CREATING COLLABORATIVE RESEARCH ENVIRONMENT IN HIGH PERFORMANCE COMPUTING: AN ANALYSIS OF TURKEY

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ABSTRACT

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The use of High-Performance Computing (HPC) has become vital not only in computer science but also in many scientific areas ranging from Covid-19 studies to space sciences. Thus, although HPC is at the heart of many small and large-scale collaborations, its relationship with collaboration is quite limited in the literature. The studies mainly focused on HPC return on investment. In this thesis, collaboration in studies using HPC is investigated from the researcher's perspective using HPC. The study is carried out specifically in Turkey to answer the following question: : “How should Turkey form its HPC environment regarding collaborative research?” Qualitative approach is employed collecting data through interviews with the researchers affiliated with Turkish universities. According to the findings, scarcity of resources, lack of personnel, and technical inadequacies in Turkey stand out. In addition to all these shortcomings, the lack of communication channels undermines collaboration most notably. In the light of these results, a structure under the roof of a common platform is proposed as a policy proposal. This structure is expected to support the collaboration of scientists using HPC in Turkey.

Keywords: HPC, collaboration, common platform, policy, computing

ÖZ

YÜKSEK BAŞARIMLI HESAPLAMA ÇALIŞMALARINDA İŞBİRLİKÇİ ARAŞTIRMA ORTAMI YARATMAK: TÜRKİYE ÜZERİNE BİR ANALİZ

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Yüksek Başarımlı Hesaplama (HPC) kullanımı sadece bilgisayar bilimlerinde değil, Covid-19 araştırmalarından uzay bilimlerine kadar geniş bir yelpazede birçok bilimsel çalışmada hayati hale gelmiştir. Bu nedenle HPC, birçok küçük ve büyük ölçekli işbirliğinin merkezinde yer almaktadır. Literatürde HPC ve işbirliği arasındaki ilişki oldukça sınırlıdır. Çalışmalar, HPC'nin yatırım getirisine odaklanarak yürütülmüştür. Bu tezde, HPC kullanan çalışmalarda işbirliği, HPC kullanan araştırmacının bakış açısından tartışılmaktadır. Çalışma, Türkiye özelinde yürütülmekte ve "Türkiye, işbirlikçi araştırma bakımından HPC ortamını nasıl oluşturmalı?" sorusuna yanıt aranmaktadır. Türkiye'de HPC kullanan araştırmacıların gözünden ortaya çıkan bulgulardan yararlanarak bu soruyu yanıtlamak için nitel araştırma tercih edilmiştir. Bu nedenle veriler, Türkiye'deki üniversitelere bağlı araştırmacılarla yapılan görüşmelerle toplanmıştır. Analizler sonucunda Türkiye'de kaynak kıtlığı, personel eksikliği ve teknik yetersizlikler göze çarpmaktadır. Tüm bu eksikliklere ek olarak, iletişim kanallarının eksikliği en belirgin şekilde işbirliğini baltalamaktadır. Bu sonuçlar ışığında, politika önerisi olarak ortak bir platform çatısı altında bir yapı

önerilmektedir. Bu yapı, Türkiye'de HPC kullanan bilim insanlarının işbirliğini desteklemeye odaklanmıştır.

Anahtar Kelimeler: süperbilgisayar, başarım, politika, işbirliği

To the memory of my grandmother
To my mother

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LIST OF ABBREVIATIONS

HPC: High-Performance Computing

UHEM: The National Center for High-Performance Computing

TRUBA: Turkish National e-Science e-Infrastructure

TÜBİTAK: The Scientific and Technological Research Council of Turkey

CHAPTER 1

INTRODUCTION

One of the biggest trends of scientific research, groundbreaking projects, and innovative inventions is High-Performance Computing (HPC) applications. Investments in HPC centers significantly affect the current efficiency and scale of scientific studies of countries such as China, France, United Kingdom, United States, and Italy (Joseph et al., 2013; Ludwig, 2012). Used for digital innovations, which are indispensable for the digital economy, HPC improves economic growth and competition by encouraging the adoption of digital innovations in many sectors (Gigler, Casorati, & Verbeek, 2018). Investments in supercomputers used in innovative projects such as planetary exploration or drug development have further intensified the international scientific, industrial and economic competitive environment. In this rapidly growing competitive environment, new investments are made everyday (Kalbe, 2019).

HPC studies are carried out to solve social problems such as public health, climate change, and earthquakes (Lee & Lee, 2021). The demand for big data processing is increasing in order to find rational solutions to the fundamental problems of the global digital world, and HPC is preferred as an effective tool to meet these demands (Sterling et al., 2018). It is expected that the interest in HPC studies, which are used in many sectors, will increase further based on the rapid development of big data (Gigler, Casorati, & Verbeek, 2018).

Despite these benefits of HPC in many fields, there are still some challenges. Studies with HPC take place in a highly competitive environment (Usman et al., 2018). In this environment, researchers from various fields establish scientific colaborations to conduct research together. Thus, the importance of the HPC centers and the environments where researchers gather has increased (Khan et al., 2019). Considering the use of HPC, countries implement effectively in terms of quality and efficiency in order not to fall behind in the global competition (EuroHPC Joint Undertaking, 2022; Neely, 2014).

In the 2016 HPC Strategy Implementation Regulation of the European Union, HPC was considered as the engine that powers the new global digital economy. Vast amounts of data are produced, transported, stored, and processed in a digital economy that interconnects various applications and sectors, which brings the considerable need for computational power. The nature of computing is also changing, with an increasing number of applications. Therefore, implementing efficient policies towards research with HPC has utmost importance (The European Commission, 2016).

Today, complex research, groundbreaking inventions, and big science projects are realized with collaborations (Price, 1963). Thus, the nature of research with HPC is explored in terms of collaboration in this thesis. Collaboration is inherent in HPC, which meets the need for research and complex computation with big data. Scientific communities doing research with HPC are coming together. At the same time, they meet in environments where they can publish their research and make projects. Such environments facilitate the use of HPC.

This thesis aims to provide policies for Turkey's HPC environment regarding research collaboration. Research collaboration, as defined by Katz and Martin (1997), is collaboration within science established by interaction between researchers or inter-institutional and international. The environments in which researchers interact with each other to conduct research, either virtually or physically, are scientific collaboration environments (Bennett & Gadlin, 2012). In these environments, even if researchers do not conduct research with interaction, there may be environments where they conduct research together with division of labor (Chompalov et al., 2002). In the literature review chapter, existing literature on the nature of HPC and the research environment are presented. The relationship between the collaboration environment and research using HPC as interpreted in the literature is presented. The research question of the thesis is “How should Turkey form its HPC environment regarding collaborative research?" Considering the research question of the thesis, the gaps noticed in the literature are indicated. The questions arising from these gaps constitute the sub-questions of the main research question of the thesis.

In order to find answers to these questions arised from literature review, qualitative method is applied. The application of this methodology is explained in the third chapter. Method selection and sampling are also described in detail. Furthermore, the processes of the analysis obtaining strong findings are presented. The elimination of potential biases and ensuring reliability in reaching strong conclusions are provided.

The findings that emerged from the analysis are presented in detail in the fourth chapter. The findings structure consists of four clusters which are Research, Collaboration, Resource, and Disciplinary Gaps. These became the main sections of the findings chapter. The Research section presents findings on the nature of research with HPC. The analysis of the findings regarding collaboration is shown in the Collaboration section. The effects of HPC resources on collaboration and research environment are explained in the Resource section. The findings on how an HPC resource is allocated for research and the consequences of these allocations are also analyzed in this section. Disciplinary gaps arise from the differences of disciplines such as their perspectives, theories, concepts, and the methods they use (Klein & Miller, 1983). There are disciplinary gaps in the use of HPC as a tool by researchers from different disciplines conducting data-intensive research together (Ogier et al., 2018). These gaps usually arise when scientists from different fields other than computer science take part in a research using HPC (Hu & Zhang, 2017). The findings on disciplinary gaps in research conducted with HPC and how they are tried to be filled in Turkey are analyzed in the Disciplinary Gaps section.

The findings of this thesis are discussed in the fifth chapter. The cases that overlap and contradict the findings in the literature are presented. Simultaneously, it is shown how the gaps noticed in the literature review are filled in this thesis. Possible future studies are also offered in this chapter. This chapter, where the findings are discussed, sheds light on the recommendations in the conclusion chapter.

In the sixth chapter, I present the policy recommendations that I created with the analysis of the findings Policy plans that can contribute to Turkey's research environment with HPC in the context of collaboration are proposed. These recommendations constitute the answer to the research question.

Six appendices are provided in this thesis. The first one is the approval of the METU human subjects ethics committee. The second and the third ones are the first and second version of the interview guide. The fourth appendix is the codebook formed with the help of QDA Miner program. The others are the Turkish summary and thesis permission form.

There are four novel contributions of this thesis:
First of all, the use of HPC and its impact on scientific research is a newly studied area in the literature. There are studies that examine the impact of HPC investments on the research environment (Ludwig, 2012; Scrivner et al., 2018; Stewart et al., 2018). These studies aim to show return on the investments on HPC. Considering the contributions of collaboration to science, studies on the relationship between collaboration and HPC, and the nature of these research environments are very few. In this thesis, the nature of research with HPC is examined regarding research collaboration.

Second, researchers who are HPC users are in the center of this thesis. Since the studies that have been done so far are publication-oriented (Apon et al., 2010; DeLeon et al., 2015; Von Laszewski et al., 2015), they classify the collaborations that resulted in publication as successful. They do not include the perspective of the researcher. Even if a research does not result in a publication, it is included within the scope of this thesis. That is why this thesis addresses the researchers' own needs and desires from their perspective. Thus, this thesis makes a contribution to the scientific community using HPC in Turkey.

