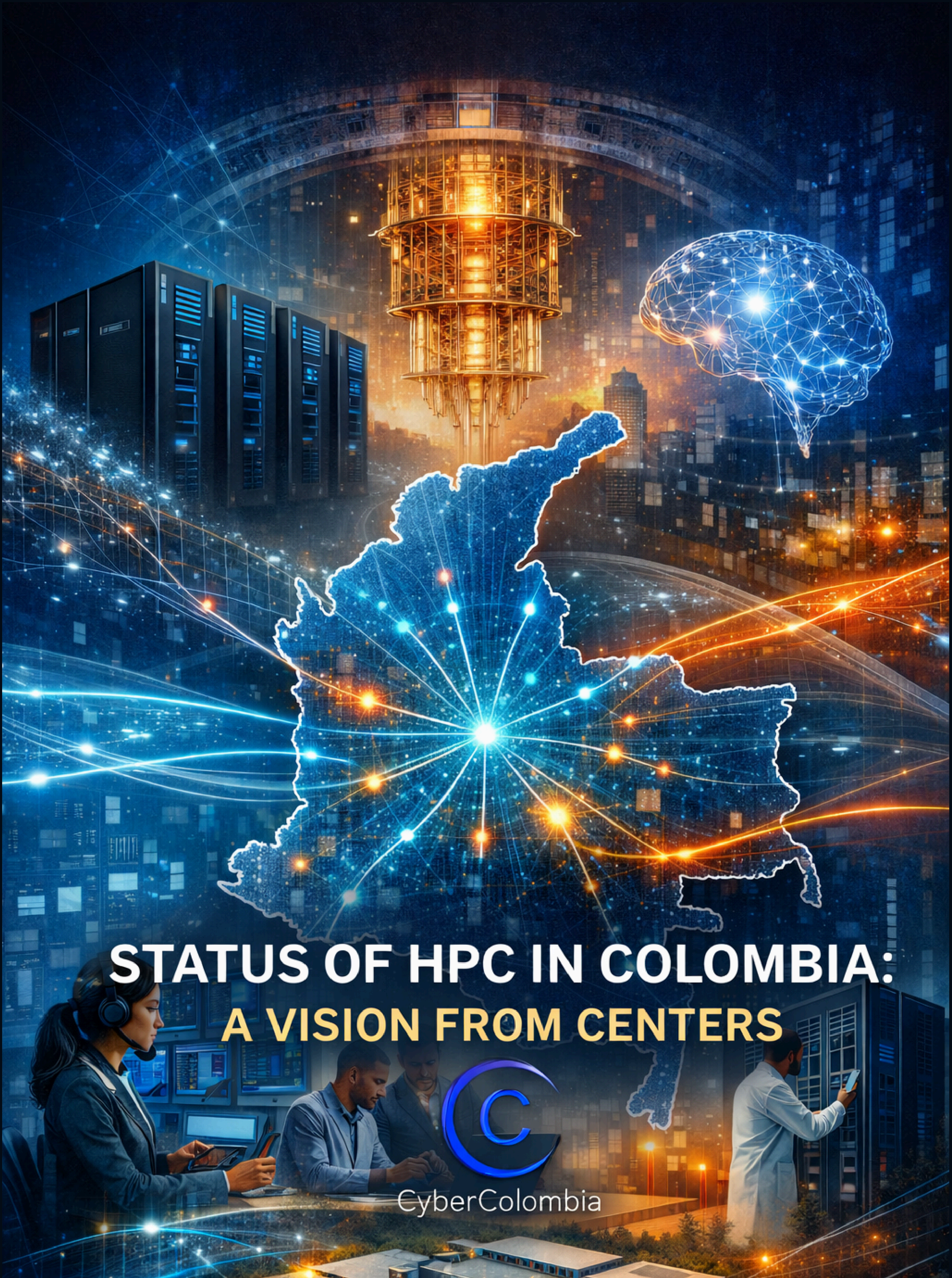

STATUS OF HPC IN COLOMBIA: A VISION FROM CENTERS

CyberColombia

WHO WE ARE

CyberColombia is a collaborative ecosystem of interdisciplinary professionals from industry, academia, and international organizations, committed to advancing **High-Performance Computing (HPC), Artificial Intelligence (AI)**, and emerging technologies to drive scientific and technological innovation in Colombia and Latin America. Our mission is to accelerate research and applied development in critical scientific domains—including physics, mathematics, geosciences, computational biology, and industrial engineering—through advanced digital infrastructure and AI-driven solutions. We focus on large-scale data analysis, machine learning, deep learning, and simulation-based science as core components of modern research workflows. As part of our strategic expansion, **Quantum Computing (QC)** has been incorporated as an emergency and high-priority area. We aim to build national capabilities in this emerging field by developing foundational and applied training programs that cover quantum theory, logic gates, quantum algorithms, and the use of accessible cloud-based quantum platforms. Through these efforts, CyberColombia seeks to foster the emergence of a Quantum Ecosystem, actively connecting with local universities, research centers, and regional partners to build the next generation of quantum-aware scientists and engineers.

EXECUTIVE SUMMARY

This report represents another key contribution to **CyberColombia**’s ongoing effort to strengthen collaboration, technical exchange, and operational capacity across Colombia’s **High-Performance Computing (HPC)**, **Artificial Intelligence (AI)**, **Quantum**, and **emerging-technologies** communities.

The findings presented here derive from the *Estado de la Computación de Alto Desempeño (HPC) en Colombia* survey, launched in March 2025 and kept open through August 2025, which focuses on our first strategic pillar: strengthening the HPC community. It builds on the direct participation of administrators, faculty leaders, technical staff, and principal investigators who manage, operate, and rely on critical computational infrastructure nationwide—actors who play a central role in shaping the country’s advanced-computing ecosystem. Participation was voluntary, widely promoted across the community, and involved no compensation whatsoever.

The result is more than a statistical overview—it is a diagnostic shaped by the experiences and perspectives of those who design, operate, and rely on the country’s computational backbone. The report reflects both the operational realities and the forward-looking ambitions of Colombia’s HPC stakeholders, capturing the diversity of

ownership sectors (public and private), funding models, educational roles, and scientific applications that define the national landscape from their perspective.

This document is intended to serve as a strategic resource that:

- **Guides public and private institutions in prioritizing and planning investments** in HPC, AI, quantum, and advanced digital infrastructure based on actual national capacity, demand, and identified gaps.

- **Informs government agencies and policymakers** about the operational challenges, funding needs, sustainability requirements, and institutional interdependencies that shape Colombia's HPC ecosystem, enabling more aligned policies and long-term planning.

- **Supports the design of national programs and incentives** for talent development, infrastructure modernization, and research competitiveness in high-performance and emerging technologies.

- **Provides evidence to strengthen decision-making processes** in universities, research centers, and industry by offering a realistic picture of current capabilities, usage patterns, and bottlenecks.

- **Enables deeper scientific, technological, and industrial collaboration** by mapping actors, capabilities, and potential partnerships across regions and sectors—facilitating coordinated initiatives within Colombia and with international partners.

- **Identifies opportunities for shared services, resource consolidation, and federated infrastructure**, helping institutions reduce costs and improve utilization of existing HPC assets.

CyberColombia invites academic, industrial, and government stakeholders to examine the findings, reflect on the evidence presented, and contribute to the collective effort to strengthen a robust, inclusive, and sustainable HPC ecosystem in the country.

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ACKNOWLEDGMENTS

We extend our sincere gratitude to all the individuals and institutions that contributed to the national survey *Estado de la Computación de Alto Desempeño (HPC) en Colombia*. This report was made possible through the practical insights and detailed information provided by HPC center directors, coordinators, and technical staff, who shared concrete data on system configurations, operational practices, funding models, and training activities.

We also acknowledge the academic leaders and researchers who assessed the capabilities and needs of their institutions, offering critical inputs on gaps, priorities, and future requirements.

Finally, we thank the individuals responsible for completing the survey, many of whom manage or support HPC infrastructure daily, and supplied the operational perspectives necessary to build an accurate national assessment.

SURVEYED INSTITUTIONS

The following table presents the participating institutions along with their location, ownership sector (public or private), and the name of their HPC facility or the research group leading the use of HPC resources.

Table 1. Surveyed Institutions (HPC Facilities).

Institution Name	Department	City	Sector	HPC facility
Universidad Autónoma de Occidente	Valle del Cauca	Cali	Private	Grupo de investigación GITI
BIOS	Caldas	Manizales	Private	Centro de Biotecnología y Biología Computacional de Colombia
Universidad Industrial de Santander	Santander	Bucaramanga	Public	SC3UIS
Universidad EAFIT	Antioquia	Medellin	Private	Centro de Computación Científica Apolo
Universidad del Rosario	Bogotá D.C.	Bogota	Private	Laboratorio de Computación Avanzada para la Investigación de la Universidad del Rosario - CALDAS
Universidad Nacional de Colombia	Bogotá D.C.	Bogota	Public	Federación de Clusters del Centro de Excelencia para la Computación Científica, Universidad Nacional
Universidad Distrital Francisco José de Caldas	Bogotá D.C.	Bogota	Public	CECAD
Pontificia Universidad Javeriana	Bogotá D.C.	Bogota	Private	ZINE
Universidad de Cartagena	Bolívar	Cartagena	Public	Datacenter Unicartagena
Universidad del Norte	Atlantico	Barranquilla	Private	GRANADO
Universidad de los Andes	Bogotá	Bogotá	Private	HYPATIA

Figure 1 summarizes Table 1 by presenting, on the left, the number of institutions (HPC facilities) per city along with their ownership sector, while the right panel depicts the proportion of surveyed facilities by ownership sector.

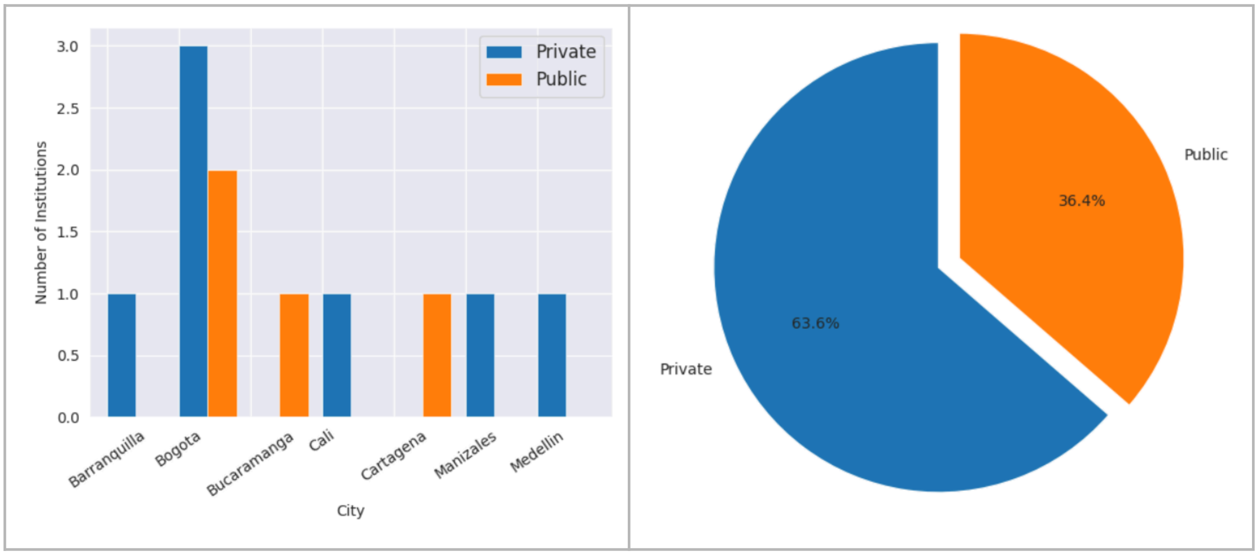

Figure 1. Distribution of Surveyed HPC facilities by City and Ownership Sector; 11/11 HPC facilities answered this question.

