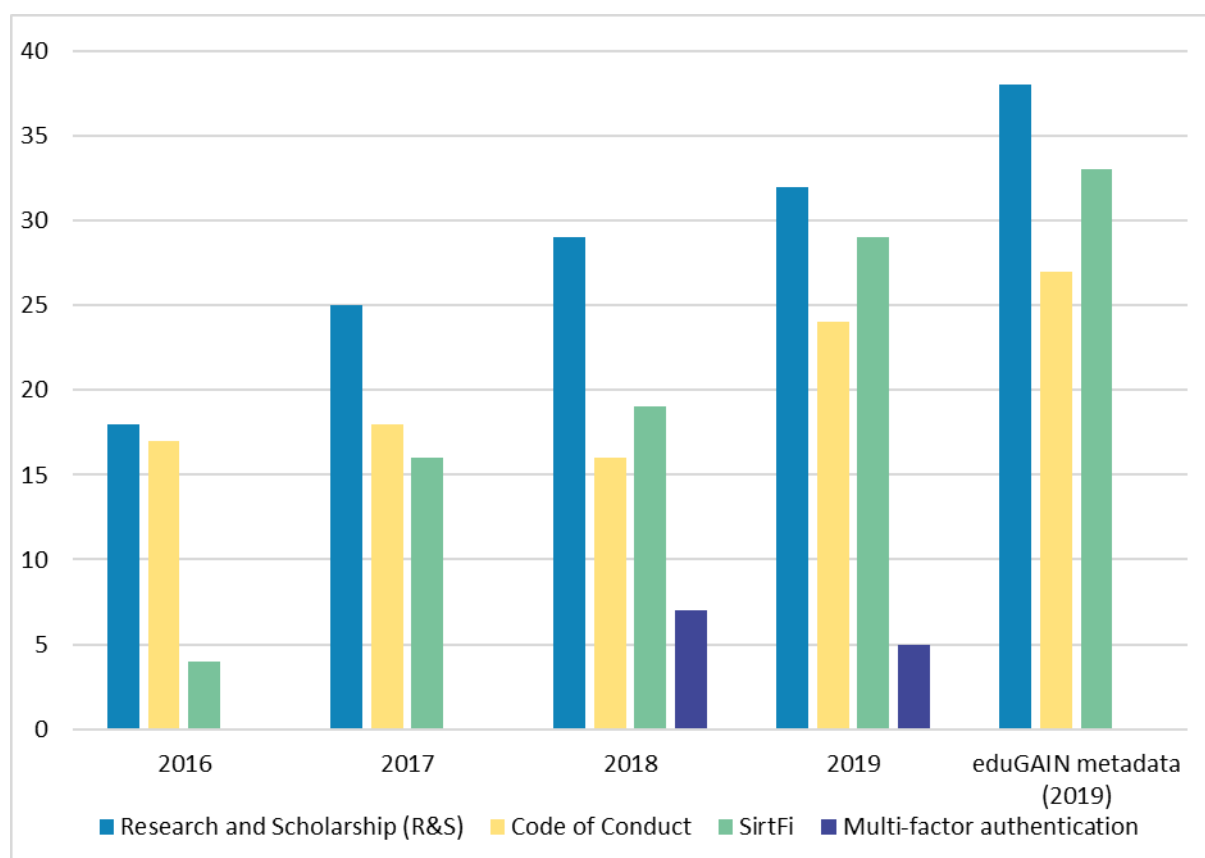
In a federated identity management system, the identity of the user is validated by the identity provider (IdP). If the authentication succeeds, the IdP will release some information (attributes) about the user to the service that initiated the authentication request. The service provider (SP) will use the information to authorise the use of the service. Due to privacy concerns, SPs are recommended to

request only the minimum set of attributes required to deliver the service, as IdPs are very conservative when releasing attributes. To support this process, the REFEDS community has defined specifications with the aim of automating the release of the attributes. One such specification is the Research and Scholarship entity for services (R&S), which enables the automatic release of a limited, specific set of attributes to services that operate in the research and education sector. To facilitate the release of attributes, REFEDS, in collaboration with eduGAIN, has also defined the Data Privacy Code of Conduct (CoCo). Service providers are encouraged to declare compliance with the CoCo, that is, to follow the principles of data minimisation and of attributes processing as defined in the CoCo.³⁵

However, the adoption of REFEDS R&S and the CoCo is only recommended, not mandatory, and only a (growing) minority of REFEDS comply with these standards (see Figure 7.2). This means that a service provider may receive all attributes, or no attributes at all, depending on the IdP. This can have an impact on the user’s experience, as they may not be able to access their desired service.

7.1.1.3 Multi-Factor Authentication

More recently, multi-factor authentication (MFA) has gained traction to improve the security of sign-ons, though so far only a small minority of REFEDs have implemented MFA (Figure 7.2).



Note: The figure shows compliance to the Research and Scholarship attribute release schema, adherence to the Code of Conduct data protection requirements, implementation of the Sirtfi security incident response framework and implementation of multi-factor authentication procedures for log-on. The right-most columns show the adherence to the standards according to data from the eduGAIN service. The higher

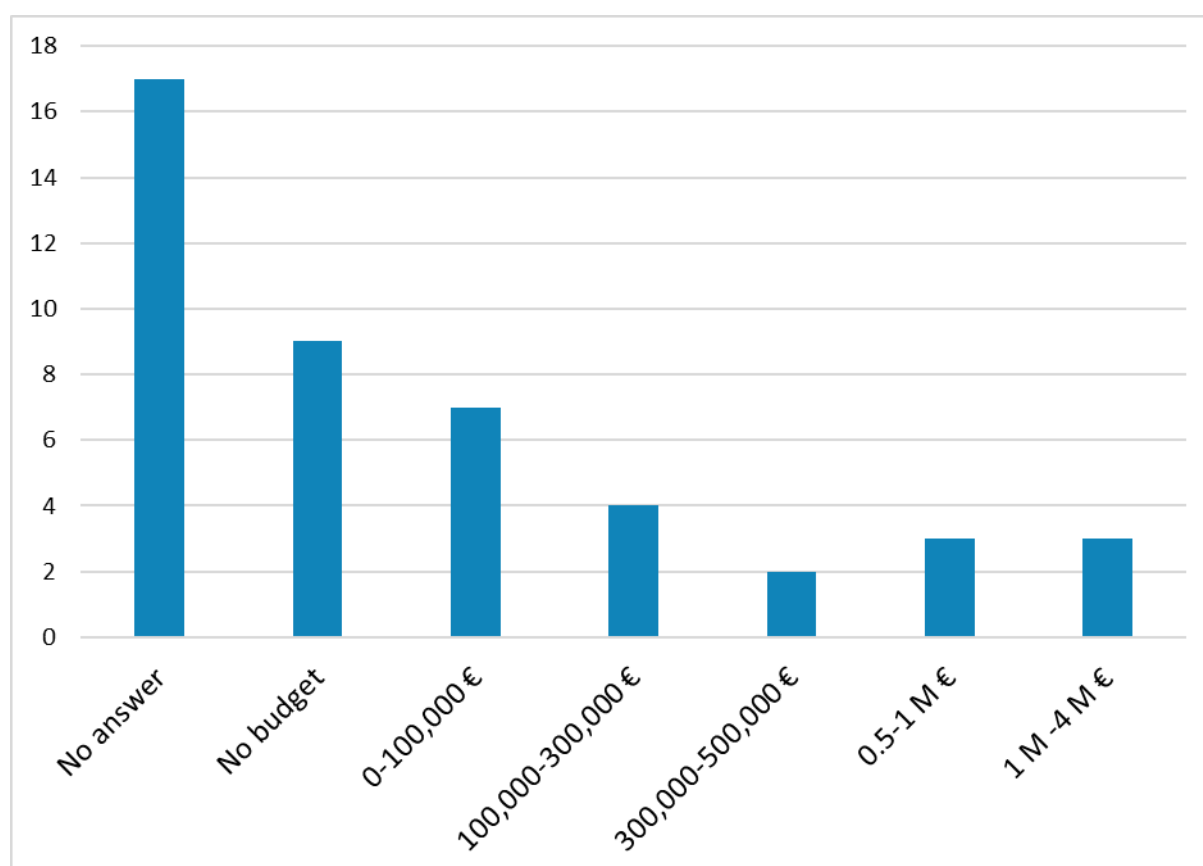
³⁵ More information on R&S and CoCo can be found at [\[REFEDS R&S\]](#) and [\[CoCo\]](#) respectively.

numbers provided by eduGAIN reflect the fact that the response rate to the REFEDS surveys is less than 100%. The counter-intuitive fall in the number of MFA implementations is likely another effect of fluctuations in the response rate of the surveys – it seems unlikely that REFEDs made the considerable effort to introduce this feature only to drop it the following year.