Third, a qualitative methodology is adopted to answer the research question of the thesis. Stewart et al. (2019) emphasizes that qualitative analysis is a powerful method for examining the non-financial contributions of infrastructures like HPC. Studies so far have been based on a quantitative analysis, and studies with qualitative analysis are limited (Stewart et al., 2019). For this reason, the usage of a qualitative methodology is another significant contribution of this thesis.

Fourth, the studies about HPC's contribution to the research environment regarding collaboration are limited, particularly in Turkey. We haven't been able to find studies on the effect of HPC use on the research environment specific to Turkey. This thesis offers valuable policy recommendations with necessary solutions to fill these gaps.

CHAPTER 2

LITERATURE REVIEW

Science's evolution into becoming more data-intensive, networked, and collaborative has been defined as the fourth-paradigm of scientific research (Bell et al., 2009; Hey et al., 2007). Within this paradigm, as the accumulation of knowledge increases, the need for scientific research to be carried out by people from various fields also increases (Wuchty et al., 2007). Wagner (2018) also emphasizes that the abundance of sources, easy ways of communication, easy access to information, and the development of advanced equipment shifted science into a collective system. These changing patterns are seen globally. Thus, this era is called "*the collaborative era in science*".

As mentioned by Wagner (2018), this era triggers collaborations. Individual scientific studies are now behind the times (Cronin, 2001). Multiple-author publications are getting more citations, and the trend towards collaborative scientific research is increasing (Wuchty et al., 2007). One of the drivers of this change in science is the emergence of big data.

Big data can be defined as data too large to be stored, acquired, managed, processed, and analyzed by traditional methods (Chen et al., 2014). As can be understood from its definition, big data research is inherently dependent on complex structures (Chen et al., 2014). It is observed that collaboration increases with data growth and increases as the complexity of research questions increases. Studies show that research questions that are too complex to solve the researchers by themselves trigger collaboration (Hara et al., 2003; Iglič et al., 2017; Morrison, 2017). Not surprisingly, big data researchers collaborate more than researchers not dealing with big data (Metzler et al., 2016). This kind of collaboration aims to achieve goals that cannot be achieved alone (Bennett &

Gadlin, 2012). The complex structure brought by big data research is compatible with this motivation.

2.1. High-Performance Computing (HPC)

A collaborative environment in big data research is widely mentioned in the literature in the context of data-intensive paradigm. The features of big data bring many research challenges and necessitate the use of advanced tools (Chen & Zhang, 2014; Patgiri & Ahmed, 2017). One of the tools that can meet this data-intensive paradigm's needs is High-Performance Computing (HPC). HPC assigns a series of tasks to be performed simultaneously and replicates key physical components such as processors and memory banks to solve a complex problem. The system software and programming models that provide management of an HPC system differ from the conventional computer in terms of parallelism and distribution (Sterling et al., 2018).

HPC is utilized in fields for R&D, future projection, and theoretical study purposes (K. Lee & Lee, 2021). Computations with HPC is common in popular topics such as drug discovery (Pitera, 2009) and Covid-19 research (H. Lee et al., 2021). Moreover, it is seen that HPC resources are preferred for computations on daily problems. For instance, HPC resources are needed for weather forecasts and simulations for future projections (Manubens-Gil et al., 2016). In addition to these common uses, HPC is also used in social sciences such as anthropology (Sellers et al., 2009) and archeology (Melero, 2013). In an anthropology study, a dinosaur's gait was simulated by high-performance computing using an 8000-core computer (Sellers et al., 2009). In this study, the paleontological information obtained from the fossils, the biological information about the anatomy, physiology and biomechanics of existing animals were integrated into the HPC environment. Another study mentions new research developments in the HPC environment, drawing attention to the difficulties of existing models used in archaeological research (Melero, 2013). As can be understood from these examples, computations are made with HPC in studies that bring together a variety of data and different disciplines. In this respect, HPC creates a working environment that allows for the computations required by big data (Fox et al., 2016).

2.2. Definition of Collaboration in the Thesis

Turkey's HPC research environment is discussed regarding collaboration in this thesis. However, collaboration is a comprehensive concept. Collaboration can be encountered in many different dimensions in research with HPC. The concept also differs from field to field. For instance, multi-authored publications are frequently encountered in the field of physics where HPC is heavily used (Götz et al., 2017). However, how much of the work done for these publications can be accepted as “true collaboration” is a matter of debate (Cronin, 2001). It is unacceptable to define a study as a collaborative work only when there are many names on a publication. Those whose names are on the publication as per their contract cannot be accepted as part of collaboration if they have not contributed anything (Canals et al., 2017).

According to Bennett et al.s (2018) definition of collaboration, researchers must interact with each other. However, research with HPC can require very different collaboration needs. Division of labor as in multidisciplinary studies or collaboration with a computer scientist to bridge the disciplinary gaps are quite common in research with HPC (Hu & Zhang, 2017). Therefore, the concept of collaboration is not narrowed down much in this thesis. Even if researchers do not interact, the needs such as division of labor in collaboration with HPC are indicators of the need of researchers for each other.

2.3. The Relationship Between HPC and Collaboration in the Context of Turkey

Turkey is a good research area for the use of HPC for collaboration. Turkey has two national HPC centers. These centers are not HPC centers that were established just to promote collaboration. Unlike in Turkey, there are centers in the world, such as EuroHPC centers[1], established with the aim of creating a common platform with significant investments. Conducting research on the country like European countries where HPC centers were established for collaborative purposes would create bias.

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[1] EuroHPC JU (European High Performance Computing Joint Undertaking) is an EU-dependent entity that aims to build a large HPC community across Europe. For more information: https://eurohpc-ju.europa.eu/

Researchers from many different fields are using and collaborating with HPC in Turkey. There are conferences organized for HPC development in the country (Ulusal Yüksek Başarımlı Hesaplama Konferansları, 2022). Turkey, which has targets in science and technology policies, aims to develop HPC infrastructures in the field of Artificial Intelligence according to the National Artificial Intelligence Strategy (2021-2025) (Presidency of the Republic of Türkiye, 2021). In this respect, Turkey is open to development in HPC area.

In this thesis, I examined HPC regarding research collaboration. Studies using large amounts of complex data or using data in various forms from many different disciplines can be carried out using HPC for many different purposes, such as simulation and data mining (Götz, 2017). Considering the various uses of HPC, the scope of collaboration in this thesis, and the context of Turkey in particular, one of the basic sub-questions of the thesis emerges: *Why do researchers in Turkey use HPC?* This question is important to understand nature of research with HPC in Turkey. Understanding this nature gives us the basis for understanding HPC use in the collaborative environment.

2.4. HPC Resource in Collaborative Research

Resource is essential in research collaborations according to the literature. The increase in technological developments and the development of the resources used in scientific research have facilitated scientific collaborations. Advanced technological resources regarding performance cannot be afforded by a researcher alone. Therefore, researchers collaborate to access high-ticket resources (Katz & Martin, 1997). Similarly, HPC resources are not cheap enough for individuals (Thota, 2016) or even countries to acquire them alone (The European Union, 2018). Although the system components are expensive, they are needed to successfully perform scientific computations. HPC systems can meet the high accuracy and precision requirements of complex calculations or simulations while performing intensive computations (Götz, 2017). Apon et al. (2014) found that easy access to HPC tools increases research output. The same study draws attention to the fact that research using HPC cannot be done in any other way without HPC. Regarding the fact that the need to share resources promotes a collaborative environment (Iglič et al., 2017; Morrison, 2017), the following question comes to mind: *How can researchers in Turkey access HPC tools while collaborating?*

The use of advanced tools on adequate computing infrastructure is a necessity in big data research. Accessing adequate infrastructure is one of the biggest challenges (Metzler et al., 2016; Chen & Zhang, 2014). Supercomputers with the necessary hardware power are needed to perform data-intensive high-performance scientific computations. These supercomputers are often built in the form of large data centers. Data-intensive research can push the limits of even in a well-established HPC infrastructure. In other words, hardware power may not be enough to compute some complex calculations, theories or intensive simulations. Therefore, advanced software architecture configurations need to be done (D. Zhao et al., 2015). Moreover, environments that allow scientists to perform High-Performance computations on the same network can be required, and these networks stimulate collaboration (Z. Zhao et al., 2005). Considering a common network, the collaboration environment can be made more efficient by combining the distributed HPC resources of different scientific communities. This allows scientists in different locations to do research together (McGregor et al., 2015). Considering these, the second research question is: *How do researchers in Turkey choose which HPC resource to use?*

The nature of big data has made collaboration in research almost essential (Kacfah Emani et al., 2015). According to the study of Hu & Zhang (2017), when using big data in scientific research, more collaboration stands out in Computer Science and Engineering than in other disciplines. These disciplines are identified as centers in the interdisciplinary network of scientists researching big data. It is revealed that Computer Science is the field where other fields apply the most for collaboration in big data research on account of producing new methods and techniques for big data studies. Additionally, Lazer et al (2009) emphasized that a new era emerged from social scientists and computer scientists' collaboration called computational social science. These studies have concluded that Computer Science helps other disciplines to close disciplinary gaps in big data research. In this context, the question arises: *How do researhers in Turkey fill disciplinary gaps in research using HPC?*

In another study conducted in the USA, local HPC resources in the Chemistry, Civil and Environmental Engineering, and Physics departments increase the academic research output (Apon et al., 2014). Although the research output in Computer Science field is less than the output in these fields, the reason may be the interdisciplinary nature of Computer Science (Apon et al., 2014). It is seen that HPC is used intensively in fields such as Computer Science, Chemistry, Civil and Environmental Engineering, and Physics. The high use of HPC in these fields means high demand for the HPC resources. Local centers seem to be a good opportunity in areas with such high demand. The question arises: *What are the effects of local HPC resource investments in areas with high user demand in Turkey?*

In social sciences, it is observed that good collaborations are established with computer scientists because of their access to big data tools (Cowls & Schroeder, 2015). According to this, it is only possible to conduct big data research with the use of tools that originated from these disciplines. Fang et al. (2015) provided a multidisciplinary approach to big data. According to this approach, collaboration is required between statisticians, engineers, and computer scientists to develop new tools or big data research methods. The question of *Do researchers in Turkey enhance HPC tools? If so, how do they do it?* is asked accordingly.