HPC FACILITIES: FUNDING MODELS

The sustainability and effective operation of High-Performance Computing (HPC) facilities are directly influenced by the funding models that support them. The following results are derived from responses to the question "***Describe your funding scheme***." Table 2 summarizes the identified funding models and the frequency with which they are used across HPC facilities. Figure 2 presents the frequency of each model by city, while Figure 2 classifies institutions into public and private and illustrates the predominant funding sources within each sector.

Table 2. Distribution of HPC facilities by funding models.

Category	Description	Number of Institutions
Institutional Funds	HPC facilities are primarily supported through internal funding from their host institution (e.g., university budget allocations or direct subsidies).	2
Self-generated Funds	Financial sustainability is achieved through the sale of services, consulting, external grants, or strategic partnerships.	3
Mixed Model	Combines institutional support with external project funding, service-based income, or other third-party sources.	5

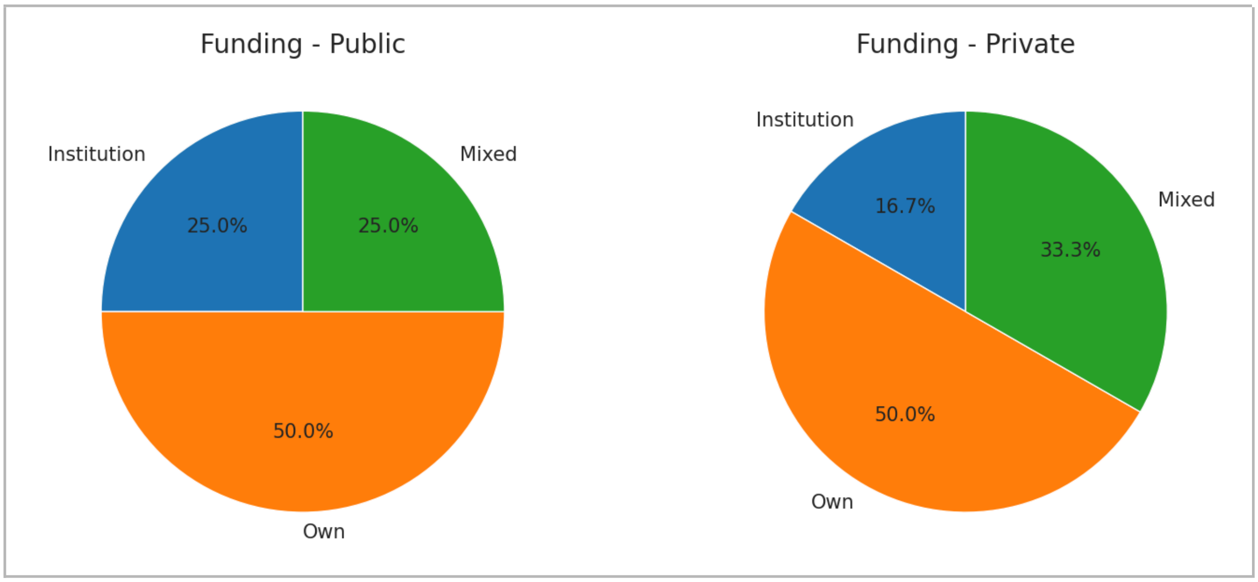

Figure 2. Comparison of funding models used by HPC facilities in public and private institutions; 11/11 HPC facilities answered this question.

A combined analysis of Table 2 and Figure 2 highlights differences in the funding models adopted by HPC facilities across ownership sectors.

According to Table 2, the **mixed funding model** is the most prevalent, accounting for **five institutions**, followed by **self-generated funds** with **three institutions**, and **institutional funding** with **two institutions**.

From a sectoral perspective, **public institutions exhibit a relatively balanced distribution** across funding schemes. As shown in Figure 2, **25%** rely on institutional funds, **25%** on self-generated funds, and **50%** adopt a mixed funding model.

In contrast, **private institutions rely more heavily on non-institutional funding mechanisms**. Mixed and self-generated models together represent **83.3%** of the facilities in this sector (**50% mixed** and **33.3% self-generated**), while **institutional funding accounts for only 16.7%**.

Overall, these results indicate that mixed funding models play a central role across both ownership sectors, while purely institutional support is comparatively less common, particularly among private HPC facilities.

HPC FACILITIES: FUNDING SOURCES

The degree to which High-Performance Computing (HPC) facilities participate in national or regional projects is a critical indicator of their integration into broader scientific ecosystems, their operational maturity, and their ability to secure external funding or form research alliances. Other international communities have recognized the importance of cross-institutional collaborations and the involvement of both private and public sectors.

This section analyzes two aspects based on projects in which each HPC facility has participated during the past two years: (i) the **number and types of projects** in which each HPC facility is involved at the local (city), regional, and national levels; and (ii) the **funding sources supporting the deployment of these projects**, including national public funding (e.g., Minciencias, Regalías), institutional funds (university or internal budgets), international grants, and unspecified ‘other’ mechanisms. Together, these dimensions provide an overview of the funding landscape adopted by the surveyed HPC facilities.

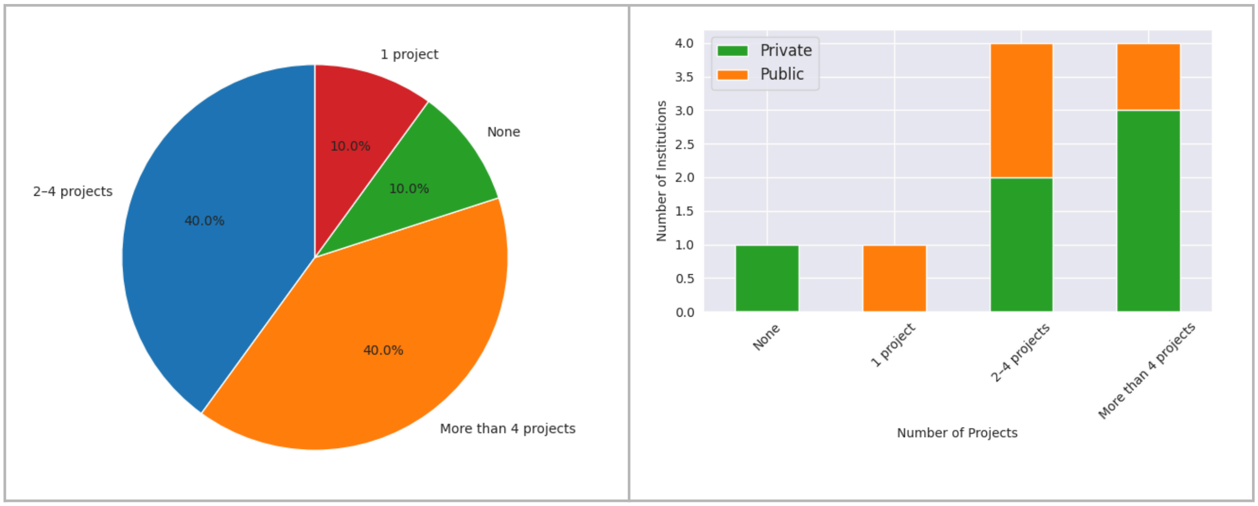

Figure 3. HPC Facilities by Project Participation Level and Ownership Sector; 10/11 HPC facilities answered this question.

According to Figure 3, 80% of the institutions participated in at least two national or regional projects during the analyzed period, while only one institution reported no participation.

Financial support plays a defining role in the development and sustainability of High-Performance Computing (HPC) infrastructures, as it directly influences institutional capacity, autonomy, and scalability of scientific impact. Identifying the funding sources on which institutions rely provides insight into dependency patterns, exposure to external collaboration, vulnerability to national policy changes, and long-term viability and expansion strategies. In contexts such as Colombia, where funding opportunities are limited and highly centralized, this analysis is particularly relevant for informing policy decisions and institutional planning.

To capture this information, the survey asked respondents to indicate the sources that funded their projects ("***The projects have been funded by***"). Multiple responses were allowed. The reported funding sources include national public funding (e.g., Minciencias, Regalías), institutional funds (university or internal budgets), international grants, and unspecified "other" mechanisms.

Figure 4 presents the funding sources reported by HPC facilities, showing on the left their occurrence by ownership sector and on the right their distribution by city. The figure summarizes the individual funding mechanisms used to support projects.

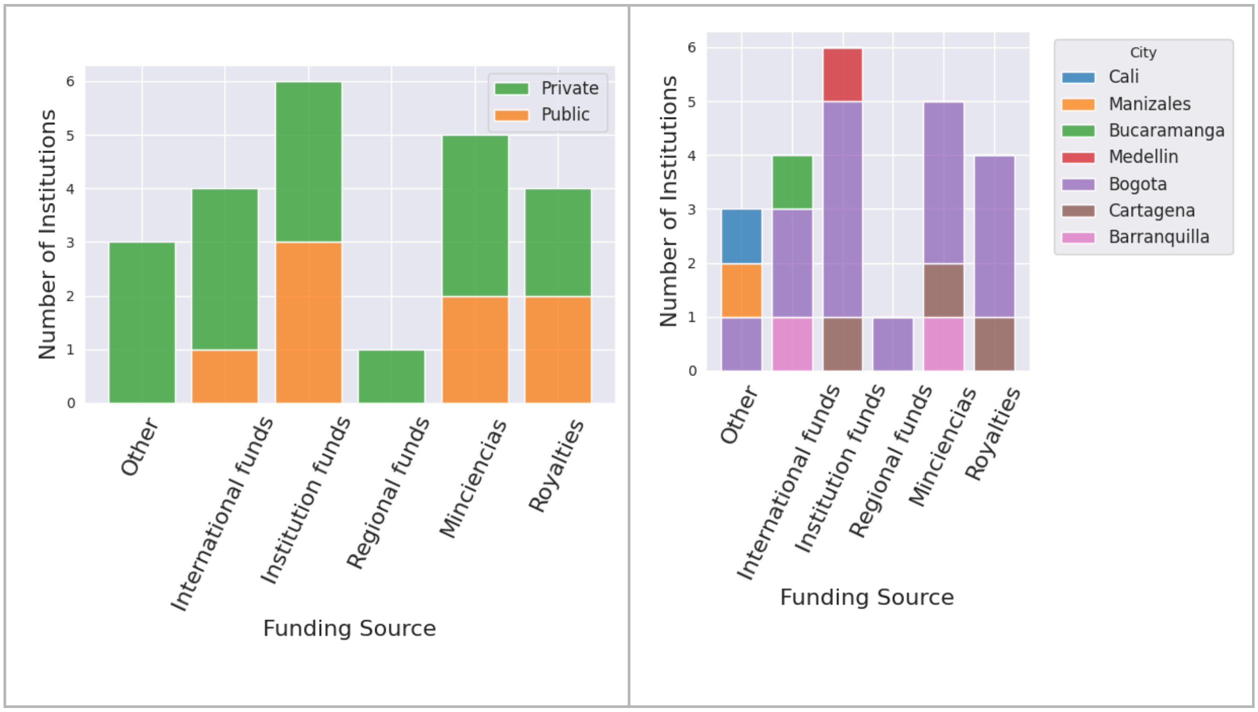

Figure 4. Occurrence of Funding Sources Mentioned by HPC Facilities, by Ownership Sector and City.

When disaggregated by ownership sector, private institutions exhibit a more diversified funding profile, combining national public funding (e.g., Minciencias), institutional resources, international grants, and unspecified “other” sources. This pattern suggests a flexible and externally oriented funding strategy. In contrast, public institutions show a stronger concentration in structured national programs, particularly Minciencias and Regalías, and rely more heavily on internal planning and national calls, with limited participation in international funding. Overall, this indicates that private institutions may be more agile in accessing heterogeneous funding sources, whereas public institutions benefit from more stable but less diversified mechanisms.