Figure 7.2: Self-reported compliance of REFEDS to various security standards

7.1.2 Identity Federation Budgets

Despite the core role that identity federations play, the budget allocated to them is still rather limited. 73% of federations that responded to the REFEDS survey have less than €100,000 or do not have an allocated budget for their activity (Figure 7.3).



Note: The response rate for this question was relatively low. Nevertheless, it is clear that in many cases this core function has no budget of its own.

Figure 7.3: Budgets allocated to REFEDS according to the REFEDS survey

7.2 eduGAIN

Education and, especially, research are increasingly borderless, which presents a challenge to the mainly nationally organised identity federations. This problem is addressed by eduGAIN, an international interederation service that connects national identity federations [eduGAIN]. eduGAIN

enables the secure exchange of identity information between 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 5,000 in 2019 (Figure 7.5).

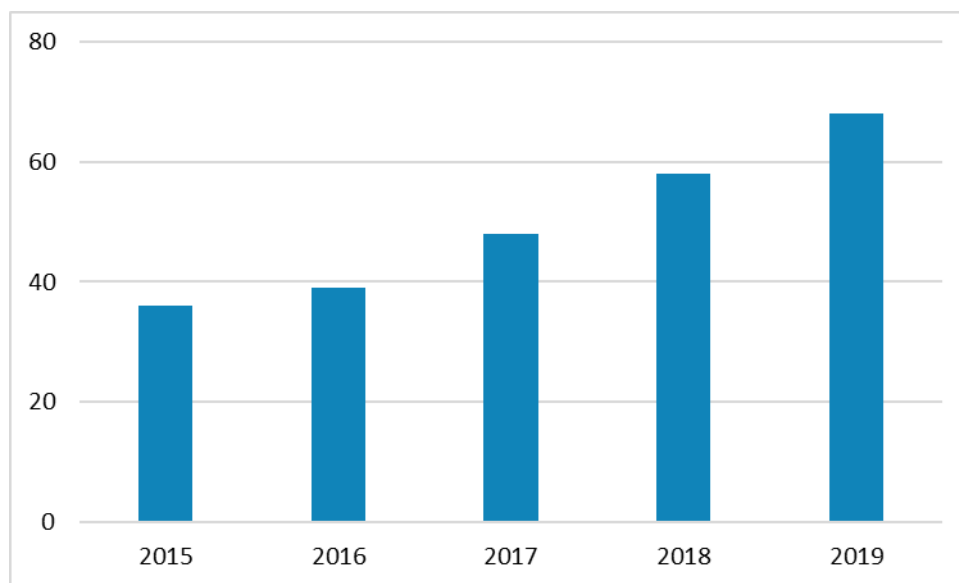
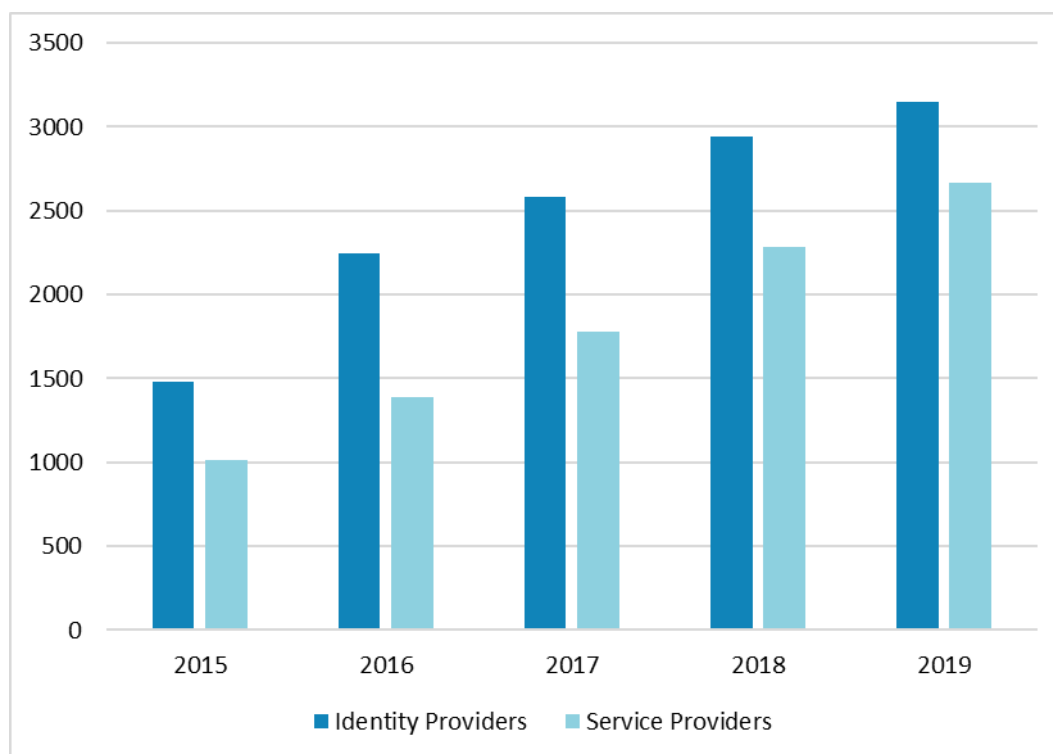


Figure 7.4: Number of identity federations using the eduGAIN inter-federation service 2015–2019



Note: The numbers have increased considerably over the years, though growth rates have slowed slightly (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%).