2.5. Nature of Collaboration in Research with HPC

Considering the nature of HPC, the findings on why there is collaboration in research with HPC are examined in this sub-section. In this context, the question of *why researchers using HPC in Turkey collaborate* is on the agenda.

HPC tools increase research output with their intensive processing capacity and perform long-time tasks in scientific research (Kepner, 2004). Thus, HPC increases scientific productivity by increasing knowledge production in infrastructures (Ferreira da Silva et al., 2017). With the increase in scientific productivity the need for information sharing increases.

Information sharing has increased with the development of telecommunication tools (Gibbons et al., 1994; Katz & Martin, 1997). The scientific community seeks and produces new ways for high sharing needs. Hence, traditional forms of scientific communication are also changing dynamically in the age of collaboration. Data-intensive research requires high-scale computational tools with data-sharing facilities (Kim, 2017). Data-sharing tools help researchers to collect, process, analyze, and manage data together. Thus, academics in Turkey state that these data-sharing tools encourage them to collaborate (Dogan et al., 2020).

The prevalence and development of data-sharing tools facilitate research collaboration and publishing activities (Hey et al., 2009; Tenopir et al., 2011). HPC infrastructures that allow data-sharing increases research productivity in this respect (Scrivner et al., 2018). Apon et al. (2010) show that an institution's steady HPC investments significantly increase the average number of publications. According to this study, consistent HPC investments are rewarding in terms of the competitive power of the researchers as they increase the number of publications by researchers.

The ease with which these tools provide data-sharing is not the only reason they encourage collaboration. Some argue that these tools encourage collaboration as they foster communication between researchers (Hassandoust & Kazerouni, 2011). With the development of data-sharing tools, it has become easier for researchers to communicate with other researchers in their research field. The opportunities arising from the data-sharing tools help researchers to access people in elite scientific societies (Birnholtz & Bietz, 2003). These private societies are called invisible colleges by Price (1963). This concept also emerges from the association of scientific communication with human nature and behavior. Individual interests and concerns are the parameters determining the sharing behavior of researchers (Kim, 2017).

The increase in collaboration is observed as an increase in the number of publications and their impact (Glänzel, 2002). This effect is one of the motivations of scientists to collaborate. This motivation is explained by the scientist's desire to be recognized (Katz & Martin, 1997; Price, 1963). This argument implies that one of the motivations of scientists in HPC collaboration may be to increase the number of their publications and scientific impact.

In contrast to scientists' motivation for higher recognition, Ynalvez & Shrum (2011) put forth that scientists' motivation to increase their productivity stems not from the desire to be recognized but from a desire to increase their professional career opportunities. According to Hallonsten (2014), researchers enter areas other than their own to keep multiple opportunities open. There is a great risk that researchers will fail in their carreer when they focus on just one opportunity. Thus, researchers eliminate the risks by reducing the resource, fund, and publication pressures on them. In terms of career concerns, working within collaborative projects may not always be beneficial for everyone. Some studies reveal that early career researchers do not see collaborative environments as a safe career path. To be considered successful, young scientists have to consider their benefits in publication and citation numbers. They cannot withstand failures because their reputation is not well-established (Bennett & Gadlin, 2012; Davies & Horst, 2015). The key to recognition and a sustainable career is reputation. Scientists are aware that reputation can open many doors for them, from getting funds to reaching various resources. This is why many conflicts arise in collaborations (Stephan, 2012). Smith et al. (2020) think that competition is the reason why mid-career researchers have more disagreements than senior researchers in collaboration. This brings us to the subject of many conflicts: authorship disputes (Gasparyan et al., 2013; Strange, 2008)

The issue of publication is seen as one of the most significant conflicts in research collaboration (Canals et al., 2017). There are people whose names are on the publications just because of the job contract (Canals et al., 2017). Practices such as honorary authorship, ghost authorship, hyperauthorship undermine collaborative scientific research (Cronin, 2001). Authorship disputes cause misbehavior of scientists varying from hostility to sabotage of the work. These improper practices negatively affect the whole scientific community worldwide, including big data and interdisciplinary research (Smith et al., 2020). From this perspective, the authorship habits of HPC collaborations in Turkey are not known.

Although we are in a data-intensive collaborative era, literature shows that collaborations are not suitable for every type of scientific research. Many conflicts can occur for many different reasons (Bennett & Gadlin, 2014). These conflicts can affect the scientific environment and research outcomes positively or negatively. Studies show that if collaboration costs are more than the benefits, it is not wise to collaborate (Katz & Martin, 1997; Sonnenwald, 2007).

Researchers can experience full cooperation or conflicts within a collaboration environment, or there may be changing dynamics. This results from the change of researchers' interests within the collaborative research process (Atkinson et al., 1998). Collaboration in scientific research may be conducted in discrete or fully interactive groups, with a sharp division of labor or cooperative work, with or without a leader or hierarchy (Chompalov et al., 2002). These parameters can have many different consequences. Therefore, considering these issues, a clear vision and goals should be set (Sonnenwald, 2007).

There are general and individual factors affecting all types of scientific collaboration. Trust, conflict, competition, and communication in collaborative scientific studies are seen from different perspectives in the literature. Each of these is handled in detail in this literature review to undertand dynamics in research collaboration environment.

Studies claim that communication is an integral part of the collaborative environment (Bennett & Gadlin, 2014; Bennett & Gadlin, 2012; Disis & Slattery, 2010; Hall et al., 2012; Wagner, 2018). The collaborative research environment depends on human nature; in other words, behavior and communication style (Bennett & Gadlin, 2012). From this perspective, reciprocity (Morrison, 2017) and trust are seen as the most important elements of communication in collaboration (Bennett & Gadlin, 2012; Wagner, 2018). These elements influence the researchers' choice of collaborators (Price, 1963) and affect research productivity.

On the contrary, Shrum et al. (2001) found that trust is not higher in collaborations formed through pre-existing relationships. Additionally, no relationship is found between trust and performance. Although this study can be criticized in terms of being conducted within an elitist environment, the view that communication is not seen as a vital factor in collaborative scientific research is supported by some other researchers (Chompalov et al., 2002; Evans & Marvin, 2006; Lowe & Phillipson, 2009). Similar to the study conducted by Shrum et al. (2001), Iglič et al. (2017) found that there is more collaboration within research among people who have not met in person.

Those who give importance to communication power in collaboration research argue that interdisciplinary work is also an efficient form of research. Working in full interaction between researchers rather than through a complete division of labor increases production (Bennett & Gadlin, 2014; Hackett et al., 2019). Researchers' collaboration with full interaction by eliminating disciplinary boundaries is the basis of Hampton & Parker's (2011)synthesis model. This model opposes excessive specialization. Accordingly, it is necessary to eliminate disciplinary boundaries with interactive communication for an efficient data-intensive study. Emphasis is placed on the importance of building trust by meeting face to face and communicating in the study conducted by Hampton and Parker (2011). Hence, it is found that the productivity of research groups correlated with each meeting regarding the research impact. However, Leahey and Reikowsky (2008) find that increased specialization in sociology increases scientific productivity. At the same time, they admit that new discoveries will not come out as in synthesis studies. Collaboration can be made in line with clear goals and vision by sharing tasks with a sharp division of labor. In this type of collaborative environment, researchers do not need to communicate with each other. While each researcher or research group (in large-scale projects) fulfills its task, the tasks in the areas they lack are carried out by other researchers or groups.

The calibration model (Centellas et al., 2014) also supports the existence of strong disciplinary identities. Based on the ethnographic data, Centellas et al. (2014) show that collaboration can happen without consensus. According to them, conflicts and disciplinary boundaries foster the research environment, leading to better and more innovative outcomes.

Poor communication between researchers in an extensive multidisciplinary study may not affect the study. However, interdisciplinary or transdisciplinary studies cannot be conducted without communication and interaction between researchers (Aydinoglu, 2013). Communication is also a complex structure depending on human nature.

Furthermore, collaborative research is a complex system that is affected by many parameters (Aydinoglu, 2010; Wagner, 2018).

In the literature, trust, communication, interdisciplinarity, and conflict management have been discussed in different ways regarding their effects on collaborative scientific research environments. In this respect, there is no research on the effects of these parameters on collaboration in Turkey's HPC environment.

2.6. Collaboration-oriented HPC Resource Deployment Policies

In big data studies, institutional approaches and policies affect the collaborative environment of research in terms of communication and interdisciplinarity. In this context, collaboration is more comfortable in a platform that can provide distributed infrastructure service[2]. According to Hey & Trefethen (2005), the platform that enables the shared use of distributed High-Performance computing resources, called Cyberinfrastructure in the USA and e-science in Europe, facilitates collaboration by bringing together researchers in computer science and other researchers. The solutions produced jointly by these interdisciplinary researchers contribute to the development of science.