The city-level analysis reveals distinct local funding behaviors. Bogotá displays the widest range of funding sources, including Minciencias, institutional, international, and regional funds, reflecting strong integration with national programs. Cartagena relies primarily on public funding through Minciencias and Regalías, while Bucaramanga reports only international funding, suggesting either an outward-oriented strategy or limited alignment with national calls. Barranquilla combines national and international sources, indicating multi-level engagement. In contrast, Cali and Manizales report only unspecified “other” sources, pointing to a weak connection with national or international funding structures. Medellín relies exclusively on institutional funds, indicating a high degree of internal autonomy but limited external engagement.

Table 3 summarizes the combinations of funding sources reported by the surveyed HPC facilities, along with the number of institutions adopting each combination. The table highlights how different funding mechanisms are jointly leveraged to support HPC activities, providing an overview of prevailing and less common financing strategies across institutions.

Table 3. Combinations of Funding Sources Reported by HPC Facilities

Funding Source Combination	Number of Institutions
Minciencias, Regalias, Fondos de la institución	2
Fondos de la institución	2
Otros	2
Fondos Regionales, Fondos de la institución, Otros	1
Minciencias, Fondos internacionales	1
Fondos internacionales	1
Minciencias, Regalias, Fondos de la institución, Fondos internacionales	1

HPC FACILITIES: SERVICES OFFERED

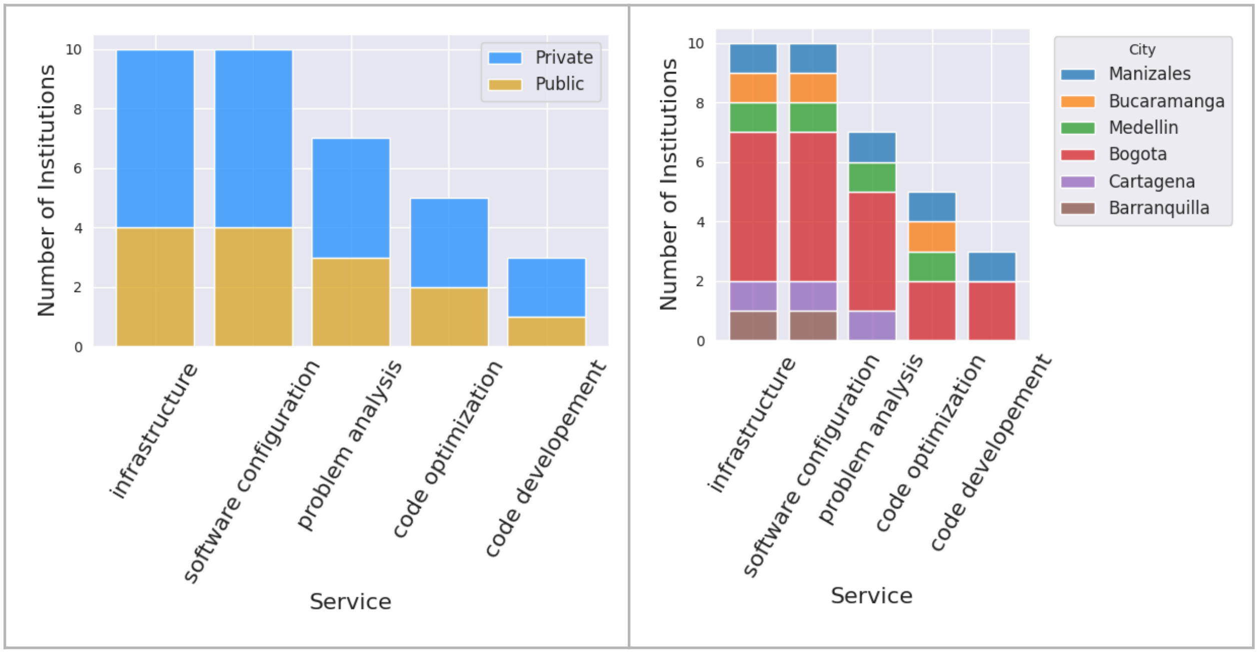

Figure 5. Occurrence of Services Mentioned by HPC Facilities, by Ownership Sector and City; 11/11 HPC facilities answered this question.

Figure 5 (left) shows the occurrence of services reported by HPC facilities when grouped by ownership sector. Both public and private institutions consistently provide **infrastructure access** and **software configuration**, which are the most frequently reported services across the dataset. **Problem analysis support** is also widely offered by both sectors, though it appears less frequently than the two baseline services. More advanced services—such as **code optimization** and **development of scalable codes**—are reported less often overall. Private institutions account for a larger share of these advanced services, particularly in scalable code development, suggesting greater engagement in higher-level application support, while public institutions tend to concentrate on foundational services complemented by selective optimization and analysis support.

The right panel of Figure 5 highlights clear differences in service availability across cities. **Bogotá** exhibits the broadest service portfolio, with repeated occurrences of infrastructure, software configuration, problem analysis, code optimization, and scalable code development, reflecting its role as the main national hub for HPC services. **Manizales** also reports a complete service stack, including scalable code development. **Medellín** and **Cartagena** primarily provide infrastructure, software configuration, and problem analysis, with limited evidence of scalability-oriented services. **Bucaramanga** shows a narrower profile focused on infrastructure, software configuration, and code optimization. **Barranquilla** reports only basic services, namely infrastructure and software configuration. No services are reported for Cali, consistent with the absence of an HPC center in that city.

Taken together, the figure indicates that while **infrastructure provisioning and software configuration are universal baseline services**, more specialized capabilities—such as **code optimization** and especially **scalable code development**—are available in fewer locations and institutions. This uneven distribution suggests differing levels of technical maturity and mission focus among HPC facilities, with advanced services concentrated in a small subset of centers and cities.

As an additional observation not directly depicted in Figure 5, a qualitative review of the survey responses allows the identification of **service bundles offered by individual HPC centers**. All surveyed centers—BIOS, SC3UIS, Apolo, CALDAS, and the Federación de Clusters—report providing **infrastructure access** and **software configuration support**, confirming these as core services. Several centers (BIOS, Apolo, CALDAS, and Federación de Clusters) further extend their offerings with **accompaniment in problem analysis**, while a broader subset also includes **code optimization** as part of their service portfolio. More specialized, research-oriented activities aimed at the **development of scalable codes** are reported only by BIOS and the Federación de Clusters, indicating a higher level of technical specialization. Finally, CALDAS reports additional **other services** that fall outside the predefined categories, reflecting institution-specific support capabilities.

HPC FACILITIES: COLLABORATION

High-Performance Computing (HPC) is a foundational enabler of scientific and technological progress. It allows researchers and institutions to simulate complex systems, analyze vast datasets, and accelerate innovation across domains such as climate modeling, genomics, engineering, artificial intelligence, and national security. However, the effective deployment of HPC capabilities is not only a matter of infrastructure or talent—it fundamentally depends on **collaboration**.

In highly specialized and resource-intensive fields like HPC, collaboration fulfills multiple critical functions:

- **Infrastructure sharing**: Given the high cost of acquiring and maintaining supercomputing infrastructure, partnerships allow institutions to pool resources and access otherwise unattainable capabilities.

- **Capacity building**: Joint efforts in training, research, and curriculum development enable knowledge transfer and the development of a skilled national workforce.

- **Scientific production and impact**: Collaborative projects—especially international and inter-institutional—are statistically correlated with higher publication rates, innovation outcomes, and societal relevance.

- **Policy and standardization**: Coordinated efforts promote harmonization of data practices, interoperability of systems, and alignment with national and international HPC strategies.

In the Colombian context, the need for effective collaboration in HPC is even more pronounced due to several structural and developmental factors:

- **Decentralized institutional capacity**: While some institutions have established advanced computing infrastructure and research groups, others lack the critical mass to sustain standalone HPC programs. Collaboration becomes essential to bridge these gaps.

- **Emerging ecosystem**: Colombia's HPC ecosystem is in a formative phase. Strengthening ties between academia, research centers, industry, and government is vital to consolidate progress and avoid fragmentation.

- **Regional disparities**: Collaboration can help mitigate geographic inequalities by enabling regional universities and research centers to access national-level resources and expertise.

- **Alignment with national goals**: Colombia's national development strategies emphasize innovation, environmental sustainability, and digital transformation—all of which require scalable computational solutions that can only be achieved through sustained inter-institutional collaboration.

Active Participation in the National HPC Community

To assess the level of integration of HPC facilities within the broader national ecosystem, the survey included the following question: **“Do you actively participate in the national HPC community?”**. All surveyed facilities (11/11) responded to this question, and their answers are summarized in **Figure 6**, which reports the occurrence of *yes* and *no* responses by ownership sector and by city.

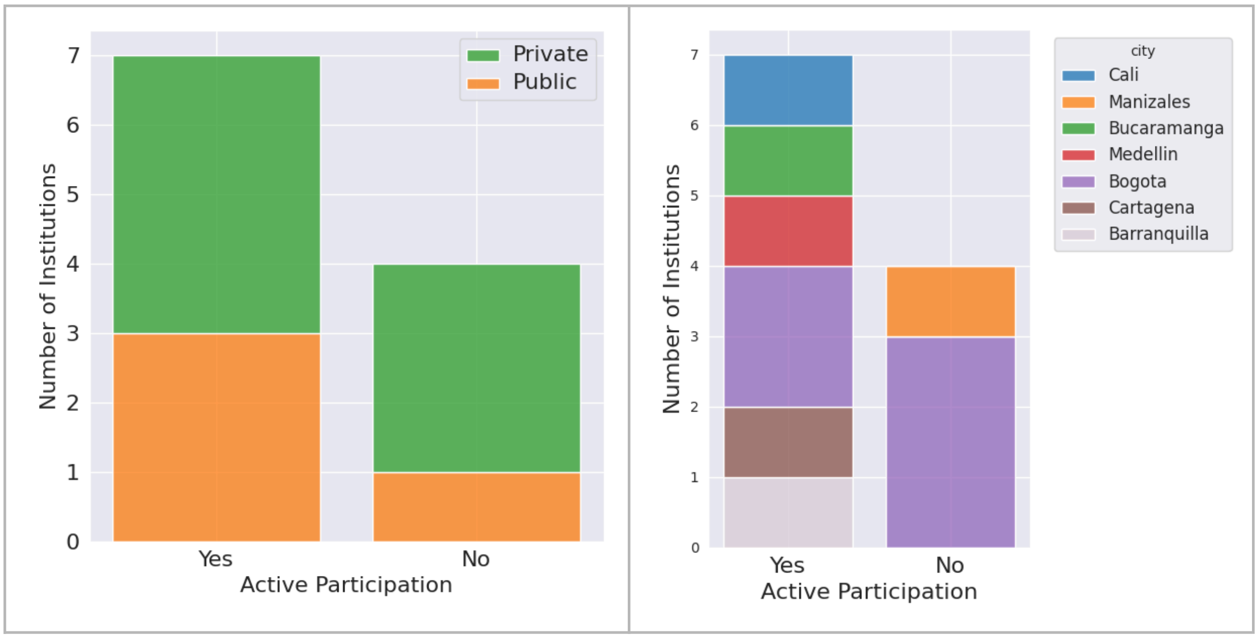

Figure 6. Participation in the National HPC Community, by Ownership Sector and City; 11/11 HPC facilities answered this question.

Figure 6 (left) shows the distribution of active participation in the national HPC community by ownership sector. Overall, most facilities report active participation. Among **public institutions**, three report active participation and one reports no participation, indicating a high level of engagement. **Private institutions** show a more mixed pattern: three report active participation, while four indicate no participation. This suggests that, while private facilities are present in the national HPC community, non-participation is more frequent in this sector than among public institutions.

The right panel of Figure 6 presents participation by city and reveals heterogeneous engagement across regions. **Bogotá** concentrates the largest number of responses, with both active participation and non-participation reported, reflecting diverse levels of engagement among facilities located in the capital. **Bucaramanga, Medellín, Cartagena, Barranquilla, and Cali** each report active participation, whereas **Manizales** reports no participation. This indicates that participation in the national HPC community is not uniformly distributed across cities and varies even within major hubs.