Figure 7.5: IdPs and SPs that are part of the eduGAIN service

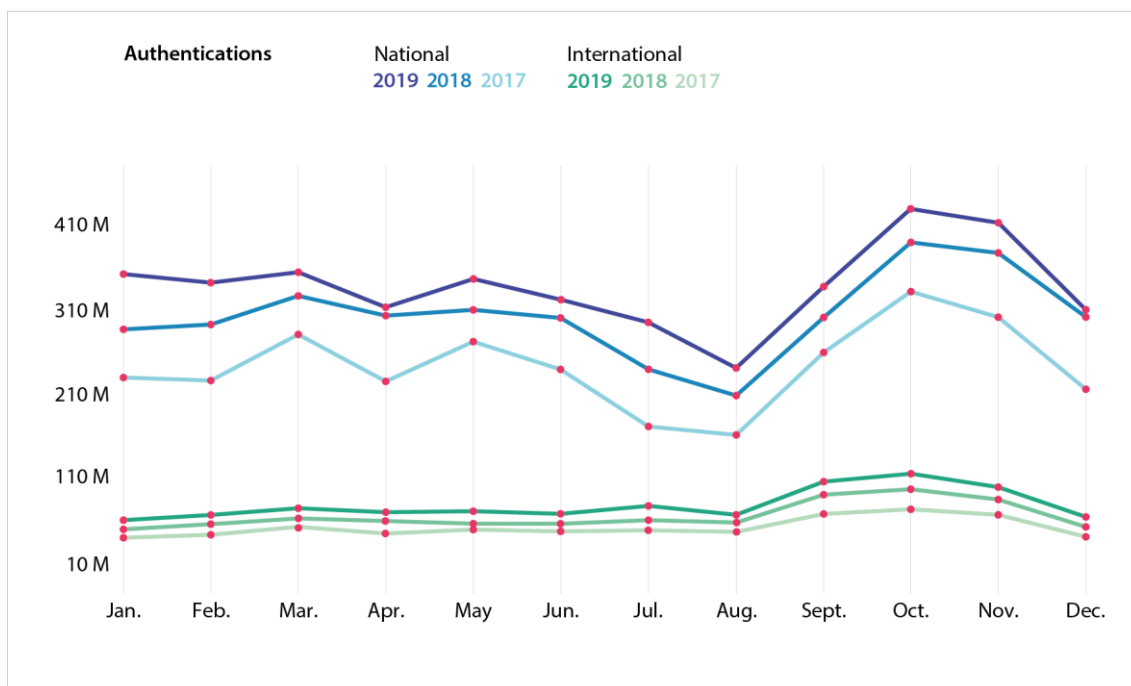
To better address the service providers' expectations as to which attributes they will receive from the various identity providers, discussions have started about defining a baseline of requirements for REFEDS identity federations; once this work is concluded, eduGAIN will require participating federations 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 106 territories. Globally, the service is delivered by regional confederations. The European service is operated by GÉANT for members of the European eduroam federation. This alliance comprises 51 autonomous roaming services who agree to a set of defined organisational and technical requirements that ultimately constitute eduroam.

eduroam is present in almost all European countries (exception: Bosnia), and its usage is growing, as illustrated by Figure 7.6.



Note: The expansion of the eduroam service is reflected in a continuous increase in the number of authentications while the usage pattern remains mostly the same. The majority of authentications happens nationally while international authentications (e.g. visiting scholars, exchange students, etc.) make up about 20% of authentications.

Figure 7.6: Authentications by eduroam month on month for the years 2017–2019

7.4 Further 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.

7.4.1 AARC and eduTEAMS

Building on the larger footprint of eduGAIN and national identity federations, the Authentication and Authorisation for Research and Collaboration (AARC) project (May 2015 to April 2019) investigated how to enable federated access for research collaborations (see also Section 4). It showed how eduGAIN’s solid foundation could be used to transport identity assertions, making it possible to build more complex authentication and authorisation infrastructures (AAs). These AAs address use cases typical of large-scale research collaborations that require group information for authorisation

purposes. AARC delivered a blueprint architecture (AARC BPA) that has become the de facto standard model for building an AAI for any research collaborations with members in multiple countries.³⁶

eduTEAMS is GÉANT's implementation of the AARC BPA (other e-infrastructures have their own implementation) [[eduTEAMS](#)]. eduTEAMS is an "AAI as a service" offered by GÉANT to support research collaborations, or virtual collaborations, and, more generally, to manage virtual teams and access to their resources. The adoption of eduTEAMS has exceeded expectations; by the end of 2019, there were 7 deployments of eduTEAMS for different research infrastructures.

7.4.2 EOSC

AARC's results and, in particular, 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.

7.4.3 Student Mobility and MyAcademicID

Student mobility has always been an area of interest in the NREN community. In recent years, it has received increased focus, with a high number of students applying for grants for the Erasmus student exchange programme every year. The European Commission is supporting the digital transformation of the Erasmus programme via the European Student Card Initiative.

The European NREN community and GÉANT are participating in the MyAcademicID project [[MyAcademicID](#)]. MyAcademicID aims to design and deploy a platform to enable electronic identification and authentication for higher education students through a single European student eID scheme. This will pave the way for easy and secure access to electronic services, simplified administrative procedures and faster information exchange. The European Student eID for Higher Education is the result of the integration of eduGAIN, eIDAS and the European Student Identifier.

7.4.4 InAcademia

With the aim to better support services that are required to validate only whether or not a user is a student, GÉANT and NRENs have worked together to launch InAcademia [[InAcademia](#)]. The service leverages federated access to validate a user's identity and returns a yes/no value; services use this information to determine whether a user is entitled to a discount. In December 2019 the business pilot was concluded and the production service was launched.

7.5 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.

³⁶More information on the AARC blueprint architecture can be found in the AARC2 deliverable *Evolution of the AARC Blueprint Architecture* [[AARC2_DJRA1.4](#)].

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

Cloud computing and cloud services in general is a field that is increasing in importance and expanding in size. This is also the case for the research and education sector. This growth in demand across R&E means NRENs will have a significant and substantial role in the delivery of cloud services. There are three key roles that NRENs can perform:

1. **Providers of cloud services.** A number of NRENs provide cloud services to their customers directly. These services, like the NRENs themselves, are diverse, due to differing local circumstances. Some types of cloud services, such as virtual machines, email and file storage, are more common than others. Across the NREN community, however, all service types are covered, including Infrastructure as a Service (IaaS), Platform as a Service (PaaS) and Software as a Service (SaaS) (see the box in Section 8.1 for an explanation of these terms).

Some NRENs have taken lower-level software services and added value by including more features on top, a common model when providing videoconferencing and media hosting services. These sorts of service offers bring additional financial and manpower costs, and they have to compete with commercial offers, which limits their attractiveness for most NRENs.

2. **Procurement support.** NRENs can leverage the combined buying power of their user bases and reduce the procurement costs through establishing and promoting framework purchasing agreements. A prominent, Europe-wide framework that serves this purpose is the GÉANT 2016 IaaS Framework, which from 2020 onwards will be replaced by the GÉANT IaaS+ Framework, the tender for which is run by the Open Clouds for Research Environments project (OCRE) [[OCRE](#)].
3. **Centres of excellence.** In this role, NRENs can leverage the knowledge and expertise they have gained to advise institutions in their countries on the best cloud adoption path. This approach minimises the cloud adoption “learning curve” amongst the different user groups and reduces the need for relearning (often relearning the same mistakes) within groups that are similar. This maximises the knowledge capital of the region and group. In addition, NRENs themselves share their expertise with other NRENs across the community.

NRENs can (and often do) perform multiple roles, depending on the requirements of their users, the regulations controlling the operation of the NREN, and the skills and resources available to the NREN.

This section presents data from the NREN Compendium survey, where NRENs provide data about their service portfolio, and from GÉANT’s Cloud team. These two sources illustrate:

- The cloud services that the NRENs offer to their customers as part of their service portfolio.
- The support that NRENs offer their customers in the procurement of commercial cloud services via the GÉANT 2016 IaaS Framework.