Institute or government policies can have a major impact on the collaborative research environment regarding these infrastructures. While institutes offer the service of sophisticated infrastructures of this scale, they are also rewarded with the realization of large-scale projects with extraordinary outputs. The impact of publications increases with sophisticated e-science infrastructure (Von Laszewski et al., 2015). There is a problem with globally distributed resources and the possibility of access to them. With access to these resources, both research quality and educational goals can be achieved. Universities ensure that distributed resources are presented on e-science platforms to make breakthrough discoveries (Ursuleanu et al., 2010).

One of the elements that can enhance e-science infrastructure is virtualization (Ursuleanu et al., 2010). The difficulty of storing and processing big data increases the

[2] It is an infrastructure in which resources located in different locations serve users in a virtual common network.

costs. Thereupon, users who cannot store their data due to the volume of the data or location of data in different geographical locations turn to appropriate options. HPC on cloud provides ease of use and reduces costs (Lynn et al., 2020; Mauch et al., 2013). Cloud platforms enable uploading, sharing, and analyzing data on the platform used by researchers from many different locations. Hence, an infrastructure allocation where resources are reasonably provided is essential in the sense of collaboration (Xia et al., 2016).

2.7. HPC Strategies in the World

The U.S. and China are in a leading position in the world market by developing HPC technologies at an advanced level. The U.S. has invested billions of dollars in total in HPC (Ezell & Atkinson, 2016). The most prominent examples of the return on these investments are the supercomputers named Summit and Sierra. In 2014, the U.S. Department of Energy (DOE) announced an investment of $325 million for the Summit and Sierra supercomputers (The U.S. Department of Energy (DOE), 2014). After these investments, Summit ranked first in 2018 and 2019 TOP500[3] lists (TOP500, 2021f) and Sierra ranked second in 2019 lists (TOP500, 2021e) of TOP500. As of November 2021 Summit ranks second and Sierra third (TOP500, 2021d).

China has implemented HPC projects under its 11th, 12th, and 13th five-year plans since 2006. A solid HPC program is seen as a critical element in solving major problems such as biotechnology, material science, climate, aerospace, and physics (Chen et al., 2020). China, which has two supercomputers in the top-10 in the TOP500 list as of November 2021 (TOP500, 2021d), has the highest share by holding 34.6% of the world's HPC systems (TOP500, 2021c).

Fugaku supercomputer was developed in partnership with RIKEN and Fujitsu in Japan. This project was supported by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan. The Fugaku supercomputer is the world's fastest supercomputer, ranking first in the TOP500 list as of November 2021 (TOP500, 2021d).

[3] TOP500 is the list of the world's best 500 supercomputers that provide High-Performance computing. The list has been published twice a year since 1993 (TOP500, 2021a).

In order not to lag behind this rapidly developing technology, other countries cooperate and expand project scales with common working environments. For example, the European Union has identified the need for joint undertakings by emphasizing that member states cannot sustainably establish their own HPC ecosystems by themselves (The European Commission, 2018). Based on these requirements, EuroHPC JU (European High-Performance Computing Joint Undertaking) was established as a legal financing institution that will enable the European Union to collect its resources in a shared HPC pool. It is based on a declaration launched in Rome in March 2017 and signed by several European countries committed to raising Europe's HPC power (European Union, 2018). As announced on April 5, 2019, Turkey has joined the EuroHPC JU as the 28^{th} member (European Comission, 2019). The center in Barcelona, where Turkey is a member, has not been put into use yet.

Turkey has not had a supercomputer on the TOP500 list since 2007. The National Center for High-Performance Computing (UHEM) within İstanbul Technical University first ranked 353 in TOP500 list in November 2006. After it ranked 240 in June 2007, it fell to 484 in November 2007. UHEM has not been listed again since then (TOP500, 2021b).

2.8. The Scope of the Thesis

A study conducted through the collaboration of institutes and universities found that HPC research boosts innovation (Thota et al., 2016). The impact of HPC on innovation is beyond the research question of this thesis; accordingly, the HPC usage in the industry or in the private sector are not discussed in this thesis. The literature review has been deliberately limited to scientific research within the framework of the research question.

The literature is searched within the boundaries of the research question - of the thesis: *How Turkey should form its HPC environment regarding collaborative research*. To sum up, HPC studies are needed due to the nature of big data. As a requirement, complex research questions require collaboration by bringing together researchers from many different disciplines. The increasingly collaborative structure of the global scientific community also diversifies the qualities sought in HPC ecosystems. In addition to computing performance, researchers have expectations from the HPC ecosystem. They prefer platforms that facilitate their communication as well as a virtual network where they can use the infrastructure jointly. The collaborative nature of the research environment brings along many complex parameters such as human nature, infrastructure problems, career goals, and funding needs. These parameters have also been examined in the literature regarding their effects on the collaboration environment. There are many studies in the literature on scientific collaboration. In this literature review, these studies are narrowed down so as to be in line with the research question. Although HPC environments' effect on research outcomes is investigated in the literature, research is insufficient in terms of HPC's impact on collaborative research. There is a gap in the literature about the HPC ecosystems on a collaborative basis.

CHAPTER 3

METHODOLOGY

The main research question of this thesis is "How should Turkey form its HPC environment regarding collaborative research?" Sub-questions that emerged from the literature review are as follows:

- Why do researchers in Turkey use HPC?
- Why do researchers using HPC in Turkey collaborate in HPC research?
- What are the effects of the parameters of -trust, communication, conflict management- on collaboration in Turkey's HPC environment?
- How can researchers in Turkey access HPC tools while collaborating?
- How do researchers in Turkey choose which HPC resources to use?
- What are the effects of local HPC resource investments in areas with high user demand in Turkey?
- How do researchers in Turkey fill disciplinary gaps in research using HPC?
- How do researchers in Turkey enhance HPC tools?

The data is generated through in-depth interviews. In this chapter, the reasons for selecting a qualitative methodology and interview method are explained. The data analysis techniques are also presented.

In the literature, there are studies on research collaboration with quantitative and qualitative methodologies. Handling the issue with only a quantitative methodology does not give accurate results regarding collaboration due to the nature of the fields like big data studies (Canals et al., 2017; Cronin, 2001).

Qualitative inquiry is an effort to find meaning (Patton, 2002). In qualitative methodology, non-numerical, iterative, and data collection and analysis are performed by focusing on participant's perspective (Hignett & McDermott, 2015).

The question of “why” and “how” researchers collaborate with HPC in their research can be found through the qualitative methodology. When a quantitative study is performed, results can be found as collaboration is common in research with HPC. However, this falls short of explaining the nature of a researcher in a collaborative research with HPC. In this sense, the qualitative methodology provides robust and rich data in the framework of the thesis question. Moreover, the qualitative methodology provides local and specific data, which is convenient to do analysis specifically for Turkey.

It would be wise to use a qualitative methodology in collaboration studies. Parties from a wide variety of fields collaborate for a wide variety of reasons. These collaborations also produce various results. This complex structure should not be viewed from a narrow frame (Katz & Martin, 1997). Processing qualitative research provides an understanding of how these collaborations are formed, how they are conducted and ended. In these collaborations, the issues are happening in the mental constructs of the researchers conducting research with HPC. Qualitative methodology is suitable for finding hidden truths and deep causes behind events. Collaboration has an intrinsic nature that can only be revealed through qualitative methods. Therefore, I handle the issue from a broad perspective with qualitative methodologies.

Qualitative research is necessary to examine the collaborations that occur due to the nature of big data (Hu & Zhang, 2017). In this thesis, it is aimed to enable researchers to convey their experiences, relationships, and perceptions while using HPC in their own words. Therefore, collaborations made specifically with HPC are handled from many angles and analyzed in this thesis.

3.1. The Interview Method

The analysis process is not based on comparisons to get statistical data or to support any quantitative finding. Thus, the analysis is discovery-oriented. The aim is to get the perspectives of individuals to construct the truth.

Interviews were conducted according to the “Long Interview” method of McCracken (1998). With the help of this method, researchers can convey their experiences, relationships, and perceptions in their own words. Thus, this study aims to collect intensive data on the tendencies of HPC research in Turkey.

3.1.1. Sampling

The main criteria in choosing the researchers in the sample is to be affiliated with a university in Turkey and use HPC in their research. There are two national HPC resources for scientific use: UHEM (The National Center for High Performance Computing)[4] and TRUBA (Turkish National e-Science e-Infrastructure)[5]. TRUBA publishes booklets containing the studies of the users. Publications made using UHEM are listed with their citation information on UHEM's website (UHEM (National Center for High Performance Computing), 2022). For the sampling, researchers who have published using national HPC resources were randomly selected and e-mailed. For the random selection, I made a list of the people in Microsoft Excel whose e-mail addresses I could access publicly on the Internet. Moreover, I attended the 1st Workshop on High-Performance Computing and Applications on 21.12.2019 at Middle East Technical University and the 6th National High-Performance Computing Conference on 8-9 October 2020 in Ankara (held online due to Covid-19 pandemic). I added the workshop and conference participants whose e-mail addresses I could find to the list in Microsoft Excel. I created a random list using Microsoft Excel's random sorting methods. I sent invitation e-mails to the first 50 people in the random sorted list. There were 13 responses, nine of whom accepted the interview. Interviews were conducted with the nine people who accepted, and then a snowball sampling method was applied to find other interviewees. However, I had to interview researchers using

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[4] For more information: https://en.uhem.itu.edu.tr/

[5] For more information: https://www.truba.gov.tr/index.php/en/main-page/

HPC resources other than TRUBA and UHEM. Moreover, the necessity of interviewing researchers from different fields to avoid bias was taken into account while applying snowball sampling. Ten e-mails were sent via snowball sampling. Seven of them responded to the e-mails and agreed to be interviewed. I conducted interviews with these seven people as well. Consequently, I conducted interviews with 16 people in total.