Taken together, the figure shows that active participation in the national HPC community is common but not universal across facilities. Differences observed by ownership sector and city point to uneven levels of integration within the national ecosystem, suggesting opportunities to strengthen engagement among less-participative institutions and regions.

Working With Other Institutions

To examine collaboration patterns among HPC facilities, the survey included the question **"What kind of institutions do you collaborate with?"** All surveyed facilities (11/11) responded to this question. The reported collaborators were subsequently grouped into three categories—**international**, **national**, and **regional**—and the results are summarized in **Figure 7**, which presents the occurrence of collaboration types by ownership sector and by city.

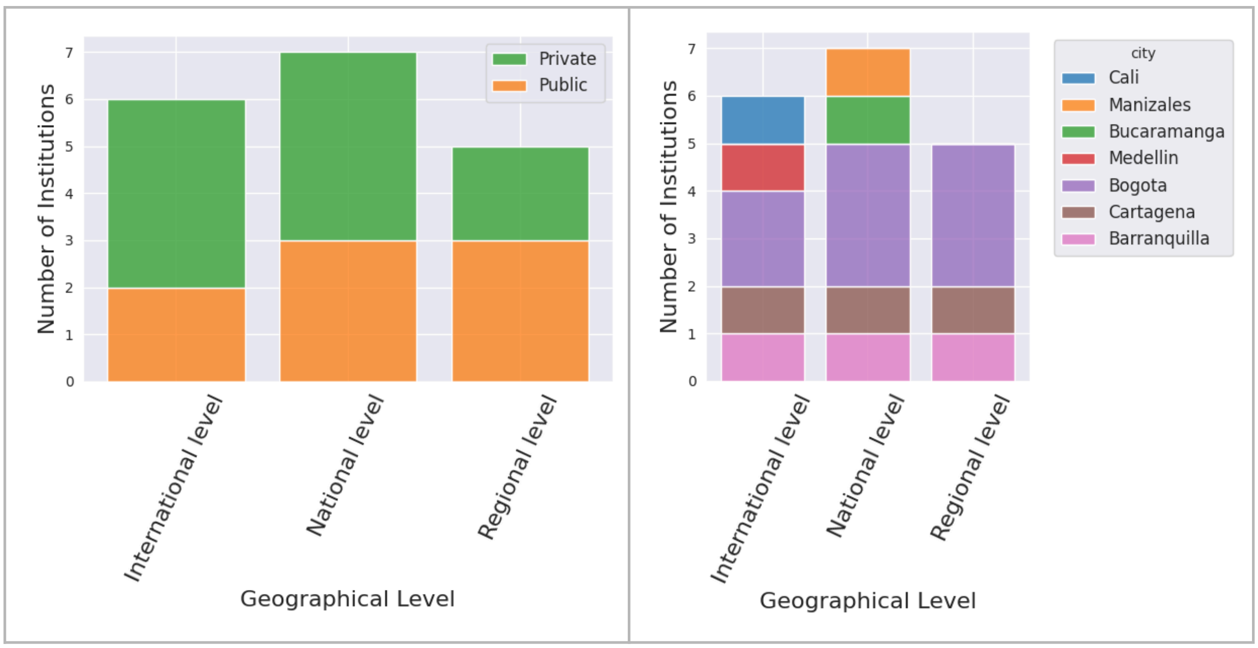

Figure 7. Collaboration with others, by Ownership Sector and City; 11/11 HPC facilities answered this question.

Figure 7 (left) presents the occurrence of collaboration types by ownership sector. Both public and private HPC facilities report collaborations at the **national**, **international**, and **regional** levels. National-level collaboration is the most frequently reported category across both sectors. Public institutions show a balanced presence across the three categories, with repeated occurrences of national, regional, and international collaborations. Private institutions also participate across all collaboration levels, with national and international collaborations appearing slightly more frequently than regional ones. Overall, the figure indicates that collaboration is not confined to a single level for either sector, but national partnerships constitute the dominant mode of engagement.

The right panel of Figure 7 illustrates how collaboration types are distributed across cities. Bogotá concentrates the largest number of reported collaborations and exhibits all three categories—national, international, and regional—indicating a diverse collaboration profile. Cartagena and Barranquilla also report collaborations at all three levels, though with fewer occurrences. Manizales and Bucaramanga report only national-level collaborations, while Medellín and Cali report international collaborations. These results show that collaboration patterns vary significantly by city, with some locations engaging across multiple levels and others reporting more specialized or limited collaboration scopes.

Taken together, Figure 7 shows that collaboration with external institutions is widespread among the surveyed HPC facilities, but the **breadth of collaboration types differs by ownership sector and city**. National-level collaboration is the most common across the dataset, while international and regional collaborations are present but unevenly distributed. These differences point to varying degrees of integration within the broader HPC ecosystem across regions and institutional contexts.

Affiliations With Networks

To further assess institutional integration within national HPC and research networking initiatives, the survey included two additional questions addressing affiliation with **RENATA** and participation in **RedCCA**. The responses are summarized in **Figure 8**, which reports participation using *yes* and *no* categories for RENATA (left), and *yes*, *no*, and *not aware* for RedCCA (right).

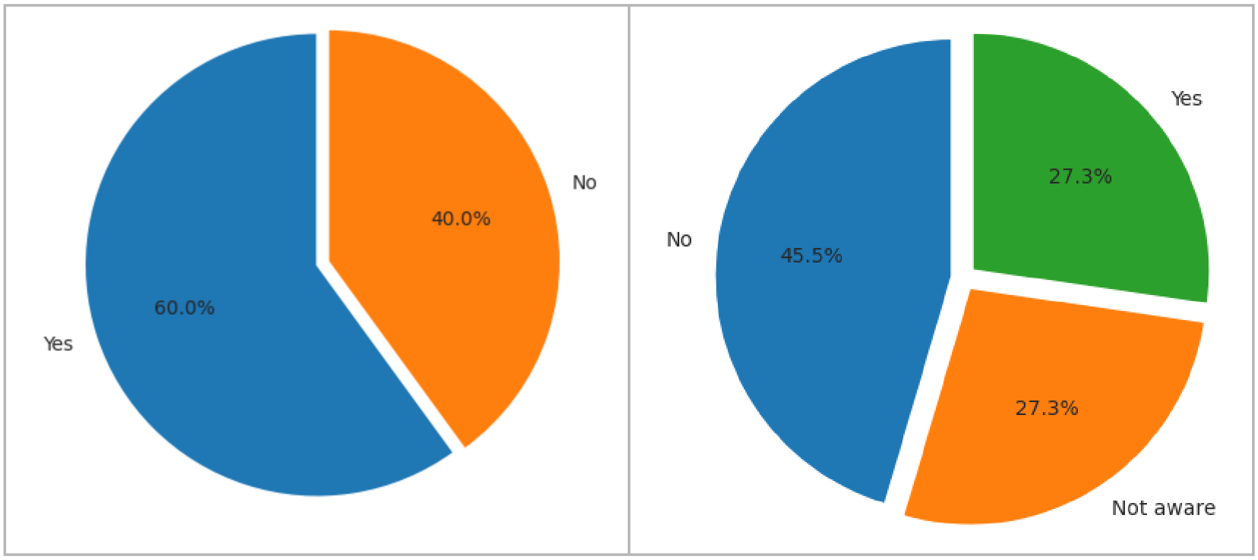

Figure 8. Affiliation to RENATA (left)and Participation in REDCA (Right).

The left panel of Figure 8 shows the affiliation status of HPC facilities with **RENATA**. Out of the 11 surveyed institutions, **six report being affiliated**, **four indicate no affiliation**, and **one does not provide a valid response**. This distribution indicates that affiliation with the national research and education network is present in a majority of cases, but it is not universal across the surveyed facilities. The coexistence of affiliated and non-affiliated institutions highlights uneven integration with RENATA within the national HPC landscape.

The right panel of Figure 8 summarizes participation in **RedCCA**. Only **three institutions report active participation**, while **five indicate that they do not participate**, and **three report not being aware of the initiative**. Compared to RENATA affiliation, participation in RedCCA is notably lower, and the presence of "not aware" responses suggests limited visibility of this initiative among a subset of HPC facilities.

Taken together, Figure 8 highlights a contrast between **formal network affiliation** and **active participation in a coordinated HPC community initiative**. While RENATA affiliation is relatively widespread, engagement with RedCCA remains limited and, in some cases, unknown to institutions. This gap suggests that awareness and participation in community-oriented HPC initiatives do not automatically follow from network affiliation and may require targeted dissemination and engagement efforts.

RENATA is Colombia's National Research and Education Network, responsible for connecting and integrating the actors of the National System of Science, Technology, and Innovation through advanced networking infrastructure and services that enable academic collaboration at the national and international levels. **RedCCA** is a national initiative built on RENATA that seeks to create a supercomputing community by integrating geographically distributed HPC resources and expertise—currently involving institutions such as the Universidad Industrial de Santander and the Universidad de los Andes—to support non-profit scientific and academic initiatives of national interest.

Participation in Regional Events

To assess engagement with regional capacity-building and research-oriented initiatives, the survey included a question on **participation in key regional HPC events**, specifically the **HPC Summer School** and the **CARLA (Latin American High Performance Computing Conference)**. All surveyed facilities (11/11) responded to this question, and the results are summarized in **Figure 9**, which reports participation by ownership sector and by city.

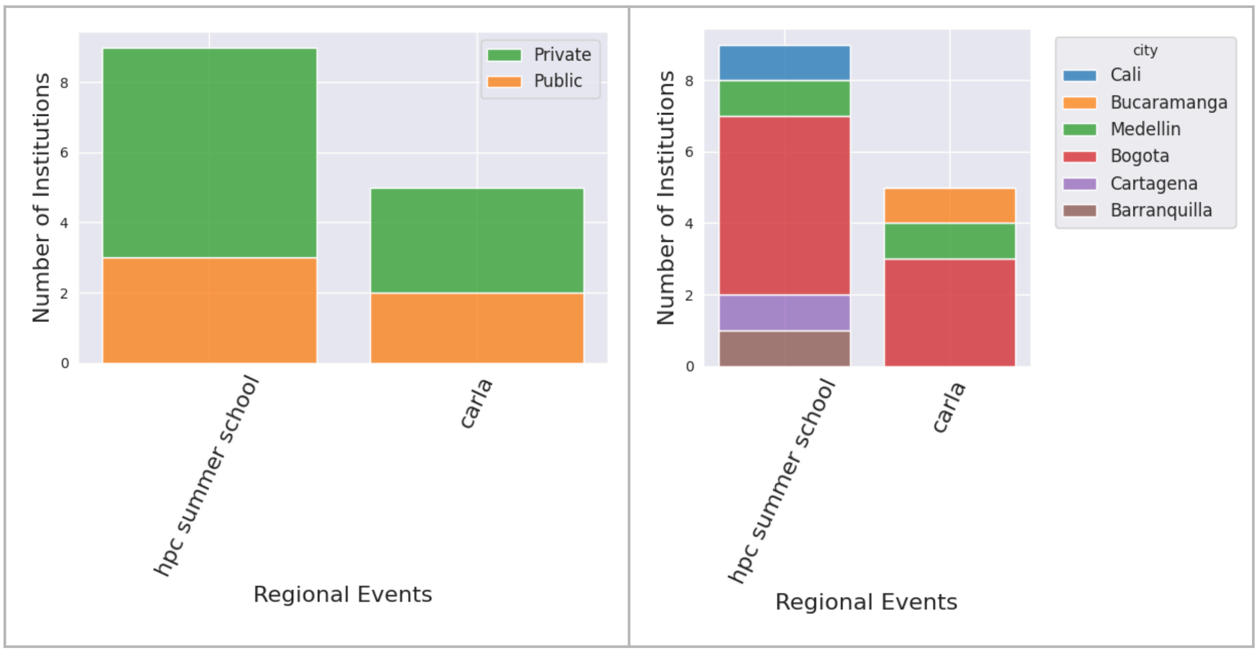

Figure 9. Participation in regional events, by Ownership Sector and City; 11/11 HPC facilities answered this question.