8.1 Cloud Service Portfolios

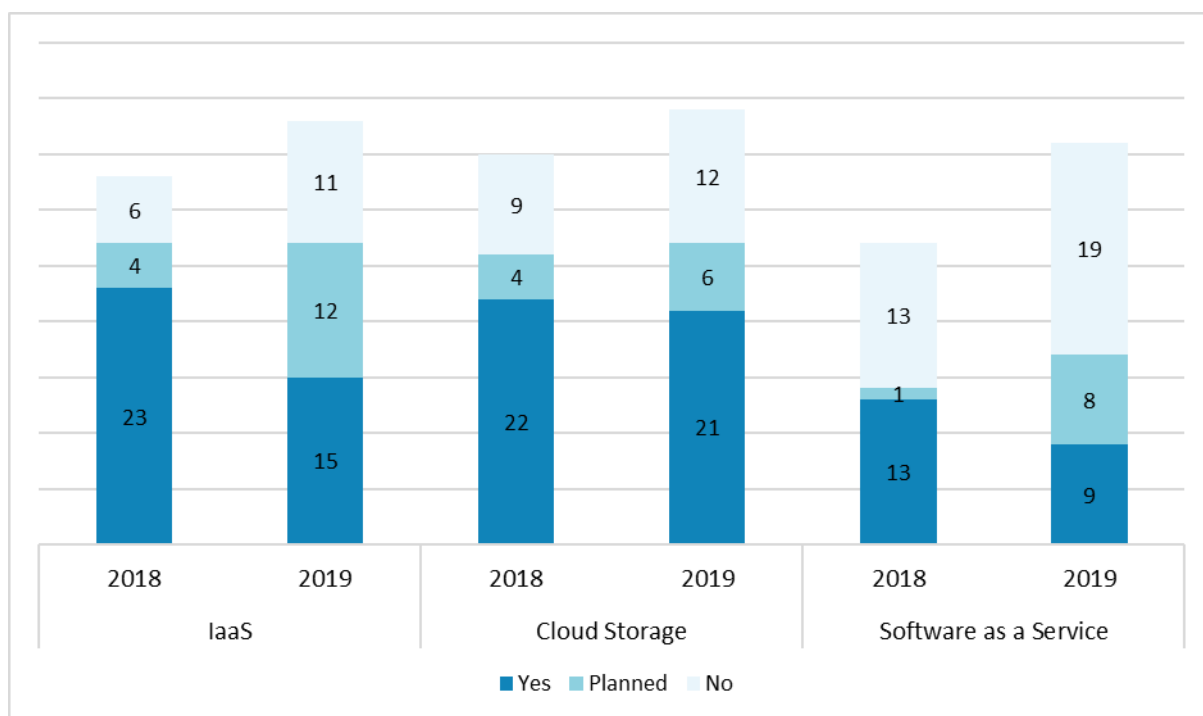
The Compendium survey asked about three types of cloud services in the service portfolio of NRENS: IaaS, cloud storage and, very generically, SaaS (excluding file storage). According to the data the NRENS provided (summarised in Figure 8.1 below), the provision of all three types of services has decreased. The strongest fall was recorded for IaaS, which only 15 NRENS reported offering to their clients, as opposed to 23 in 2018. Furthermore, SaaS and cloud storage are offered by fewer NRENS (9 vs. 13 and 22 vs. 21, respectively). However, there is some uncertainty here, as not all NRENS have provided this information. The reported reduction might well reflect the easy commercial availability of these services, which would make dedicated in-house services provided by the NRENS obsolete.³⁷

Interestingly though, NRENS did report an intention to increase their cloud service offering in the coming year. While some NRENS have closed down certain cloud services, others (and in some cases the same NRENS) plan to add various cloud services to their portfolio. This likely reflects the changing cloudscape as well: while many cloud services have become a commodity that is best procured on the open market, some requirements are not always easily guaranteed by commercial providers (predominantly due to data privacy and data security concerns), which opens a niche for cloud services provided by NRENS.

Cloud Services

Generally, cloud services are distinguished as either Infrastructure as a Service (IaaS), or cloud-delivered Platform as a Service (PaaS) and Software as a Service (SaaS) solutions. IaaS provides the customer with a virtual data centre but leaves the choice of operation systems and software entirely to the customer. PaaS offerings are cloud-based software development platforms. Depending on the type of applications to be developed these vary widely in complexity. SaaS provides the customer with an application through the web. As virtually any application type can be provided through the cloud, this is a very diverse area. Typical applications would be file storage applications (e.g. Dropbox), and videoconferencing but also complex systems such as learning management systems (LMS). For simplicity, PaaS and SaaS are combined under the SaaS label in this section.

³⁷ However, the changes shown in Figure 8.1 are subject to the same problems that are discussed in Footnote 29. The questions about services do not allow for differentiation between different implementations – which could explain the observed reduction in the number of NRENS that responded, as no suitable response option was offered. Such fluctuations in the response rate can generate anomalies in the data. We will strive to mitigate this in future Compendium surveys by improving the service questions to allow more detailed responses and by communicating to the NRENS the importance of providing consistent data.



Note: 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.

Figure 8.1: Availability of cloud services from NRENs

8.2 Community Clouds

While commercial clouds are driving NRENs to retreat from offering cloud services in some areas, there is also an opposing trend in that several NRENs are offering community clouds. This can mean either running cloud servers themselves or supporting their customers in doing so.³⁸ There are a few different reasons for offering this service.

Many NRENs have invested time and effort in in-house cloud services and have built a strong user base within their members; giving up such well-established services is not necessarily a good business decision.

Another important motivation to invest in community clouds is an unease among NRENs and their member institutions about the consequences of relying entirely on services procured from commercial actors. The security of data stored overseas, outside the European Union, is a growing concern, as well as vendor lock-in, trust, ownership questions and the difficulty of predicting cost.

³⁸ The platform of choice for such private clouds is often provided by VMware Inc. or OpenStack, but in addition many NRENs also offer cloud services that are tailored towards a specific community. Today these services mostly encompass IaaS. Moving beyond the internal private cloud, a strategic goal for most NRENs is to offer or support a cloud service to their own community, e.g. IaaS (VMs), storage and container-orchestration systems such as Kubernetes, or SaaS services such as the OnlyOffice (Ascensio SIA) platform for document management, Jupyter Notebook, Galaxy portal, Chipster portal and Jupyter Hub.

During the preparation phase of GN4-3, there were therefore voices suggesting that the project should also investigate the potential for a community cloud offering, building on existing mechanisms for federation on top of national cloud services and suitable use cases.

While a number of NRENs successfully run community clouds – examples include GARR, SWITCH, GRNET, Funet and CESNET – there are challenges to this approach. Running a community cloud service for a large number of users is a complex and costly task, in terms of both capital expenditure and, especially, operating expenditure.³⁹

The aim of the community effort within the NREN community is therefore to foster collaboration among NRENs and also to ensure that the services would be in line with community requirements and provide interoperability based around GÉANT standards. An important step that is being considered is to federate the national community cloud services on an international level. The success of the federated approach has been proven in the past, with successful services such as eduroam and eduGAIN.⁴⁰

Scaling up these services to the pan-European level would enable a wider user base. Collaboration on development between NRENs should ease the cost burden through sharing of cloud expertise.⁴¹

8.3 Cloud Service Procurement

Even though the number of cloud-based services offered by NRENs themselves decreased between 2018 and 2019, the overall demand for such services has increased. Thanks to technological advances and the benefits of scale, the quality of available cloud services has grown immensely, while prices have plummeted. Most NRENs could not satisfy this demand with home-grown cloud services.

8.3.1 The GÉANT Infrastructure as a Service Framework

NRENs have reacted by reducing the services they themselves offer, but increasingly provide procurement support for commercial cloud services. An example of this is the GÉANT 2016 IaaS Framework [[IaaS Framework](#)], an EU-compliant procurement framework for cloud infrastructure as a

³⁹ Providing a community service requires a number of elements:

- Network interconnection.
- Support for AAI, such as eduGAIN.
- Client environment integration.
- Supporting a multi-tenant environment.
- Security requirements and data protection, e.g. for sensitive data.
- Pricing models.
- Service level agreements (SLAs).
- User-support.