3.1.2. Semi-structured Interviews

Interviews were conducted with 16 researchers. The research fields of the interviewees were Physics, Machine Engineering, Aerospace Engineering, Computer Engineering, Biophysics, Biochemistry, Bioinformatics. Five of them were Principal Investigators of their group. Interviewees ranged from research assistants to full professors. The demographics of the sample are shown in Table 3.1.

Table 3.1: Demographics of the Sample

Gender	Field	Title
Female	Physics	Assoc. Prof.
Female	Physics	Assoc. Prof.
Female	Computer Engineering	Phd
Female	Physics	Professor
Female	Physics	Assoc. Prof
Female	Chemistry	Research Assistant
Female	Biochemistry	Phd
Female	Bioinformatics	Assoc. Prof.
Male	Machine Engineering	Phd
Male	Physics	Professor
Male	Aerospace Engineering	Phd
Male	Physics	Professor
Male	Physics	Assoc. Prof.
Male	Physics	Phd
Male	Physics	Phd
Male	Biophysics	Phd

One of the interviews lasted 24 minutes. The length of other interviews varies from 35 minutes to 75 minutes. On average, interviews lasted approximately 50 minutes. I conducted the interviews in Turkish, the mother tongue of both the interviewees and myself. No conflicts or confusion arose due to the advantage of speaking in the mother tongue. Since the thesis work time interval coincided with the Covid-19 pandemic period, the interviews took place online. The interviews were conducted via Zoom, one-to-one, and synchronously. Hence, it was possible to reach researchers in universities in many different locations in Turkey. I did not encounter any problems, such as internet interruption, in any of the interviews. The interviews took place from January 2021 to May 2021. I recorded all the interviews. I did not ask the interviewees any personal questions. In the invitation email to the participants, there was also information that the interviews would be recorded. Participants who accepted joining the interview accepted to be recorded. While interviewing the participants, I informed them again that the interviews would be recorded, and I obtained the consent of the participants.

I conducted semi-structured interviews. It is useful to provide a structure so as not to stray from the research question. At the same time, leaving spaces where interviewees can express themselves freely helps to generate dense data. With this dense and unique data, the researcher try to understand the mental framework as an instrument of qualitative inquiry (McCracken, 1998). In accordance with this purpose, several open-ended "how" and "why" questions were asked.

First, I formed the guideline around the literature and the notes I took at the 1st Workshop on High-Performance Computing and Applications and the 6th National High-Performance Computing Conference. After the eighth interview, I reshaped the interview guide. The first interview guide is in Appendix-B and the revised guide is in Appendix-C.

The first questions of the interviews were grand tour questions (McCracken, 1998, p. 34) such as demographics, education, and affiliation. Hence, the interviewees warmed up to the interview by talking about themselves.

After the grand tour questions, I asked how they first started using HPC in their research in order to collect data on the questions raised in the literature review. I asked questions about how the interviewees established their collaborations in research with HPC. In this part of the interviews about collaboration, many different opinions and interesting phenomena emerged. I left the interviewees free to express themselves comfortably and did not stick to the interview guide tightly. At that point, I allowed the generation of intense data following the requirements of qualitative research. Thereupon I reshaped the interview guide after the eighth interview in line with the issues that emerged. It was beneficial to prepare a semi-structured interview guide as well as updating it instead of following a strict structured interview guide. This approach helped me to realize not so obvious relationships so that I can formulate policy recommendations that could answer the thesis question.

The last questions of the interviews were about the interviewees' expectations for the future. I waited calmly, allowing the interviewees to review the interview process for their response. Taking advantage of the enormous flexibility of the qualitative study, extensive data on policy were collected in this way.

3.2. Analysis

I transcribed all interviews verbatim using the records I took during the interviews. I had the opportunity to process all the data by taking advantage of the recorded interview. I was able to perform analyzes rigorously without any data loss. I applied Saldaña's (2013) first and second-cycle coding methods for the data coding process. I analyzed and clustered the codes with the memos adhering to the inductive approach. I present the analyses as translated into English in the text.

People conducting research using HPC in Turkey are a small community. For this reason, the data presented in the text in this thesis was also anonymized to avoid identification. I assigned different letters to some of the distinctive names in order to avoid matching these distinctive data with the personal data of the interviewees. Additionally, although a total of 16 people were interviewed, more than 16 pseudonyms were given to prevent data-matching.

In this thesis, participants are referred to as i-1 (interviewee-1), i-2 (interviewee-2), etc., not to match the identities of the interviewees and to ensure confidentiality. In order to avoid any personal data-matching, I will address all participants as “she”.

3.3. Elimination of Biases

The researcher is the instrument in data generation and analysis. Thus, I, as an inquirer, generated and analyzed the data. In this part, I describe the work I have done to prevent bias.

Turkey is an accessible research area for the researcher. It is also easy to implement the interview method in Turkey. It is suitable for research in the mother tongue of both the researcher and the interviewees.

I paid attention to the fact that the data is very diverse in the context of Turkey. Researchers who have worked in a particular field could create a bias. Therefore, researchers from different fields were selected. As the interviews took place, the use of resources came to the fore. Interviewing researchers around a particular resource could cause bias. Hence, the interviews were held with researchers using different resources. Interviewing researchers only at Turkey's large and well-established universities would also have created a bias. This bias could create severe inequality, especially in terms of policy making. To eliminate this bias, I interviewed researchers from many different universities in Anatolia. I will not mention the name of the universities to protect the personal data of the researchers, as some of the universities are newly established, and the departments have few researchers using HPC.

In order to avoid any bias, I, as the inquirer, tried to be free from prejudice as Patton (2002, p. 407) mentioned. Moreover, I tried to be careful about keeping my distance following the guideline of McCracken (1998, p. 22). I tried to minimize these effects, recognizing that the words and actions she says have an impact on the response of the interviewees.

Quotes from the interviewees are provided in the manuscript as much as possible to ensure authenticity. In the text, I tried to translate the quotes with precision in order not to spoil the narratives of the interviewees' own words and phrases.

One aspect that demonstrates the enormous value of the data collected in the thesis is that many of the researchers interviewed had experience in HPC center management. Those who used the supercomputers in the TOP500 list's top-10, those who were in the commissions of HPC centers in Europe, and those who were at the executive level of the centers in many countries around the world are among the researchers interviewed. The interviewed community was so well-qualified that they offered solutions to HPC research environment problems in Turkey while generating data. The bottom-up formation approach helped to analyze the researchers' experiences to come up with efficient policy recommendations.

CHAPTER 4

FINDINGS

In this part of the thesis, I discuss the findings that emerged as a result of the analysis of the interviews with the researchers in Turkey using HPC. The findings are grouped under four main headings: Research, Collaboration, Resource, and Disciplinary Gaps.

4.1. Research

In this section, the findings on the question of *why researchers in Turkey use HPC* are analyzed under the title of Research. The structure of this section is shown in Table 4.1. The codes that form the Research section are clustered as motivations, benefits, and challenges. The codes are listed under the clusters they belong to.

Table 4.1: The Structure of Analysis of the Research Section

Motivations	Benefits	Challenges
research question	research facilitation	fierce competition
high computational need	popularity of HPC	
precision and accuracy	easiness of computation	
converging to reality	reputation	

4.1.1. The Motivations of HPC Usage

Naturally, researchers use HPC to answer research questions. The research questions are so complex that there are high computational needs. It is seen that researchers test their theories and make their computations to converge the reality. The computations require high precision and accuracy. These motivations are analyzed with the codes of the research question, high computational need, precision and accuracy, and converging to reality.

The researchers explained in detail the reasons for using HPC. The analysis has revealed that the research questions push researchers to use HPC. The interviewees emphasized that they could not answer the research questions without using HPC. For instance, i-3 said that:

> *This is an interesting topic. The only way to do research about it is to use HPC as most of the problems cannot be solved analytically. We can only solve them through using a computer and multiprocessors. I started using it out of necessity.*

What attracts attention in the research questions of the researchers is that they have a complex structure. This complexity creates the need for intensive computation. The reason for the need for HPC resources is the high computational need for solving complex problems. i-2 explained this complexity and the high computational need it entails by depicting the following:

> *It is a nanoscale device. In order to design a nanoscale device, first you have to take atoms from one place to another and arrange them, which is not an easy task. It's like pulling hairs using pliers. You cannot pull a hair from your head using pliers. You need tweezers. Dealing with atoms is a formidable task. Experimenters' job is very difficult, but fortunately there are computational methods.*

It is revealed that one of the reasons for such a high computational requirement is simulations. These simulations are made with the aim of converging to reality. Precision and accuracy in computations are essential for researchers to get more realistic results with HPC. In this sense, the robustness of the computation is vital for achieving targeted precision and accuracy. The better the HPC is, the more realistic simulations are obtained. For example, i-7 said:

> *What I mean by "precision" there is the proximity to reality. For instance, when I make a model and you conduct an experiment of it, the smaller the difference between the model and the experiment, the more precise we call it.*

The better I can model experimental computations and real-life applications, the more precise I call it.

Apart from the reasons for the use of HPC, I also searched for the benefits and challenges of using HPC. The nature of research with HPC is examined in more detail and the benefits and challenges of using HPC are revealed.

4.1.2. The Benefits and Challenges of Using HPC

The benefits of using HPC are analyzed by the codes of research facilitation, the popularity of HPC, ease of computation, reputation. By its nature, HPC provides high computational possibilities and convenience in many research areas. HPC has also become very popular with the ease provided by computational research. Gaining a reputation with publications on hot topics make HPC use appealing. Moreover, researchers benefit from HPC to improve publication quality.