The **HPC Summer School** serves as a strategic platform for training undergraduate and graduate students, engineers, and researchers across disciplines. Its emphasis on practical workshops, tutorials, and introductory content supports the development of national HPC capabilities, particularly in institutions that lack formal HPC curricula. In contrast, **CARLA** plays a complementary role by fostering academic maturity, dissemination of scientific results, and regional integration, acting as a bridge between the Latin American HPC community and global research developments. Together, these events represent two complementary dimensions of the Colombian HPC ecosystem: community training and activation on one hand, and research consolidation and international visibility on the other.

Figure 9 (left) shows participation in regional HPC events by ownership sector, distinguishing between the **HPC Summer School** and **CARLA**. Both public and private institutions report participation in the two events. The **HPC Summer School** is the most frequently reported activity in both sectors, with a higher number of occurrences than CARLA. Private institutions account for more total participations, reflecting a larger number of reported entries, while public institutions also show consistent engagement across both events. Overall, the figure indicates broad participation in regional HPC events regardless of ownership sector, with a stronger emphasis on training-oriented activities.

The right panel of Figure 9 presents participation by city. **Bogotá** concentrates the largest number of reported participations and is the only city represented in both events multiple times, including repeated participation in the HPC Summer School and CARLA. **Medellín** also reports participation in both events, while **Cali**, **Cartagena**, and **Barranquilla** report participation exclusively in the HPC Summer School. **Bucaramanga** reports participation only in CARLA. No participation is reported for **Manizales** in either event. These results highlight notable differences in event engagement across cities.

Taken together, Figure 9 indicates that participation in regional HPC events is widespread among surveyed facilities, with a clear predominance of the HPC Summer School over CARLA. While some cities and institutions engage in both types of events, others participate in only one, suggesting variability in how HPC facilities interact with regional training- and research-oriented initiatives.

HPC FACILITIES: KNOWLEDGE GENERATION

To evaluate the research output associated with HPC activities, the survey included the question ***"Do you regularly publish results related to HPC?***" All surveyed facilities (11/11) responded to this question, and the results are summarized in **Figure 10**, which reports publication activity by ownership sector and by city.

From an **ownership sector** perspective, the results show a mixed pattern of research dissemination. Both **public and private institutions** report publishing HPC-related results, indicating that research output is not exclusive to a single sector. At the same time, non-publication is also observed in both groups, suggesting that not all HPC facilities prioritize or are structurally positioned for regular scientific dissemination. Overall, private institutions account for a larger number of affirmative responses, while public institutions display both active and inactive publication behaviors.

At the **city level**, publication activity varies across locations. **Bogotá** shows the most heterogeneous pattern, with both publishing and non-publishing institutions represented. **Cali, Bucaramanga, Medellín, and Barranquilla** each report facilities that publish HPC-related results, whereas **Manizales** and **Cartagena** report no publication activity. These results indicate that research dissemination capacity is unevenly distributed across cities and tends to be concentrated in a subset of locations within the national HPC ecosystem.

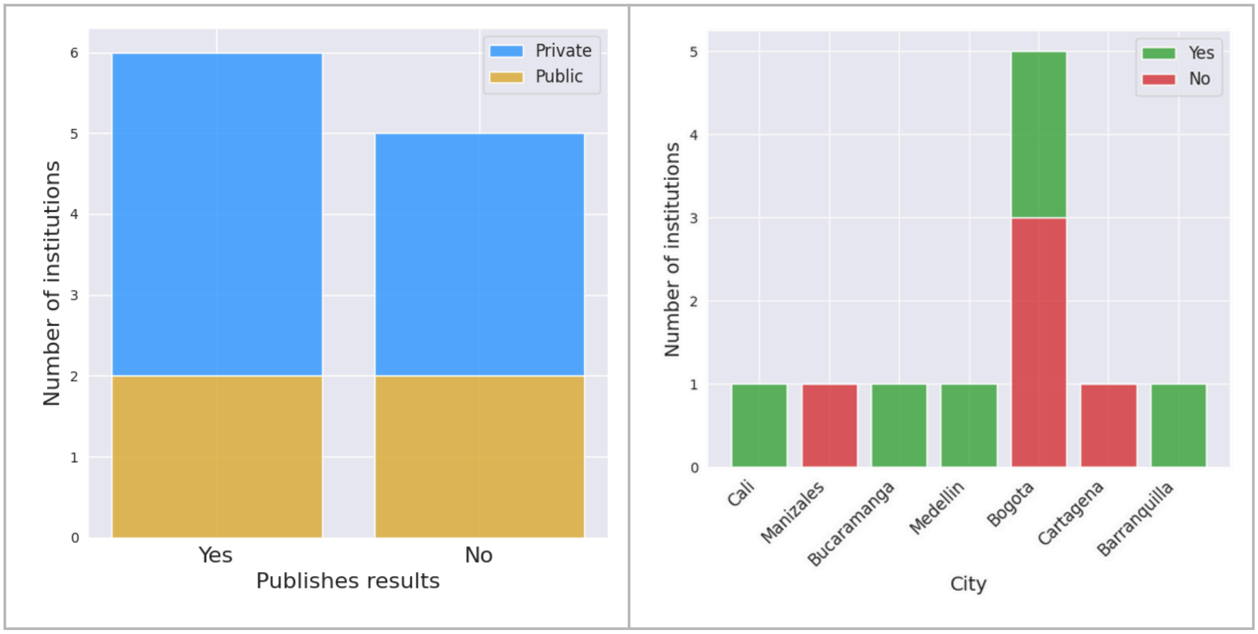

Figure 10. Publication of results, by Ownership Sector and City; 11/11 HPC facilities answered this question.

Figure 11 presents the occurrence of **reported publication areas** among the surveyed HPC facilities, based on the thematic fields in which institutions indicated regular dissemination of results.

The results show a **strong concentration in engineering and basic/applied sciences**, which together represent the most frequently reported publication areas. This confirms the central role of HPC in supporting traditional computational workloads related to modeling, simulation, and scientific computing. **Computational biology** and **data science** also appear repeatedly, highlighting the growing relevance of data-intensive and life-science applications within the HPC ecosystem.

A secondary group of application areas includes **business and finance**, **social sciences**, and **computer science**, indicating that HPC resources are increasingly used beyond classical STEM domains. Less frequently reported but still present are areas such as **energy**, **materials science**, **chemistry**, **health**, and **industry**, suggesting emerging or more specialized uses of HPC capabilities. Overall, the figure illustrates a diversified but uneven distribution of publication areas, with a clear dominance of engineering and core scientific disciplines complemented by a widening range of interdisciplinary applications.

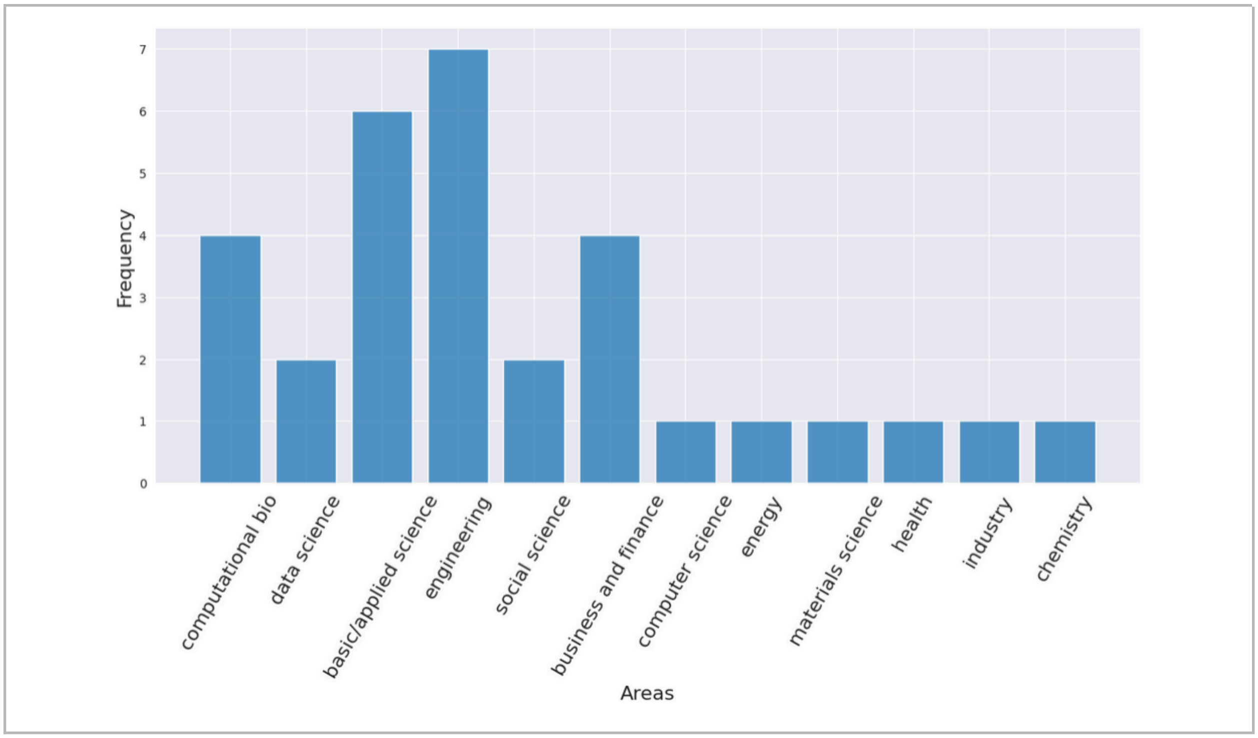

Figure 11. Occurrence of reported publication areas.

Based on the institutions that report regular publication using HPC resources, the results reveal a **diverse range of research areas**. Several publications are focused on **biotechnology and computational biology**, including topics such as genome analysis, viral transmission, pathogenic variants, and neuropathogenesis; this area often overlaps with **basic and applied science**. **Materials science** is also well represented, with research in chemistry involving molecular dynamics simulations, chemical reactions, and solvation behavior, again showing overlap with broader basic and applied science domains. Institutions that classify their work more generally under **basic/applied science** report research spanning biology, chemistry, and physics.

Although not always explicitly labeled as such, many of these publications clearly fall within **computational science and HPC**, as evidenced by the use of simulation-based and large-scale computational approaches. A more specific focus on **physics** is observed in at least one case, where research addresses the elastic and phase behavior of lipid bilayers. In contrast, some institutions provide **general or unspecified descriptions** of their publication activity, or refer externally to a **Google Scholar profile**, suggesting a wide but not explicitly categorized research scope.

Additional areas of publication include **data science**, which involves the processing and analysis of large volumes of data and frequently overlaps with other fields; **engineering**, covering topics from operations research to fluid dynamics; and **energy**, encompassing both Oil & Gas and renewable energy research. **Health-related research** is reported by institutions with medical faculties and often intersects with biology, biotechnology, and engineering. There is also evidence of **industry-oriented research**, typically overlapping with engineering topics, as well as activity in **chemistry**, closely connected to materials science and basic/applied science. Finally, two institutions report the use of HPC for research in the **social sciences**, indicating emerging adoption of high-performance computing beyond traditional STEM disciplines.

Generation of HPC Education Resources

Figure 12 summarizes responses to the survey question on whether HPC facilities have **developed teaching material related to high-performance computing**, combining an overall count of *Yes/No* responses (left) with their **distribution by city** (right). Of the 11 facilities surveyed, **9 provided valid responses** to this question.