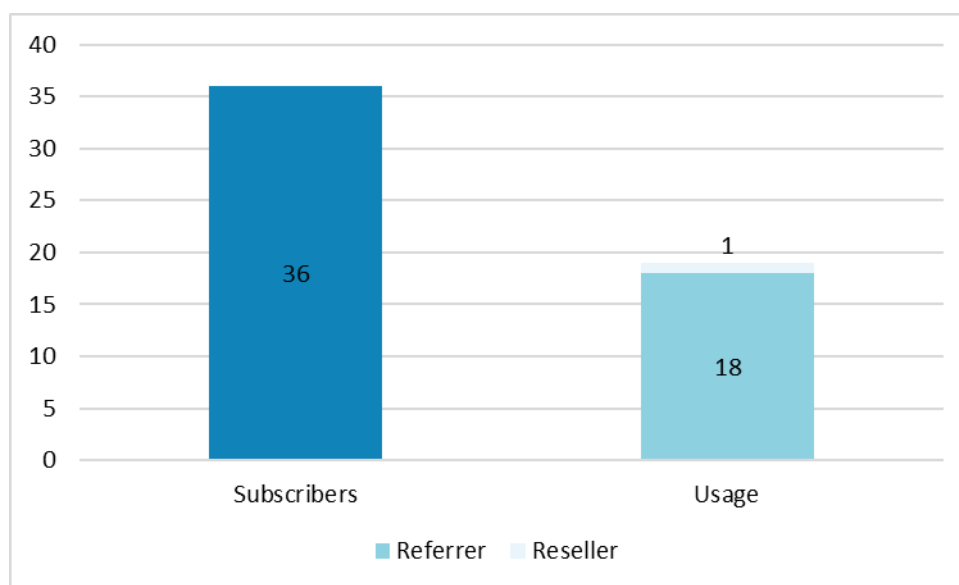
Skills and capabilities with respect to SLAs, user support and pricing differ. Among the NRENs, only a few provide all of the elements listed above for selected service models, while most provide a subset, typically user support and single sign-on through eduGAIN.

⁴⁰ There are challenges here, though: the remote access of cloud services would be a considerable drain on local services, which might make this practical only for some cloud services.

⁴¹ A community cloud service offering is being progressed in GN4-3 by Work Package 4 Network Infrastructure and Services Operations.

service.⁴² The aim was (and is) to save institutions the time-consuming and complex process of doing the procurement themselves.

The Framework allows the NRENs to act as brokers for third-party cloud providers, either as a referrer or as reseller (Figure 8.2). As a referrer (the preferred role, adopted by 35 of the NRENs participating in the survey), the NREN helps to set up the contract between the supplier and the cloud user; as a reseller (only one NREN, SURF, acted as such), the NREN purchases/negotiates via the Framework Agreement and then resells services to its customers. There are advantages to this approach (such as simplicity and certainty for the provider, resulting in better terms) but it also entails a higher risk for the NREN.



Note: “Subscribers” is the number of NRENs that were part of the Framework; “Usage” is the number of NRENs that actually made use of it, divided into those acting as referrers and those acting as resellers.

Figure 8.2: Role of NRENs in the procurement of cloud services through the GÉANT IaaS Framework

While the IaaS Framework is not the only method R&E institutions can use to procure cloud services,⁴³ and therefore it cannot claim to present all the cloud expenses of the NRENs’ customers,⁴⁴ its use is a

⁴² The procurement and adoption of Software as a Service (SaaS) solutions across the R&E community is more complex. This is due to two key factors:

Complexity. The range of SaaS solutions tends to require very specific skills and expertise to operate.

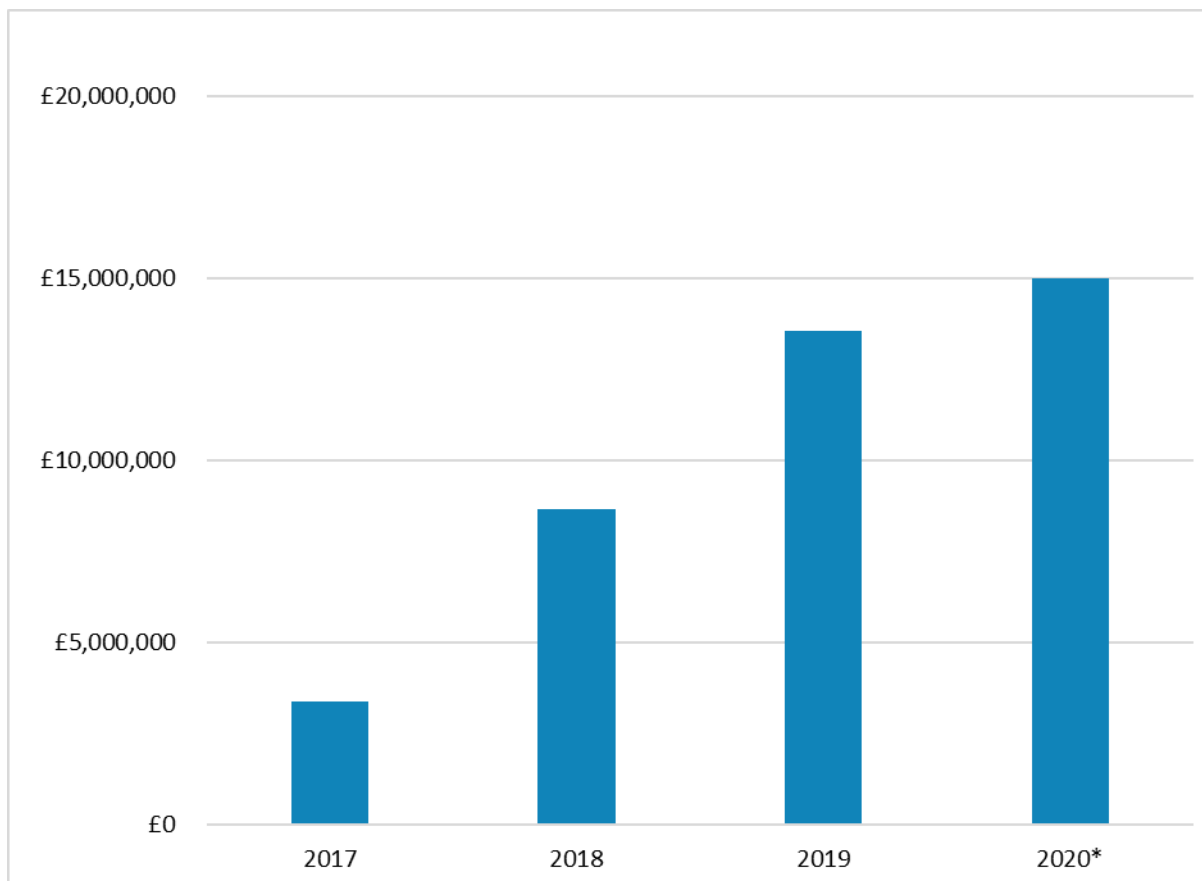
Diversity. The wide diversity of software solutions required within the European R&E context results in a very diffuse application set.

This complexity and diversity of solutions made it difficult to include SaaS solutions in the original IaaS framework. Nevertheless, work was done to facilitate the procurement of SaaS solutions in four key areas: collaboration suites, learning management platforms, file sync and share, web- and videoconferencing.

⁴³ 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).

⁴⁴ To put the numbers from the IaaS Framework in perspective: most enterprises of 1,000 employees spend in excess of 1 million euro/year on cloud services. At a Europe-wide level, NRENs as a whole service more than 20M users, i.e. the consumption levels of cloud resources through the Framework are very small. The upcoming GÉANT IaaS+ Framework, the tender for which is run by OCRE, hopes to significantly increase this, building on the relative success of the 2016 IaaS Framework.

good indicator of the increasing demand for cloud services. This is illustrated by the sums shown in Figure 8.3, which sets out the yearly consumption through the Framework. From very modest beginnings, the expenses soared to an estimated €15 million in the running year 2020, the last year of the IaaS Framework.