The use of HPC contributes to the development of the research environment. HPC facilitates research in terms of getting fast and effective results in research that can last for days. In this respect, comparing experimenters and computationers, i-25 stated the following:

The more difficult it gets for experimenters, the easier it becomes for theoreticians. While experimenters struggle to find out how they can put three or five atoms together, theoreticians sometimes spend only fifteen minutes calculating it. The lower the number of atoms, the easier it is to calculate. Thus, the first motivation is scientific curiosity.

She also added:

Another motivation is the easiness of the job. You can do it easily and quickly and get instant feedback. Moreover, you work on something that is of great scientific importance, which is very motivating. Some scientists do an experiment for a long time with no success or they don't know where it is going even long after finishing the experiment. However, it doesn't happen here. When you work computationally, you understand that you are on the wrong track half an hour later or one day later. As soon as you see the problem, you start correcting your computations, which is very fast, effective and reliable.

The interviewees mentioned the factors that have made the transition to computational sciences attractive. In this respect, interviewees described the nature of computational sciences by describing them with their own experiences. It is seen that the popularity of HPC is the reason why they have turned to computational sciences in their field. Mentioning that she foresaw the potential of computational sciences to become popular in her field, i-2 emphasized that computational sciences are essential in many fields:

> *Right now, people who want to produce products using nanotechnology need people who study computational sciences, computational physics, computational chemistry, and computational biology. Maybe the product on which you work for two years will turn into something like the wood we use now. Instead, first calculate, look at the results and if the computations indicate that it is a promising product, continue working on it. You can produce something extraordinary one year later. Therefore, computational techniques, computational physics, chemistry and biology are of great value nowadays.*

As revealed in the analysis, the easiness of computational research as compared to experimental research is attractive to researchers in terms of ease of use. Computational research does not require big labs and hands-on work. With the ease of online connection to HPC resources, the researcher is in her own lab everywhere. i-14 stated, "*During and after the pandemic, I have been able to work everywhere, which has been very advantageous. Some people have had a lot of disadvantages and psychological problems during the pandemic; however, it hasn't affected me much. It has been great to have the freedom to bring this job everywhere"* as a supportive comment for the evidence of this ease. Moreover, i-6 said she quit experimental work and switched to computational science as a result of a lack of labs for experiments:

> *I was working experimentally; however, I started working theoretically as it wasn't possible to do experiments in the university I worked. To conduct laboratory work, we were going to T [name of the university, anonimized] university. Due to these challenges, I started theoretical work.*

In research with HPC, studies can be published in quality journals. Studies with HPC can be a hot topic. Therefore, publishing with HPC and the academic reputation that comes with it make HPC use appealing to researchers. The experience stated by i-2, who gives an example of her work with a Nobel laureate on this subject, constitutes a fundamental example in this regard:

> *We worked with a group who won Nobel. We told them "We have good theoretical results about a material. If you fluoresce it, we hope that it will turn*

> *into something different. Why don’t you do the experiments?”. They did and we had a cool study. This is the result we obtained as a result of computation. Experimenters with Nobel conducted an experiment of it and we had the desired result and it was published in a good journal.*

It is evident that publication is an indispensable criterion as stated by i-3's words: *“What is important to me is academic publication. That’s the only indicator of academic success”*. Hence, there are groups that come together intending to increase the publication quality with HPC user collaboration. In this respect, many different groups of researchers support their work by using HPC for publication quality. i-8’s statements can be considered as evidence of this common practice:

> *Experimenters are looking for theorists. If you plan to publish in higher caliber journals, such as Nature and Science, they have started rejecting studies which are only experimental or only theoretical. That’s why experimenters are looking for theorists like crazy.*

Research with HPC has challenges as well as benefits. There is a fierce competition environment for publishing on hot topics with HPC. Working on hot topics intensifies the competition that stems from the large number of people working on similar topics. Publishing with HPC brings fame, but this reputation can be achieved if the researcher is able to publish in a scientific journal. To succeed in publishing, researchers must cope with fierce competition. Talking about crowded groups interested in the same subject, i-11 explained the publication process on hot topics as follows:

> *You face certain difficulties when you want to publish your study. For instance, when you send it to a journal, you have to wait for a long time for a reviewer to be appointed as they receive a large number of articles. Sometimes, your study does not receive the attention it deserves due to the large number of articles. This is a disadvantage of working on a popular academic subject.*

The interdisciplinary nature of HPC is also revealed by the findings. According to them, researchers come together to answer complex questions. Therefore, collaboration, which is the basis of the research question of this thesis, is analyzed in depth separately. Moreover, collaboration plays a vital role in overcoming challenges with HPC. This role is analyzed in the collaboration section.

4.2. Collaboration

Collaborations are established in connection with the motivations of doing research with HPC. HPC, which is used to solve complex problems, naturally results in many people from many different disciplines, coming together for complex problem-solving. Collaboration is inherent in research with HPC. The research questions and the research environment with HPC naturally require collaboration. In this section, the types of collaborations emerged from the analysis are grouped. Additionally, facilitators and barriers to collaborations with HPC are analyzed. The effects of HPC resources on collaboration are also provided. The plan for this section is shown in Table 4.2. The codes that form the Collaboration section are clustered as types of collaborations, facilitators, barriers, and effects of HPC resources on collaboration. The codes are listed under the clusters they belong to.

Table 4.2: The Structure of Analysis of the Collaboration Section

Types of Collaborations	**Facilitators**	**Barriers**	**Effects of HPC Resources on Collaboration**
topic-based	expert collaborator	lack of HPC awareness	group size
needs-based	output-oriented approach	authorship disputes	international collaboration
complementary	punctual collaborator	lack of a common scientific language	authorship tied to HPC ownership
student-instructor	previously known collaborator	lack of mutual interest	
	face-to-face communication	lack of mobility	
	wide social network		
	congresses		
	virtual tools		

4.2.1. Types of Collaborations with HPC in Turkey

The types of collaborations with HPC in Turkey are grouped as topic-based, needs-based, complementary, and student-instructor collaborations.

The researchers gather together around a topic in topic-based collaborations. For instance, i-4 said:

> *When we asked them whether we could use their code or not, they asked us to join their group and work together. As a result, we started collaborating with them. He was from England. We told them "You have a code. Can we use it while doing research about this topic?"We establish collaboration based on a topic.*

Researchers also collaborate based on their needs. They collaborate specifically according to their needs that require high computation. The following is an example of needs-based collaborations mentioned by i-7:

> *Collaboration emerges out of necessity. We don't force ourselves or others to collaborate; we generally end up collaborating to solve a problem. When we see that we can solve a part of the problem and we know that others can solve the other part, we offer people to work together and ask for their help. Sometimes, they ask for our help.*

Another factor that creates these collaborations is complementary work. In this kind of collaboration, there are efforts to support results obtained by experiment or other means with computational science. Due to this aim, there is a high demand for collaboration with researchers using HPC. In this respect, HPC and experimental collaborations are established to explain unexplained phenomena, guide the experiment, or introduce a new suggestion to the experimenter. While i-12 emphasized that theoretical studies should be supported by experiments, i-2 talked about the necessity of simulations to support experimental studies: "*Okay, the experiments indicate this but what is really happening there? Somebody has to run*[6] *a simulation and do a theoretical computation. This is when collaborators find us."*

[6] The work to do computation on an HPC system, computation process.

Student-instructor collaboration is frequently observed among researchers using HPC. It is one of the easy-to-establish collaborations. Collaborating with their students in research using HPC is common for researchers affiliated with a university in Turkey.

> *When they start working, we give students a project which requires using HPC. In this way, we help them to participate in a study that they can use in their thesis.* i-2

I asked the researchers detailed questions about their collaboration environments and habits regarding HPC use. I delved deeper into the collaboration to provide a more fruitful structure for the research question of this thesis. In this regard, the facilitators and barriers to collaborations with HPC emerged.

4.2.2. Facilitators

Expert collaborator, output-oriented approach, punctual collaborator, previously known collaborator, face-to-face communication, wide social network, congresses, and virtual tools are facilitators of collaborations in research with HPC in Turkey.

Researchers specifically choose a particular topic or research question. In this case, the collaborator's expertise in the subject they work on is an decisive criterion for researchers. It is vital to have collaborators who can answer the needs of the research questions. Researchers give importance to the experience of their collaborators in this regard. i-9 emphasized the importance of the previous works of the collaborator: "*Besides, when choosing people to work with, you take their previous work into consideration, of course"*

Another facilitator is an output-oriented approach in collaborations. Researchers establish collaborations that they believe can result in publications. The output-oriented approach forms the basis of collaborations. i-15 considers publications as results of productive collaborations among many of its works:

> *I have participated in a lot of research collaboration, the 70-80 percent of which didn't yield any results. Remaining 20-30 percent produced some results but they were not the ones I wanted. They were published. The published ones could be considered productive partnerships.*

According to the interviewees, who stated that the publication is an crucial indicator of the researcher, collaborations that result in a publication are considered successful. In this manner, the collaborations researchers consider productive and successful are possible with punctual collaborators. For instance, i-6 described this punctuality as follows:

> *If the person whom I work with don't produce any results after three or four months and constantly offer excuses, there must be a serious problem, which means that it will continue like this.*

Considering the tough competitive environment, working with a reliable collaborator is vital in research with HPC. Therefore, in order not to take risks interviewees prefer to collaborate with people they know. Previously-known collaborators are effective facilitators of collaborations. i-7, who stated that she was unwilling to collaborate with researchers she did not know, believes that success will be achieved in collaboration with a previously-known collaborator:

> *I generally prefer to work with groups which I am familiar with, which I know about or which I have collaborated before as it is difficult to deal with them or vice versa. We are also difficult to deal with. Consequently, when people who know each other work together, the possibility of success increases.*

Here comes the importance of communication, as i-10 said, "*The main trait I look for in a collaborator is good communication skills. It should be easy to talk to them and understand them.*" In the absence of communication, i-13 clearly stated, "*Only lack of communication with your collaborators may cause a project to end*." From this perspective, face-to-face communication is necessary to build a strong communication channel. It is understood that face-to-face communication increases the sense of trust and establishes better collaborations. In this regard, i-2 said:

> *Half of my current collaborations are with the collaborator friends I have made during my trips abroad… I have met them, communicated with them face to face and persuaded them. I listened to them and expressed my ideas, which is important.*

i-13 exemplified the benefits of the existence of trust as follows: "*There are people who work for ten to fifteen years and publish articles together. Actually, when people trust each other, they work more efficiently, resulting in a more productive process.*"

As it turns out, researchers with broad social networks naturally become collaborators in many collaborations. A broad social network is an effective facilitator of collaboration. The evidence of this is in i-7's following statement:

> *I see that team works develop more naturally. Moreover, some researchers, some groups are proactive, which is more exciting. Since they have wider networks, they participate in more studies, which is also another reason for the increase in collaborations.*

The interviewees stated that one of the factors that help to expand networks is events such as conferences and congresses. i-30 exemplifies the role of congresses as follows:

> *If you ask me how I meet them, congresses are useful. We can't travel during the pandemic, of course. Those travels are not only touristic. One of the functions of those congresses is meeting new people. We have certain things in common and we get along. We have started trusting each other and we're willing to work together. National and international congresses are very useful in terms of people's meeting each other and working together.*

Congresses that bring researchers together are of key importance for keeping communication strong and providing an environment of trust. i-8 complained about Turkey's situation in this regard as follows:

> *Opening communication channels in Turkey is my biggest wish. I don't know what other people are doing. I mean I want to collaborate with people in chemistry department or with experimenters. However, I don't have any idea what they are working on. They were giving talks abroad and they weren't within the departments only; they were open to all departments. In other words, we were attending the talks about different departments like engineering and physics. We were having meals together and often attend social activities. Since such community building activities are very common there, I knew what people in different departments were doing. We were talking with people from different departments and trying to find solutions to problems together. Such an environment doesn't exist in Turkey.*

Virtual tools are very helpful in situations where researchers cannot meet face to face. With the use of many different virtual tools, communication is strengthened, and collaborations can be established with confidence. Talking about using applications such as Zoom, the following statement of i-9 shows that she established the collaboration with the trust created by the strengthening of communication:

> *We met online and they read my studies. I asked them to tell me what they understood from my studies. When they told me what they understood from them and how they wanted to contribute to them, I decided to work with them. I told them I could do the computation.*

4.2.3. Barriers

In addition to the factors that facilitate collaboration, the interviewees also shared their experiences about the barriers to collaboration with HPC.

One aspect that affects all collaborations is the establishment of a mutually beneficial environment. It is essential to create an atmosphere of mutual interest. Collaboration can fail due to a lack of mutual interest**.** For instance, i-6 said:

> *Your priorities and theirs may be different. No matter how much you talk about it in the beginning of the study, they may find a study that will attract more attention. For instance, they may agree to work with a better group, which published a lot in Nature or which is a pioneer in the field. Thus, the priorities change over time when other studies interrupt your work. They may also lose interest in the study.*

The inability to create a common scientific language undermines collaborations. i-16 drew attention to the importance of a common scientific language in the research environment as "*Some [collaborators] may come to the meeting just to listen. We all need to speak a common language; we even need to evaluate the findings together.*"

It is challenging for researchers in Turkey to be able to engage in many different activities, meet other researchers, communicate with them face-to-face, and expand their social networks. For researchers in Turkey, the lack of mobility is a huge barrier to all of this. Researchers, who have difficulties benefiting from both domestic and international mobility opportunities, are condemned to an isolated research environment. i-2 demonstrates this situation by comparing researchers in Turkey and those abroad:

> *There is a good network among scientists abroad since they can always communicate with each other easily. We are not in that network, which results partly from financial problems. The limited travel budgets prevent us from attending conferences and being a member of that network.*

Interviewees claimed that they encountered the problem of a lack of HPC awareness in their collaborations with people who do not use HPC but need HPC in their research. Because of this lack of awareness, interviewees noted that their collaborators stressed them out. On this subject, indicating their disdain for doing computational work, i-15 complains that her collaborators expect miracles from her computations:

> *Experimenters have high expectations from computational scientists. They create something in their minds and ask whether we can do it or not. We don't have a magic wand. When they can't do it in the laboratory, they expect us to do it using a computer. It can't happen of course. This situation has decreased over time. I'm glad to see such a change in their attitude. Or, they underestimate what you do. They say it is easy to do computations.*

Another barrier arises from the nature of HPC research. As mentioned in the literature and by the interviewees, HPC research creates collaborative environments where multiple researchers naturally come together. However, many authorship disputes can occur when crowded collaborations are formed. There are also unethical practices in this regard. i-9 shared her experience where she ended the collaboration as soon as she realized that an unethical practice was taking place:

> *…There was another person. We couldn't continue working with him because she didn't behave ethically. Although four of us did the computation, the study was published with ten authors when she submitted it. Therefore, I stopped working with her.*

4.2.4. Effects of HPC Resources on Collaboration

The most fundamental issue affecting collaborations in research using HPC is the HPC resource, as revealed in this study. Users create collaborations around the resource. Researchers without resources have to collaborate with people or groups who have HPC resources. Other than that, researchers or groups that have access to a resource collaborate with people or groups that have better HPC resources than their own. The experience of i-12 exemplifies this:

> *We formed a good group. When we talked about computation, the first thing they asked was whether we had workstations. We told them that we had them and they said only this way we could work on the projects together. In this way, it is easier to collaborate.*

HPC resource is a factor that directly affects the collaboration using HPC. For instance, interviewees see the increase in group sizes in studies with HPC as an advantage. However, resource power[7] is one of the main factors affecting collaborations. The capacity of the resource directly affects the group size in collaborations. Stating that she could not add more students to her group due to lack of capacity, i-5 is unable to deal with sophisticated problems: *"If I have a significant amount of HPC usage capacity, I can accept more doctorate students. If you can provide them with high quality problems and if they can work on them in such an environment, they can produce [findings] of course".*

There are also authorship issues tied to HPC resource ownership. It is possible for the researcher who has the HPC resource to have her name published just because her HPC resource was used. In this respect, even if she has no contribution, her name is on the publication and she is accepted as a collaborator. For instance, i-15 mentioned the following: "*When you use those people's computers to run your computations, their names are written in the publication".*

Moreover, researchers who owns licensed HPC software are the "desired collaborator" in collaborations. Since it is difficult to access certain software, collaborations can be formed around the researcher who owns the software. i-9 exemplified this with her own experiences as follows:

> *One of the reasons for working together is the [software] license problem. For example, there is a feature I should use but I don't have a license for that; I mean I the program I devise don't look at that feature. As a result, I ask that person to do the computation; then, I have to add him or her to the study. S/he both contributes to the computation and I need the output of the licensed*

[7] The power to perform complex computations or simulations of an HPC resource.

program s/he uses in the High-Performance computing system. In this way, we create a collaboration and interdisciplinary study instead of buying the program.

There are also researchers who collaborate internationally to gain access to advanced computing powers just because of a lack of access to an advanced HPC resource in Turkey. The following quote by i-8 is a striking example of this:

If people want to collaborate, they go abroad. Generally, we can't conduct the studies about the problems the collaborators abroad want to solve using the limited infrastructure in Turkey.

To sum up, HPC resource influences the collaboration so much that the size of the collaboration group can be determined directly according to the resource capacity. In the absence of resources, researchers in Turkey seek international collaborations. Since the collaborations are built around the resource, the HPC resource owner is included as author in the publications just because she has the resource. All these reveal the direct effect of the HPC resource on collaboration. The profound impact of the HPC resource is analyzed in the Resource section.

4.3. Resource

Limited HPC resource capacity in Turkey pushes researchers to international collaboration, causing many other issues. The profound effects of HPC resource scarcity in Turkey on Turkey's research environment have come into the picture in this study.

HPC research requires access to resources that can meet high computational needs. Turkey's HPC resources are scarce in terms of research production. Researchers in Turkey select research questions and projects according to the insufficient capacity they have and avoid novel projects and research. This hinders researchers from publishing on hot topics. i-7 explained the profound effect of resource constraints with the following words:

How powerful your computer is determines the problem [you will choose]. For instance, when we have an interesting idea or when we read it somewhere and think something is an important problem, in the second stage, we ask ourselves *if we can compute it or not. If we don't have powerful enough computers to do the computation, we give it up. We say the computer we have does not have enough capacity to solve this problem.*

This challenge holds back researchers in Turkey from the benefits of using HPC, such as publication and gaining reputation. HPC resource scarcity directly affects the publication opportunities of researchers. Due to the scarcity of resources, it is difficult for researchers in Turkey to publish on time, or there is a high risk of rejection. i-12 complained that she could not complete the revision in her article due to resource constraints.

In terms of HPC resources in Turkey, Turkey is far behind in international competition. Emphasizing that the computation that a European researcher would do in five days could only be completed in two months in Turkey, i-5 epitomized Turkey's position in a tough competitive environment:

As researchers in our country, we are generally in a very highly competitive environment in terms of the studies where we use HPC. I mean, in a country with a large population like Turkey, the number of clusters you can access with or without any proposal is only two. There are two HPC systems and they fall behind the HPC systems in the world. For example, I'm using available clusters in America or Belgium in the collaborations now. Compared to them, we fall behind in terms of service, the condition of the clusters, that is the number of nodes you can access and the capacity of the computer where the computation is done.