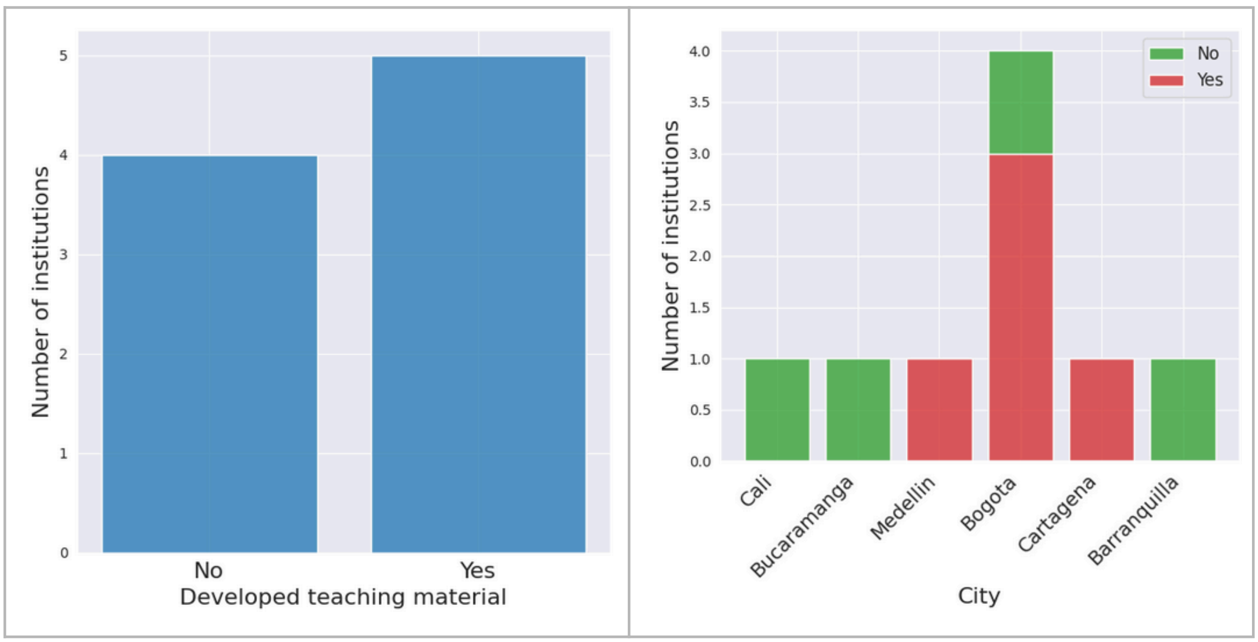

Figure 12. Developed teaching material; 9/11 HPC facilities answered this question.

Figure 12 (left) summarizes whether HPC facilities have developed teaching material related to high-performance computing. Among the **9 institutions that answered this question**, **five report having developed teaching material**, while **four indicate they have not**. This distribution shows that the production of HPC-related educational resources is present in the ecosystem but is not yet a generalized practice. Both public and private institutions appear in each group, indicating that the development of teaching material is not exclusively associated with ownership type.

The right panel of Figure 12 shows the distribution of responses by city. **Bogotá concentrates the largest number of institutions reporting the development of teaching material**, with positive responses from multiple universities located in the capital. Additional positive cases are observed in **Medellín** and **Cartagena**, indicating that educational material development is not limited to a single region. In contrast, institutions located in **Cali, Bucaramanga, and Barranquilla**, as well as one institution in Bogotá, report not having developed such materials, highlighting variability in educational engagement across cities.

In this context, teaching materials include **public repositories, technical documentation, tutorials, and online platforms** aimed at supporting training in **parallel programming, distributed computing, and scientific computing in general**. Taken together, the results suggest that while several HPC facilities actively contribute to capacity building through educational resources, a substantial fraction still focuses primarily on other activities, such as research or service provision. Expanding the development and dissemination of such materials across more institutions and cities could strengthen national HPC training efforts and promote a more uniform educational foundation for students and researchers.

Formal Courses in Institutions

The survey included the question: ***"Does your institution offer courses related to High-Performance Computing (HPC), such as parallel computing, parallel architectures, numerical methods for HPC, or parallel programming languages?"*** All 11 surveyed HPC facilities provided a response. For the purposes of analysis, responses marked as *Not applicable* were treated as negative answers (*No*), as they indicate the absence of formal teaching activities in HPC-related topics.

Figure 13 summarizes the results of this question. The left panel presents the overall frequency of institutions that formally teach HPC-related topics versus those that do not, based on the binary classification (*Yes* or *No*). The right panel disaggregates affirmative responses by the specific topics reported, highlighting the diversity of HPC-related content offered across institutions, including parallel programming, message-passing and shared-memory models (e.g., MPI, OpenMP), accelerator programming (e.g., CUDA, HIP), and domain-driven computational courses.

Table 4 reports the underlying data used to construct Figure 13, detailing, for each institution and city, whether formal HPC-related teaching is offered and, when applicable, the specific topics covered.

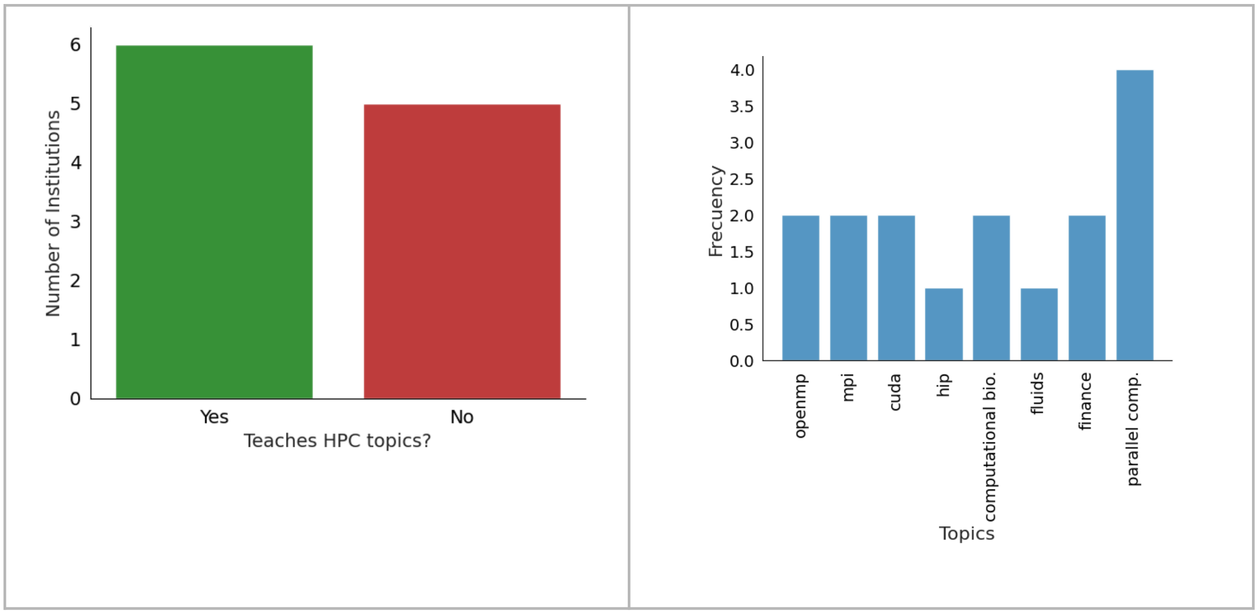

Figure 13. Teaching any HPC-related topic formally; 11/11 HPC facilities answered this question.

Table 4. Teaching any HPC-related topic formally; 11/11 HPC facilities answered this question.

Topic	Institución	Ciudad
No	Universidad Autonoma de Occidente (Private)	Cali
Not applicable	BIOS (Private)	Manizales
OpenMP, MPI, CUDA, HIP	Universidad Industrial de Santander (Public)	Bucaramanga
Computational biology, fluid simulation, fi...	Universidad EAFIT (Private)	Medellín
Computational biology, finance, OpenMP, MPI, ...	Universidad del Rosario (Private)	Bogotá
Parallel programming	Universidad Nacional de Colombia (Public)	Bogotá
Parallel programming	Universidad de Cartagena (Public)	Cartagena
No	Universidad del Norte (Private)	Barranquilla
Not applicable	Universidad Distrital Francisco José de Caldas	Bogotá
Parallel programming	Pontificia Universidad Javeriana	Bogotá
Not applicable	Universidad de los Andes	Bogotá

The left panel summarizes whether institutions formally teach any HPC-related topic. Based on the table, six out of eleven institutions report offering formal instruction in at least one HPC-related area, while five do not. Negative responses include both explicit *No* answers and cases where no topic was reported (NaN), which were treated as non-participation in formal teaching. This result indicates that slightly more than half of the surveyed HPC facilities are engaged in structured educational activities related to HPC.

The right panel presents the frequency with which specific HPC-related topics are mentioned, independent of their geographic location. The most frequently reported topic is parallel programming, followed by programming models and technologies commonly used in HPC environments, such as OpenMP, MPI, CUDA, and HIP. In addition, several institutions report domain-oriented courses that make intensive use of HPC, including computational biology, fluid simulation, and computational methods applied to finance. This distribution indicates a strong emphasis on foundational HPC skills, complemented by applied, domain-specific training.

While the right panel does not display results by city, the table shows that institutions offering formal HPC-related teaching are geographically distributed across several cities, with multiple contributions from institutions located in Bogotá and isolated contributions from Bucaramanga, Medellín, and Cartagena. Institutions reporting no formal teaching activities are also spread across different cities.

CHALLENGES: HPC FUNDING

Understanding the Barriers to HPC Funding: Why It Matters

Securing sustainable funding is one of the most critical components for the development and long-term operation of High-Performance Computing (HPC) centers. Yet, despite their strategic importance for research, innovation, and national digital transformation, many HPC initiatives in Colombia face systemic and recurring barriers that hinder access to the financial support needed.

Understanding these **funding blockages** is not merely a diagnostic exercise — it is a strategic imperative. When institutions, researchers, and decision-makers have a clear picture of the structural and procedural obstacles, they are better equipped to:

- **Make informed policy changes** that reduce friction in accessing public and private funding.
- **Design more inclusive and transparent funding instruments** tailored to the needs of diverse scientific communities and regions.
- **Mobilize institutional and inter-institutional actions** that increase the competitiveness and readiness of HPC centers to apply for national and international calls.

Moreover, by exposing the **hidden administrative burdens**, **opportunity asymmetries**, and **skills gaps in grant writing**, this analysis **highlights** the underlying issues that often go unnoticed by higher-level authorities. This visibility is essential to:

- **Engage government agencies** (e.g., Minciencias, regional innovation systems) in redesigning funding frameworks.
- **Motivate universities and private sector actors** to invest in internal capacity-building.
- **Support the creation of national coordination mechanisms** that facilitate a more equitable distribution of computational infrastructure.

Analyzing the question **“‘¿Cuál es el mayor reto para conseguir financiación? *(What is the greatest challenge you face in securing funding)”***, highlights multiple interlinked obstacles. Drawing on qualitative responses and our thematic categorization, the three principal challenges are:

1. Bureaucratic Complexity and Slow Administrative Processes

Many institutions report that **lengthy approval cycles**, **excessive paperwork**, and **multi-level sign-offs** significantly delay or even derail funding applications. This administrative overhead can:

- extend the time from proposal submission to project start by **several months**, jeopardizing time-sensitive research,
- require dedicated staff hours for compliance rather than scientific work, and
- discourage smaller or newer centers from applying, reinforcing existing disparities.

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2. Limited and Highly Competitive Funding Opportunities

Respondents across both public and private institutions emphasize that **national and regional funding calls are infrequent**, **underfunded**, and **oversubscribed**. This creates:

- a “winner-takes-all” dynamic where a few established centers secure the bulk of available grants,
- little room for emerging projects or novel, high-risk research, and
- a tendency to tailor research proposals toward guaranteed traditional topics rather than innovative, interdisciplinary applications.