Note: * The numbers for 2020 year are an estimate.

Figure 8.3: Cloud service consumption through the IaaS Framework

On the surface, the growth shown in Figure 8.3 looks impressive, but a closer look is merited. From Figure 8.2 it is already apparent that only a subset of the NRENs participating in the IaaS Framework actually used it. The picture becomes even more lopsided when looking at the country level (Table 8.1). Here it becomes clear that only a small number of NRENs are responsible for the vast majority of the cloud consumption and that one NREN, SURF, is responsible for almost three quarters of the total spending.⁴⁵

⁴⁵ Using the IaaS Framework, SURF established SURFcumulus [SURFcumulus], a subscription service for its customers that provides a single point of access for consumption (and billing) of all cloud offers within the IaaS Framework. SURF is acting like a reseller for this service, but as a not-for-profit organisation only recoups its costs. SURF started this venture very early during the tenure of the IaaS Framework and became very successful, which explains the huge share it has in in the overall expenses through the Framework. Interestingly, other NRENs are considering similar concepts, at least partially motivated by the Dutch example. However, this is not an option that will be available for all NRENs, as it requires resources and a legal set-up that not all NRENs have.

The geographical variation results from different factors, but the most important is clearly the resources an NREN can commit to the promotion and support of the IaaS Framework among its customers. How readily the R&E sector of a given country is embracing cloud services has, in the past, been a major differentiating factor between countries.

NREN	SUM
LitNet	1,948 €
RESTENA	2,500 €
Switch	19,806 €
FCT FCCN	27,350 €
DFN	37,895 €
CYNET	38,107 €
CESNET	59,300 €
GEANT	191,036 €
ACOnet	191,037 €
CARNET	308,963 €
CSC	334,237 €
Belnet	618,426 €
DEIC	784,284 €
REDIRIS	1,133,766 €
JISC	1,197,571 €
UNINETT	1,720,286 €
SUNET	1,773,105 €
HEANET	1,812,443 €
SURF	30,000,000 €

Note: Due to the inclusion of 2020, the numbers are estimates.

Table 8.1: The funds spent during the tenure of the IaaS Framework (2017–2020), by NREN

8.3.2 Moving to IaaS+

The GÉANT IaaS+ Framework will be the successor to the 2016 IaaS Framework. The tender for the IaaS+ Framework is run by the Open Clouds for Research Environments project (OCRE) [OCRE]. OCRE was launched in January 2019 and has been running a pan-European tender to establish framework agreements with cloud service providers that meet the specific requirements of the research community. The IaaS+ Framework will become available for users in 2021. As with the 2016 IaaS Framework, and benefiting from the learning experiences provided by its predecessor, IaaS+ will include IaaS offers but, in addition, it will also include any other cloud-delivered solution (such as PaaS and SaaS) that originates from the same IP owner/licensor that provides the IaaS element. IaaS+ will

also include providers of Earth Observation (EO) services.⁴⁶ The new Framework aims to accelerate the adoption of all these services in the European research community through providing ready-to-use services.

8.4 Issues Affecting Adoption of Cloud Services

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

- **Legislation and Regulations.** With data privacy laws being strengthened in the EU and at country level, there is a direct impact on cloud delivery. In particular, the new EU General Data Protection Regulation (GDPR) has direct implications for:
 - Institutions using clouds: data controllers.
 - Providers offering these clouds: data processors.

These issues affect both in-house and externally sourced services, but with in-house services there is a perception that the risks are lower. With externally sourced services, contracts have to be checked and revised, and processes on the supply and demand side have had to be changed.

- **Standardisation.** Data interoperability and portability between different clouds are still in their infancy. The absence of common standards and supplier unwillingness leads to “data islands” and vendor lock-ins.
- **Scalability.** As cloud services develop from “commodity” infrastructure platforms into more complex managed software offerings, it is likely that NRENs will face scalability issues, since the need to support multiple software platforms will require substantial resources.
- **Uncertainty and Risk Aversion.** Many institutions are adopting a “me second” approach to cloud adoption – waiting for other institutions to be the leaders. The NREN community will continue to share user experience and coordinate best practice examples to reduce the uncertainty of cloud adoption.

8.5 Summary

The service landscape and procurement models for cloud services to support research and education have now matured considerably, and cloud services are becoming a significant part of the service offering for many NRENs, via a number of different delivery models for R&E services.

The data presented here are consistent with the R&E world’s gradual move towards the use of commercial cloud services. The lower number of cloud services that are offered by NRENs directly

⁴⁶ The Earth Observation (EO) services that can be procured through the IaaS+ Framework are based on Copernicus [[Copernicus](#)]. Copernicus is the EO programme of the EU, run by the European Space Agency in partnership with the European Commission. It integrates global data from satellites and from ground-based, airborne and seaborne measurement systems that can be used for environmental, geospatial and security-related applications.

could be read as a consequence of this trend. Nevertheless, the expectation would be that NRENs will keep offering cloud-based services, but that they will target niches where their customers do not trust the commercial offerings. At the same time, NRENs have moved increasingly to help their customer base to adopt cloud technology – which prominently includes the procurement frameworks discussed in this section – with many NRENs also positioning themselves as centres of excellence to enable further uptake of cloud services by institutions, essentially providing consultancy services to their customers.

9 Education

9.1 Introduction

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

This section gives an overview of the activities of NRENs in supporting education, detailing how many and which services they offer, and also gives a brief overview of the services.

This is a new section in the Compendium, and is based on the work of the Task Force on Educational Technologies (TF-EDU) [[TF-EDU](#)],⁴⁷ in particular on two surveys among NRENs about their activities in education, carried out in 2019 and 2020.

9.2 Methodology

The surveys carried out by TF-EDU defined a number of service types (see Education 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 service-level services and services in development.⁴⁸

As this section seeks to give an overview of the current state of the educational activities among NRENs, it presents a synthesis of the two surveys rather than a comparison of their results.⁴⁹

⁴⁷ 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.

⁴⁸ 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.

⁴⁹ The two surveys differed slightly in the service types they asked about (10 in 2019 and 12 in 2018, with some overlap between them). This section therefore lists 14 possible services. This synthesis seems justified as it focuses on established (i.e. service level) services which are unlikely to have changed within the year that separates the two surveys.

9.3 Education Services

The NRENs were asked about 14 different service types across the two surveys:

- Digital learning environment (DLE).
- Providing e-content online.
- Blended and remote delivery of education nationally.
- Digital assessment and testing.
- Open badges/digital credentialing.
- Learning analytics.
- Educational staff skills training.
- Transnational education (delivery of national education overseas).
- In-house-built tools for digital learning.
- Student management systems.
- Trust and identity for education.
- Anti-plagiarism.
- Educational data mining and analytics.
- Videoconferencing for education.

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

- Blended education refers to systems that allow a mixture of face-to-face and ICT-based educational activities, learning materials and tools.
- An open badge / micro credential is a validated indicator of an accomplishment or skill that can be earned in a learning environment. Usually these are like mini degrees or certifications (hence “micro”). This enters the realm of NREN competence when it takes the form of a digital certificate.
- Learning analytics refers to collecting, analysing and reporting data from learning environments in order to improve the learning process of students. This information can then be made available to students, teachers or training management.
- Student management systems are software systems for the administration, documentation, tracking, reporting and delivery of educational courses and student performances.
- Trust and identity (T&I) for education refers to T&I applications that are specific for educational purposes, e.g. an educational ID (eduID) that works like an electronic student ID.