3. Lack of Grant-Writing Expertise and Visibility

Several centers — particularly those outside major urban hubs — cite difficulties in:

- **crafting competitive proposals** due to limited experience or internal training in grant writing,
- **identifying appropriate calls**, as information about new funding opportunities is not always effectively disseminated, and
- **building reputational visibility** to convince review panels, creating a cycle in which a lack of prior awards hinders future success.

CHALLENGES: HPC PROJECT EXECUTION

Understanding Execution Barriers in HPC Projects

In the lifecycle of a High-Performance Computing (HPC) project, having infrastructure and funding is not sufficient. Execution challenges often determine whether a project succeeds, stalls, or fails. That's why identifying **the real and recurring operational difficulties** experienced by institutions is vital—not only for internal improvement, but for shaping national strategies and external support mechanisms.

Recognizing these barriers allows us to:

- **Support targeted interventions** by funding agencies, infrastructure providers, and education/training programs.
- **Raise visibility** of hidden operational inefficiencies that reduce the effectiveness of HPC investments.
- **Create common ground** between institutions facing similar constraints, which can lead to shared solutions, best practices, and collective bargaining power for national upgrades.

The insights below are drawn from responses to the question*: ¿Cual es la mayor dificultad al ejecutar proyectos de HPC que experimenta regularmente ? (What is the greatest difficulty you experience regularly when executing HPC projects?)*

Categorization and Analysis of Execution Difficulties

From the responses, six recurring categories of difficulties were identified:

Category	Description
Limited Access to Infrastructure	Lack of availability of computing nodes, storage, or network capacity at required scale.
Lack of Trained Personnel	Absence of specialized staff for parallel programming, system administration, or optimization.
Technical and Operational Issues	Hardware failures, performance bottlenecks, outdated equipment, or downtime.
Lack of Software or Tools	Missing licenses, unsupported packages, or unavailable scientific libraries.
Time Constraints and Availability	Users' limited access due to system scheduling or shared resources.
Poor Project Management	Inadequate planning, coordination, or execution workflows for HPC-based research.

Top 3 Most Frequent Challenges

Based on the classified responses, the **three most common operational difficulties** are:

1. **Limited Access to Infrastructure**
   This includes queues, resource contention, or lack of nodes for high-scale jobs.
   Institutions often lack the scalability needed for concurrent users or large data simulations.

2. **Lack of Trained Personnel**
   There is an evident skill gap in HPC administration, code optimization, and job orchestration. This limits performance, increases error rates, and reduces effective use of infrastructure.

3. **Technical and Operational Failures**
   Recurrent problems with performance, maintenance, or hardware failure reduce system reliability. In many cases, lack of preventive maintenance or expert support exacerbates

these problems.

Public vs. Private Institutions

- **Public institutions** report a greater concern with **infrastructure availability** and **staff capacity**, reflecting the strain placed on shared resources and centralized IT support.

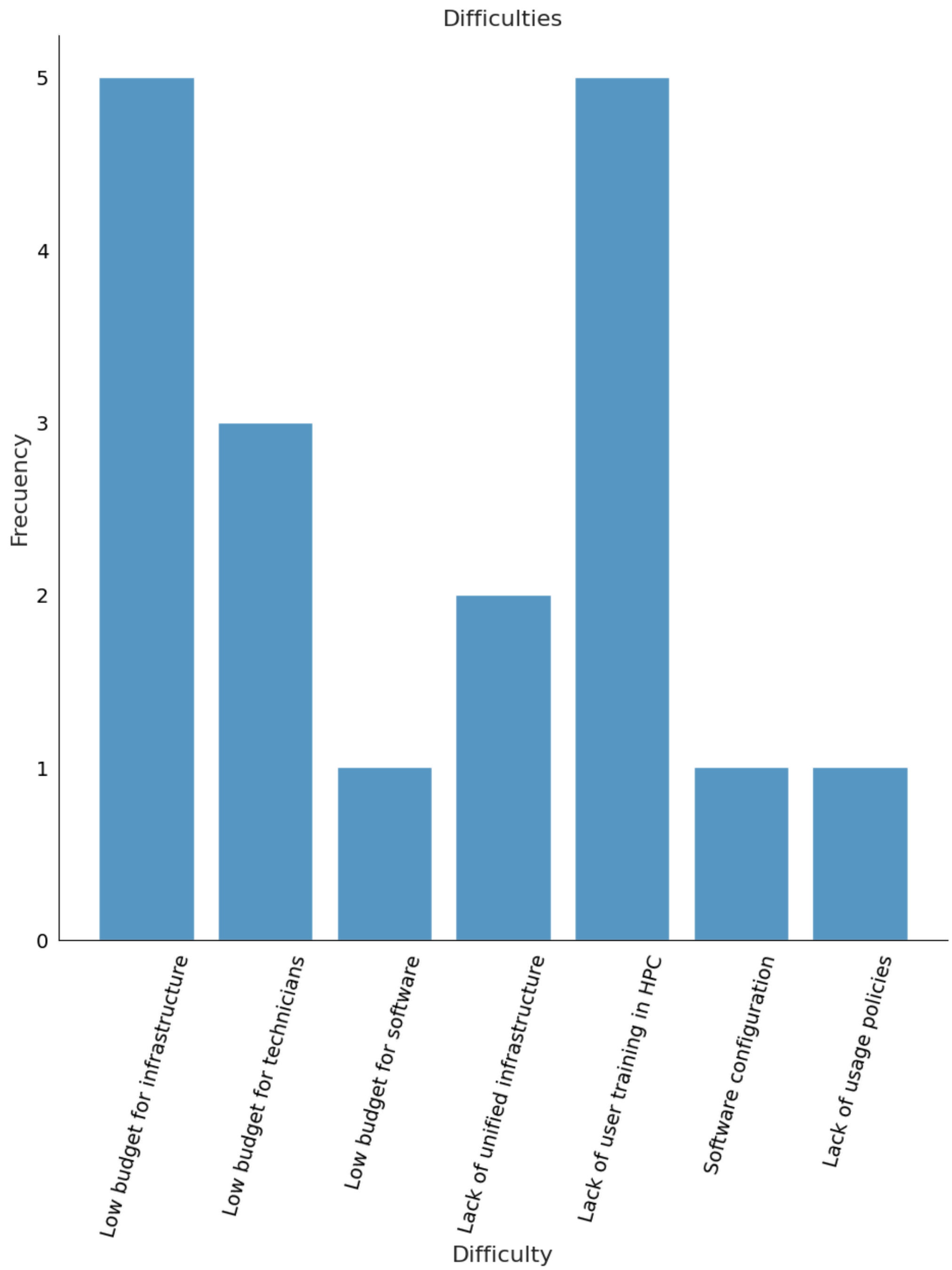
- **Private institutions** tend to face more **technical failures** and **software/tooling issues**, likely due to autonomy in procurement but fragmentation in long-term support and upgrades.

Geographical Distribution

- **Bogotá-based institutions** face a broad set of difficulties but highlight **human capital and infrastructure contention** as primary.

- **Regional institutions** (e.g., Manizales, Medellín, Barranquilla) show **hardware reliability** and **software/tooling** as frequent constraints, possibly due to legacy infrastructure or limited support teams.

- **Cali and Cartagena** reported few unique cases but aligned with broader trends in system access and staffing challenges.


Difficulties
Frecuency
0
1
2
3
4
5
Low budget for infrastructure
Low budget for technicians
Low budget for software
Lack of unified infrastructure
Lack of user training in HPC
Software configuration
Lack of usage policies
Difficulty

CHALLENGES: HPC TRAINING

Users of high-performance computing (HPC) resources at institutions and universities are primarily students and faculty members. In many cases, training in parallel computing—as well as practical knowledge of how to access computing clusters and submit jobs—is very limited outside of disciplines such as computer science. It is therefore imperative to develop an educational program that equips students and faculty with the necessary skills to become effective users of HPC services.

CHALLENGES: HPC INFRASTRUCTURE

General Overview

The question aimed to identify institutions that **still face unresolved HPC-related challenges**, whether in training or infrastructure, and whether they lack clear strategies to address them. This is a **critical indicator** of structural and operational gaps in the national HPC ecosystem.

From the analysis:

- **Over 50% of institutions** indicated they have **unresolved needs** related to HPC.
- These include gaps in specialized human capital, lack of technical support for job execution, limited knowledge of platforms, and inability to scale existing projects.
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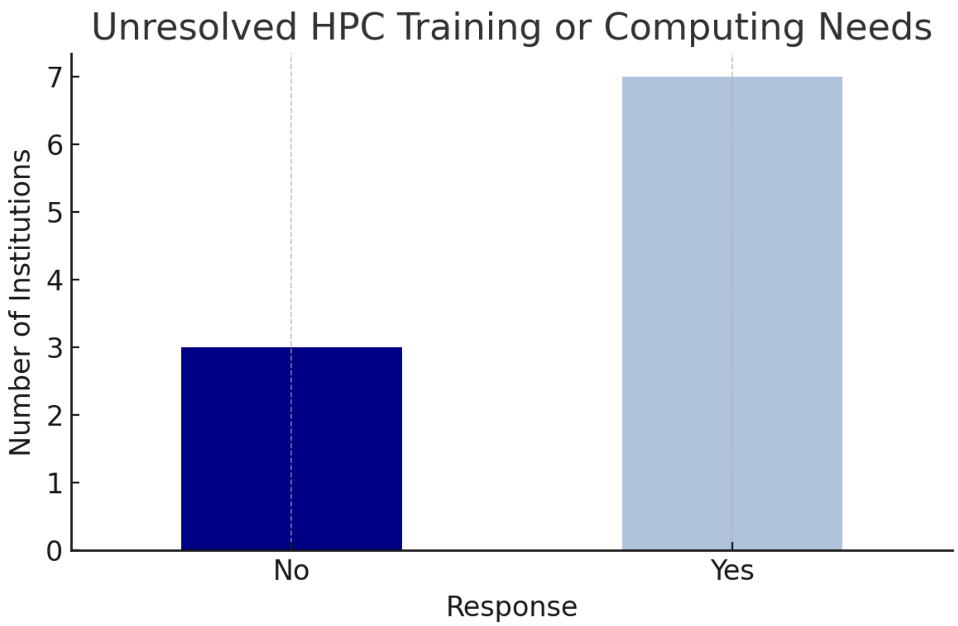
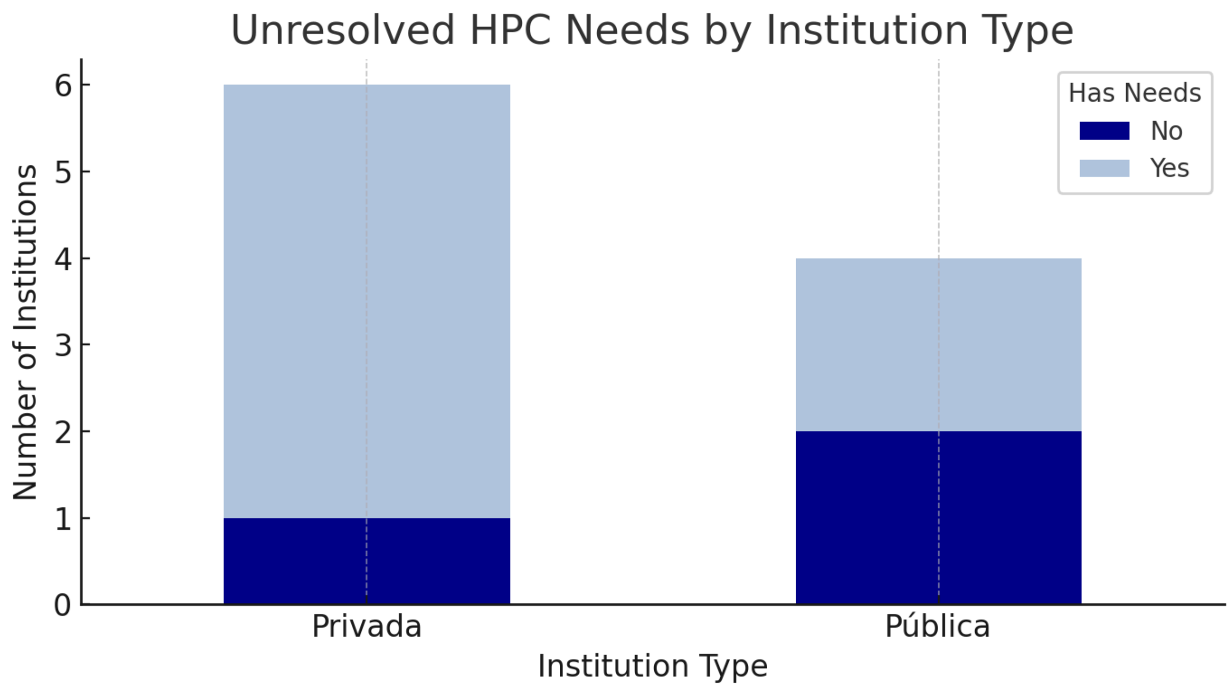