Figure 9.1 provides an overview of how common the different services are. Videoconferencing tools are 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. Another relatively common service is the provision of digital learning environments, and the large number of DLE services in development

suggests there might be more to come.⁵⁰ The other services are less common. It is perhaps somewhat surprising that only a small number of NRENs are offering education-specific T&I applications, given that this is one of the core competences of NRENs. On the other hand, this area sees a lot of services in development, so the low numbers here possibly reflect the relative recency of this development.

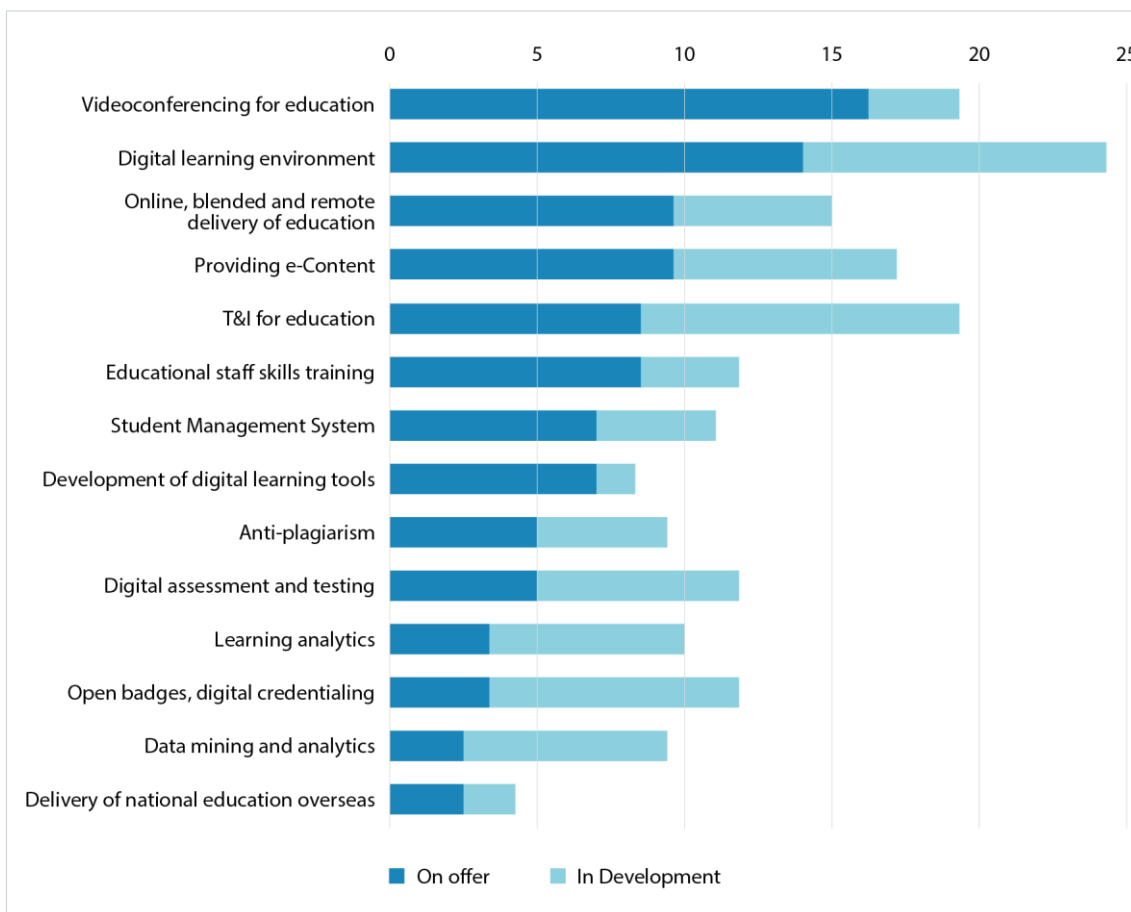


Figure 9.1: Education services provided by NRENs as well as services in development

9.4 NRENs’ Education Portfolio

Figure 9.2 shows that the majority of NRENs offer services that specifically target education, though the extent of the commitment differs.

⁵⁰ As ICT procurement is a service that many NRENs offer, this number may include procurement support for DLEs – the question did not allow this to be specified. This highlights a blind spot in the Compendium survey. In some countries the procurement of ICT tools and services for the public administration (including universities and research institution) is carried out by public entities with this specific institutional purpose. So far the Compendium survey does not explore the procurement activities of NRENs in much detail, which has also become obvious in the section on cloud services (p. 67ff). In future Compendium surveys, this important area needs to be addressed with corresponding response options.

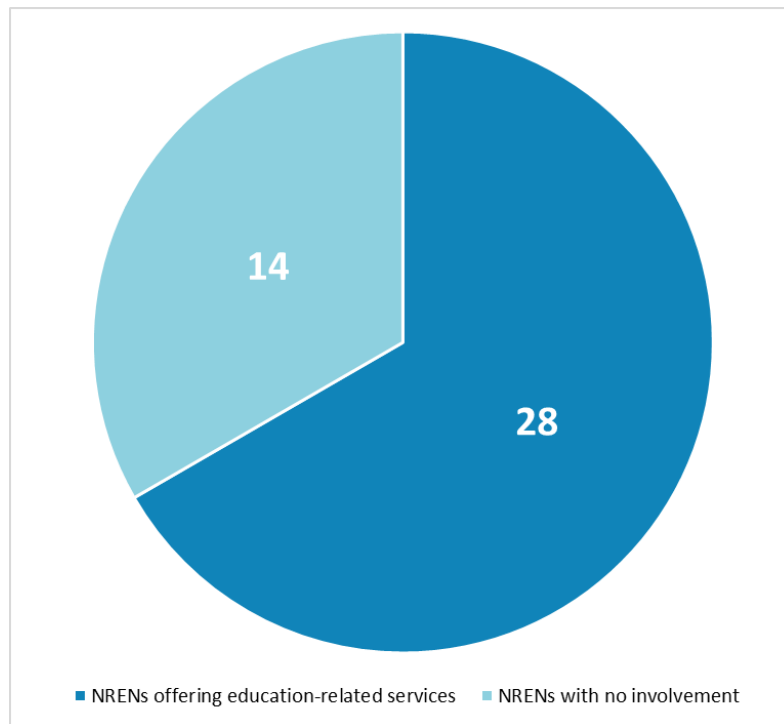


Figure 9.2: Number of NRENs with at least one service that specifically aims to support education