By Institution Type

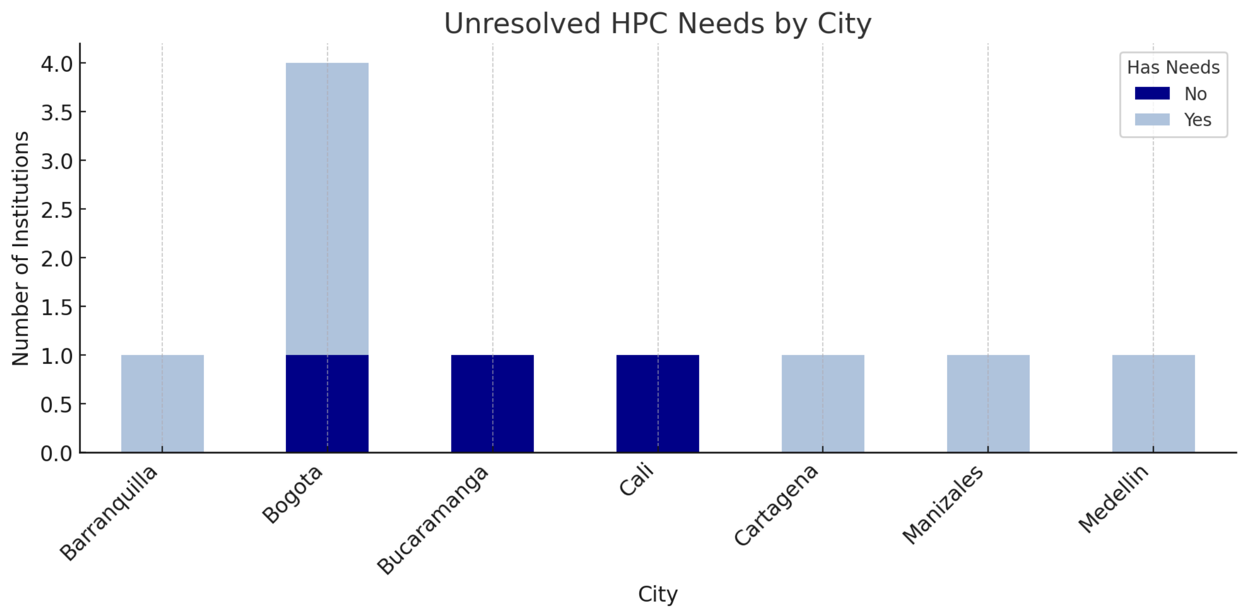
- **Private institutions** reported a higher **absolute number of unresolved needs**, aligned with their greater representation in the survey.
- **Public institutions**, although fewer in number, show an equally high proportion of needs, especially related to training and infrastructure capacity.



This suggests that **both public and private sectors share common structural challenges**, although the nature of those needs may differ slightly — public institutions often express administrative or integration barriers, while private entities report access and technical execution issues.

By City

- Cities such as **Bogotá**, **Medellín**, and **Barranquilla** reported multiple unresolved HPC needs, indicating that **geographic centrality does not guarantee problem resolution**.
- In some cases, the **lack of local or regional HPC support infrastructure** is a determining factor.
- Smaller cities with emerging academic hubs (e.g., Pasto, Bucaramanga) also reported persistent needs, reinforcing the need for **distributed support mechanisms**.

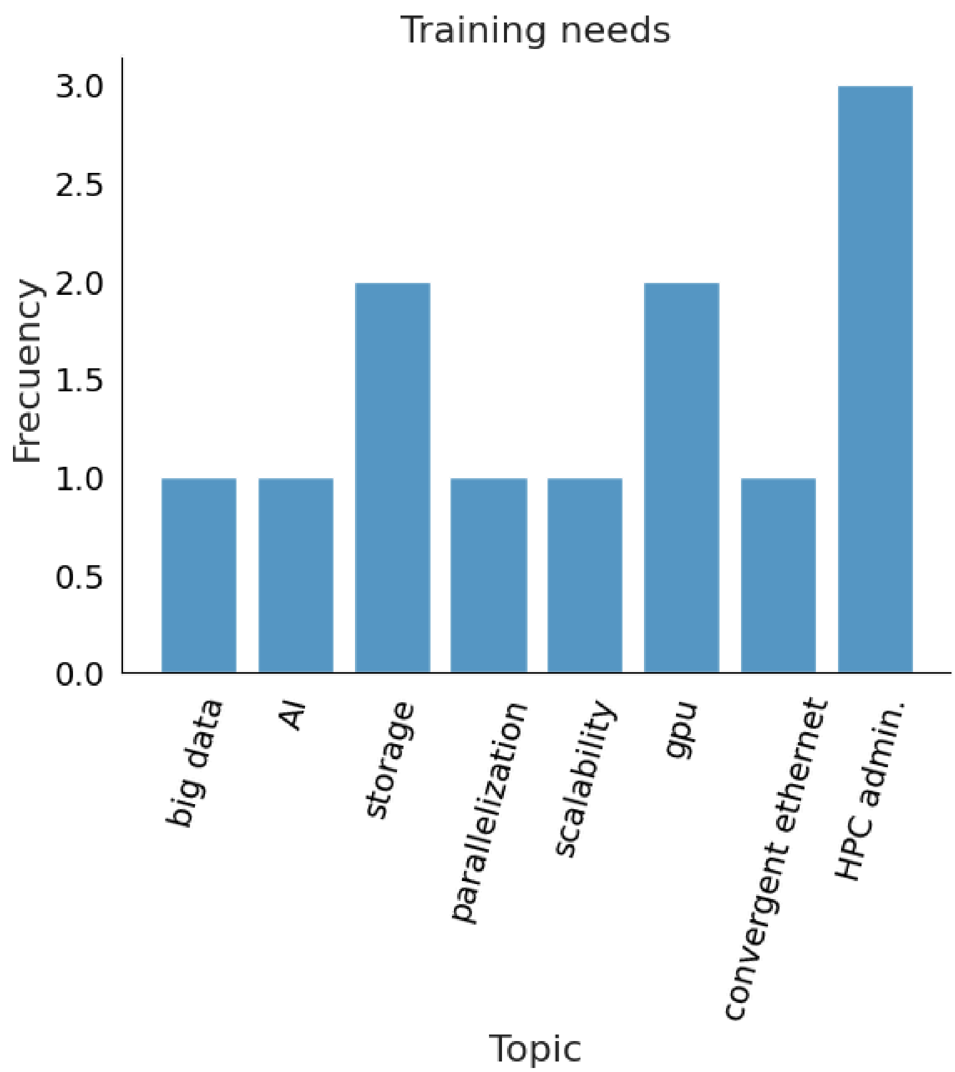


Implications

1. **The high level of unmet needs shows that the ecosystem is still maturing** — training and technical support remain critical.

2. There is a clear **opportunity for national coordination**, possibly led by RENATA, SCALAC, or regional HPC centers, to standardize access and support mechanisms.

3. Insights from this section should guide the **design of future HPC training programs**, infrastructure investment plans, and national roadmaps.


Training needs
Frecuency
3.0
2.5
2.0
1.5
1.0
0.5
0.0
big data
AI
storage
parallelization
scalability
gpu
convergent ethernet
HPC admin.
Topic

MOVING FORWARD: CYBERCOLOMBIA PERSPECTIVE

Over the course of more than three months, this national survey consolidated the input of leading HPC actors across Colombia—universities, research centers, and technological institutions. The data, curated through in-depth responses, institutional collaboration, and regional inclusion, provides the most accurate snapshot to date of the **Colombian HPC ecosystem**.

Key findings include:

- **Widespread Institutional Participation:** A significant majority of institutions are actively engaged in national and regional HPC events such as the *HPC Summer School* and *CARLA*, which serve as pillars of education and scientific communication in the community.

- **Strong Training Demand:** More than half of the institutions report unresolved needs in HPC training and computing capabilities, indicating a gap between infrastructure availability and institutional capacity to utilize it.

- **Decentralized Engagement but Centralized Challenges:** Institutions from across the country—Bogotá, Medellín, Manizales, Bucaramanga, and beyond—demonstrate varying levels of participation, but share common structural obstacles such as funding, technical support, and resource access.

- **Collaborative Culture:** Institutions report strong horizontal collaboration with national universities, research networks, and international consortia, but often lack coordinated engagement with public policy agencies and national funding mechanisms.

- **Critical Gaps in Infrastructure Sustainability:** Funding sources are varied but unstable. Many rely on internal budgets or temporary project grants, with few institutions reporting sustainable or scalable funding strategies.

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2. Strategic Vision for the Colombian HPC Community

This report reveals a **mature but underleveraged HPC ecosystem**. Colombia possesses:

- Talented researchers,
- Operational infrastructure,
- Institutional diversity,
- And growing regional and international visibility.

However, it lacks:

- A national HPC policy framework,
- Sustainable funding models,
- Systematic integration of training and research,
- Clear coordination between infrastructure providers (e.g., RENATA) and users.

There is a clear opportunity to **transition from a dispersed network of HPC actors to a coordinated national system** that supports scientific, technological, and industrial transformation.

Based on this analysis, we propose the following **three pillars for collective action**:

A. National HPC Integration Plan

Led by academic and research institutions, supported by public and private stakeholders.

- Establish a **Colombian National HPC Committee** with representation from universities, CyberColombia, RENATA, SCALAC, RedClara.

- Define a **5-year roadmap** for training, infrastructure, and sustainability of HPC services, based on cooperative effort.

B. Strategic Training and Human Capital Development

- Expand and formalize programs like the *HPC Summer School* into a **national curriculum**, with hybrid formats and certification.

- Fund **HPC internships and fellowships**, especially for underrepresented regions and institutions.

- Promote HPC in graduate programs across engineering, physics, biology, and data science.

C. National Funding and Infrastructure Mobilization

- Purpose to Policy Maker and **stable funding instruments** for shared infrastructure, open platforms, and support centers.

- Incentivize cross-sector HPC projects through public-private partnerships.

- Evaluate and interact to create a HPC vision about RENATA's role to ensure technical interconnection with RedCLARA and active community engagement.

While the institutional and technical base of the HPC community in Colombia is solid, it remains **fragmented from national policy structures**. This represents a **critical bottleneck** for achieving system-wide transformation.

D. Engaging Minciencias and Regional Governments

- **Minciencias**, as the **national policy and funding authority for science and technology**, has not yet fully integrated High-Performance Computing as a strategic axis in its planning instruments (e.g., national science agendas, digital transformation roadmaps, innovation hubs).

- The survey results show that most HPC initiatives are **led bottom-up by academic actors**, without consistent programmatic support from top-down planning frameworks.

- In parallel, **regional governments** — especially in departments with research universities — are **underutilized allies**. They can play a vital role in:

- Facilitating HPC infrastructure in local innovation districts.
  Funding regional clusters of scientific computing.
- Supporting education programs in partnership with universities.