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

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

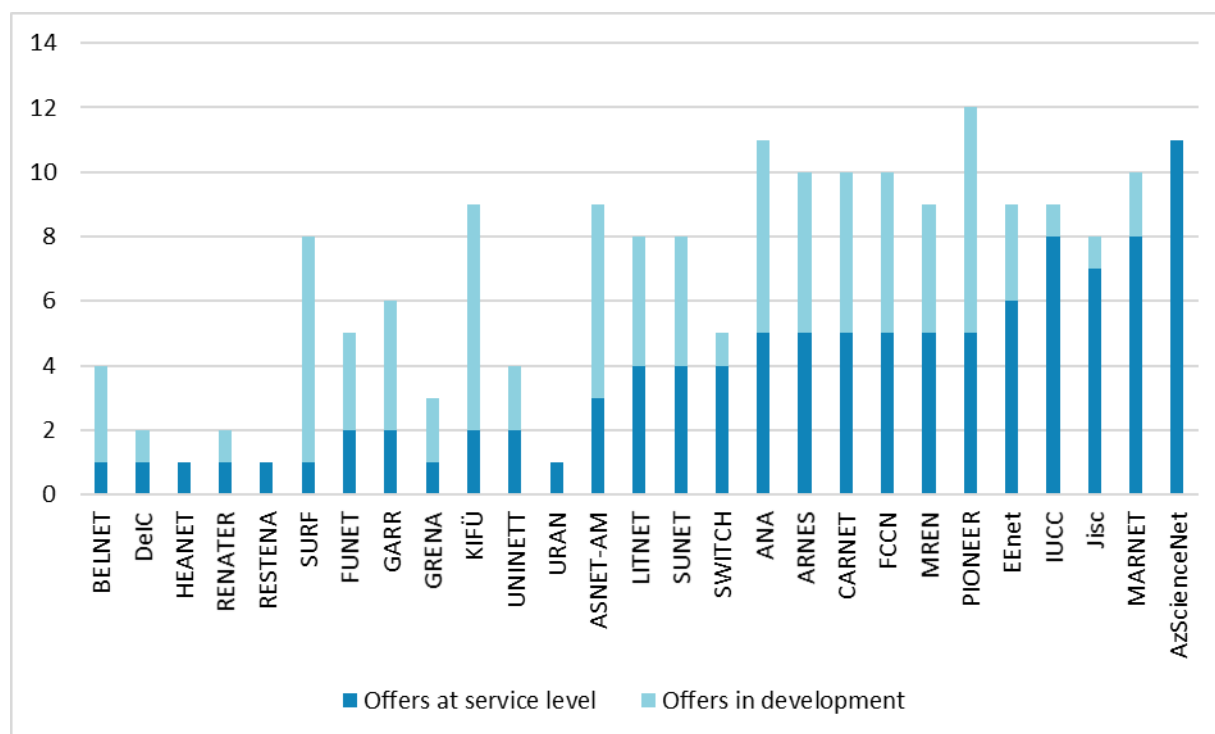


Figure 9.3: Number of education services provided and in development, by NREN

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

	DLE	e-content	Remote education	Digital assessment	Digital credentials	Learning analytics	Training	Transnational education	In-house tools	Student Management	T&I	Anti-plagiarism	Data mining and analytics	Video conferencing
ANA				⊙					⊙	⊙	⊙	⊙		⊙
ARNES	⊙	⊙	⊙		⊙		⊙		⊙					⊙
ASNET-AM	⊙		⊙				⊙							⊙
AzScienceNet	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙
Belnet														⊙
CARNET	⊙	⊙	⊙				⊙		⊙	⊙				⊙
DeIC		⊙												
EEnet	⊙	⊙	⊙	⊙					⊙	⊙				⊙
FCCN	⊙	⊙	⊙						⊙					⊙
FUNET			⊙	⊙										
GARR			⊙				⊙							⊙
GRENA	⊙							⊙						
HEANET														⊙

	DLE	e-content	Remote education	Digital assessment	Digital credentials	Learning analytics	Training	Transnational education	In-house tools	Student Management	T&I	Anti-plagiarism	Data mining and analytics	Video conferencing
IUCC	⊙	⊙	⊙	⊙					⊙	⊙	⊙	⊙		⊙
Jisc	⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙		⊙		⊙	
KIFÜ											⊙			⊙
LITNET	⊙	⊙					⊙			⊙		⊙		
MREN	⊙	⊙		⊙			⊙					⊙		⊙
PIONIER	⊙	⊙	⊙				⊙		⊙					⊙
RENATER			⊙											
RESTENA											⊙			
SUNET	⊙	⊙	⊙								⊙			⊙
SURF		⊙			⊙									
SWITCH	⊙								⊙		⊙			⊙
UNINETT	⊙			⊙										
URAN	⊙													

Table 9.1: NREN portfolios of currently provided education services

9.5 Summary

Supporting the ICT needs of the education sector is a well-established and growing field. However, it is not clear whether more NRENs will enter the sector. While many NRENs are actively developing new services, all of those that are doing so already have an established education service portfolio, so there seem to be no NRENs about to enter the fray.

However, as ICT tools have become even more important for the education sector with the recent COVID-19 crisis, more NRENs might become tasked with expanding their support for the sector, tapping into their expertise in ICT 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. A good example is cloud services, where the landscape has changed considerably over the years and with it the role NRENs play in the delivery of these services. Another example is the role of NRENs in education: while NRENs have always served the education sector, more recently many NRENs have now moved to offer services that target its needs specifically. Both developments are reflected in the Compendium, which now documents these activities.

Future iterations of the Compendium will be similarly responsive, carefully considering which data will be useful to understand the NREN community – and useful for the community to know about – when producing the annual Compendium report. 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 reorganisation 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 (see also [\[ASSOCIATION\]](#)).

Short Name	Full Name	Country	Website
ACOnet	Vienna University Computer Centre	Austria	www.aco.net
AMRES/UoB	Akadska 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	https://basnet.by/en/
Belnet	Belnet	Belgium	www.belnet.be
BREN	Bulgarian Research and Education Network	Bulgaria	www.bren.bg
CARNET	Hrvatska akademska i istrazivacka mreza	Croatia	www.carnet.hr
CESNET	CESNET, zajmove sdruzeni pravnickych osob	Czech Republic	www.ces.net
CyNet	ΚΥΠΡΙΑΚΟ ΕΡΕΥΝΗΤΙΚΟ ΚΑΙ ΑΚΑΔΗΜΑΪΚΟ ΔΙΚΤΥΟ (ΚΥΠΡΙΑΚΟ ΕΡΕΥΝΗΤΙΚΟ ΚΑΙ ΑΚΑΔΗΜΑΪΚΟ ΔΙΚΤΥΟ)	Cyprus	www.cynet.ac.cy
DFN	Verein zur Förderung eines Deutschen Forschungsnetzes e.V.	Germany	www.dfn.de
EENet	EENet	Estonia	www.eenet.ee
FCT FCCN	Fundação para a Ciência e a Tecnologia Computação Científica Nacional	Portugal	www.fct.pt
GARR	Consortium GARR	Italy	www.garr.it
GRENA	Georgian Research and Educational Networking Association	Georgia	www.grena.ge

Short Name	Full Name	Country	Website
GRNET	Greek Research and Technology Network	Greece	www.grnet.gr
HEAnet	HEAnet Limited	Ireland	www.heanet.ie
LANET	Ministry of Education and Science	Latvia	http://www.lumii.lv
IUCC	Inter University Computation Centre	Israel	www.iucc.ac.il
Jisc	Jisc Collections and Janet Limited	UK	https://www.jisc.ac.uk/
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
SARNET	Academic and Research Network of the Republic of Srpska	Bosnia & Herzegovina	http://www.iusarnet.net/
SURFnet⁵¹	SURFnet B.V.	Netherlands	www.surfnet.nl
SWITCH	SWITCH	Switzerland	www.switch.ch

⁵¹ In 2020, SURFnet began a series of organisational and name changes, and is now known as "SURF".

Short Name	Full Name	Country	Website
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

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.

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.

Gary James, Procurement Officer (GÉANT), is an experienced public sector procurement professional and joined the GÉANT Procurement Team in 2016. In 2018 he joined the IaaS Framework Agreement Management Team with a responsibility for contract and vendor management, including compiling sales reports from suppliers on the framework and data management. Gary was able to bring this experience to the tender process for the IaaS+ Framework Agreement, which will replace the IaaS Framework Agreement in January 2021.

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.

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

Dan Still, Partnerships Manager (CSC), leads the community cloud effort in GN4-3. He is responsible for developing industry partnerships and research collaborations in HPC and cloud computing. Dan joined CSC in 2005 and before his current position worked in different roles as manager of the CSC supercomputer operations and research data management services teams.

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 or Wavelength. Data transmission laser light from third-party equipment; an alien wave system multiplexes alien light together with local signals using DWDM.
BPA	Blueprint Architecture
CCNP	Cisco Certified Network Professional
CERN	European Organisation for Nuclear Research
CISO	Chief Information Security Officer
CoCo	Code of Conduct
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 (10 ¹⁸ 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
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 (10^{15} 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 (10^{12} 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