Drawing attention to the importance of the HPC capacity ownership of countries in this regard, she continued:

At this point, the availability of HPC systems is very important. If you have fast enough HPC systems at your disposal, you stand out in this race, if not, you fall behind. Actually, this is a bit of a situation… computer capacity stands out. It became very important. At this point, they [researchers in abroad] are more advantageous than us.

Resource constraints make the competition fierce even within Turkey itself. Researchers are secretive about their projects. As i-8 expressed, "*I don't want to tell her what I study so that she won't write the project before I do."* She stressed that this behaviour was due to limited resources.

Findings in the Resource section are grouped as shown in Table 4.3. The codes that form the Resource section are clustered as Turkey's HPC power, local and central resource allocation, allocation of a resource to users, field-specific center, and allocation with support. The codes are listed under the clusters they belong to.

Table 4.3: The Structure of Analysis of the Resource Section

Turkey's HPC Power	Local and Central Resource Allocation	Allocation of a Resource to Users	Field-Specific Center	Allocation with Support
TOP-500	high computing power	prioritization	specify fields	hour-based usage
exascale	q-time	commission		priority code
huge investment	dividing computations			membership fee
	off-peak hours			inapproriate practices
	installations			
	technical staff			
	infrastructure			
	idle			
	certain group			

4.3.1. Turkey's HPC Power

A scientific discovery is not probable due to the lack of HPC capacity in Turkey, which does not have a computer in the TOP500 list. As of June 2021, the last supercomputer on the TOP500 list has 1500 TFlops/s Rmax with 34400 cores[8], while the top of the list has 442010 TFlops/s Rmax with 7630848 cores. There are no cores below 440000 in the top 10 of the TOP500 list. The last (500th) supercomputer is also stated to have 34400 cores. According to TÜBİTAK (The Scientific and Technological Research Council of Turkey)'s EuroCC Turkey report, Turkey's best supercomputer center has 20000 cores (TÜBİTAK ULAKBİM, 2021). When the TOP500 list as of June 2021 is compared to Turkey, one can see how far behind the current era Turkey is.

The fact that Turkey does not have any supercomputer in the TOP500 list is evidence of Turkey's insufficient HPC capacity, as i-5 said: "*At least, we must have a system that is in the top 50. Turkey considers itself among the top twenty economies in the world.*" On the same subject, i-7 made the following comment about the systems used in Turkey: "*what I understand from supercomputing is running a lot of processors to solve a single problem. We are not at that level yet".*

Supercomputers that can perform exascale calculations are considered top-level supercomputers. Countries and associations are in exascale[9] races. The biggest reason for this is the contribution of supercomputers to the digital economy. Countries invest in supercomputers to strengthen their innovative power and thereby boost their digital economies. However, owning a high-capacity supercomputer requires a considerable investment. Most of the time, HPC centers obtained by state support or even by the support of multiple countries. When talking about the cost of a system established in the USA, i-6 evaluated the possibility of establishing the same system in Turkey as: "*It may cost 400.000 $, which we can't afford. [laughs] In order for us to buy it, we need the government funding or our university should be able to afford it."*

The inductive approach followed in this study required deepening the issue of HPC resources. Thus, I asked interviewees questions about their resource usage. As it turns

[8] Although there are architectures that allow high-performance computations with fewer cores, more cores still mean higher-performance computing.

[9] An exascale HPC system has a capacity of 10^{18} calculations per second. This is far above the capacity of the supercomputers used today.

out, HPC resource scarcity forces researchers to use a mix of the resources listed below:

- local center
- national center
- foreign resource (with a foreign collaborator)
- cloud platform with a fee

HPC centers, in terms of services provided in HPC centers, act as a collaborative hub for large-scale research where researchers from many different disciplines come together (Ogier et al., 2018). Organizations or institutions cooperate for scientific research by opening the infrastructures of their HPC centers to common use (Girone et al., 2021; Pérez-Calero Yzquierdo, 2020). Another option is to build a common HPC infrastructure (Goscinski et al., 2015; Khan et al., 2019). Some challenges are encountered in the use of common infrastructure: computational performance issues that come with the increasing size and complexity of shared data, data storage issues, and data sharing issues (Khan et al., 2019). All of this is based on resource allocation. Resource allocation even differs according to applications (Pérez-Calero Yzquierdo, 2020). The findings of this thesis showed that there are policy deficiencies regarding resource allocation in Turkey.

Efficient use of HPC resources where such high investments are made is necessary to avoid wasting resources. Thus, efficient allocation of such expensive machines is considered imperative rather than increasing the capacity. There are two concepts of allocation. The first allocation is based on location allocation: local or central. The second is the allocation of a resource to users, regardless of whether it is local or central.

4.3.2. Local and Central Resource Allocation

First of all, local center establishment stands out with different implementations. These local resources can only be used by one teacher, group, or department. Other than that, there are local resources used by more than one department or at the use of the institute. Some universities in Turkey have their own local centers (TÜBİTAK ULAKBİM, 2021). Except for private sector centers, there are two central public HPC centers in Turkey for scientific use: UHEM and TRUBA.

Central HPC resources are also needed by users who have local resources. It is not possible to run large-scale jobs that require high computing power locally. In this case, researchers use the same centers to run their jobs that require high computing power since the capacity of the central HPC resources is also limited. Hence, long queue waiting times (q-time) occur as a result of user density. Thus, users try to do computations by dividing their jobs into low-capacity computers in their preferred central HPC resources to meet their high computing needs. As a result, researchers find solutions that do not fit their intended use; as i-6 said, "*Demand is high but there aren't enough computers. That's why we use computers with low operating systems, which causes problems for me*."

HPC users in Turkey have been accustomed to the lack of capacity in many ways. The interviewees mention that it is difficult for a researcher to use only one resource. Most of the time, the problem is solved by dividing computation tasks into machines (locally or at the center) and sharing computation among the people in their project. It is even solved by having students do some of the computations. i-15 shared her comments about other researchers who did not divide computations :

> *I met a researcher who told me that they could no longer use their TRUBA account as their credit had expired. I was surprised to hear that. I wondered how they could have run so many computations. People do not know how to use it [HPC system]. For instance, I don't submit all my computations to the same place. Instead, I divide them and tell my students to submit some of them to X [local center name, anonimized] and some others to TRUBA; the rest of my students do something simpler on their computers.*

The researchers got used to resource scarcity as understood from i-15's following statement: "*There's nothing we can do. We need to be aware of where we live*".

If the researchers do not have a human resource that can make their computations or a machine that they can use locally, they have to use the HPC resources in the most efficient way. Otherwise, they have to endure long waiting times in the central HPC resources. There are also those who follow the off-peak hours while using the central HPC resources for this. For instance, emphasizing that she had no HPC resource other than the central HPC resource, i-10 noted that she did her computations at the center at night: "*That's why it is better to run it [computation] especially at night; When I run them at night, they wait in the queue and finish quickly*".

One of the trends in the world is GPU[10] usage. Jobs requiring higher computing power can be done in a shorter time with the GPU. If only considered locally, CPU[11] is a commonly used technology which is cheaper than GPU. GPU usage is more robust compared to CPU. However, it is not easy to access GPU due to the high cost. In this respect, it is expected from the national centers to meet the high computation needs. Considering large-scale collaborations, high-performance computing capacity becomes paramount necessity. However, GPU resources are limited in Turkey. Thus, there are long queues in the HPC centers. Users are trying to divide their computations without using the machine they need to use for high computing needs. In this respect, i-5 stated that she had difficulty in obtaining new generation HPC resources as "*Our main problem is that we have to wait in the queue for a long time. Especially in recently updated state-of-the-art systems, we spend a lot of time waiting in the queue.*" Additionally, i-15 explained that while researchers need high-level computational resources, they have to divide the computations into low computation resources due to the resource scarcity as follows:

> *There are long queues. On the other hand, there are 4-5 computers. If you insist on using Akya [GPU resource], you have to wait. However, if you decide to use Barbun [another resource without GPU], or another one, [you don't have to wait that long in the queue]. You can divide the computation into different groups. This is not optimum, of course, but you can run it this way*.

Although local centers are not suitable for jobs requiring high computing power, they are often preferred to avoid long q-time in central resources and to be able to divide

[10] GPU (Graphics Processing Unit): The Graphics Processing Unit is a computer chip that performs fast computations. It was originally used for purposes such as image processing. Today, it is also programmed for jobs that require high computation, such as machine learning.

[11] CPU (Central Processing Unit): The main part of any digital computer system, usually consisting of main memory, control unit, and arithmetic-logic unit.

the computations. For example, i-9 stated that she used the resources of different universities as well as the central resource and emphasized that these were not enough: "*I also use our own system. We're trying to improve our own system so as to save time"*.

Local resources are not as sufficient as the central system for high-level computations. i-11 summarized her situation as follows:

> *Although we have our own HPC machine and clusters here, it is not sufficient all the time. Or we use our own servers which we bought with project funding. We also have our own servers on which we're working. If they are not enough, I use TRUBA.*

Similarly, i-12 said that she uses central resources when local resources are not enough. However, central resources are not enough either:

> *After I returned [to Turkey], I learned that TÜBİTAK built workstations and provided service. When the workstations we built here didn't work, I used TÜBİTAK's workstations. When they were first built, they were very good. I was able to get in the line quickly and run my computations. A few years later, my computations didn't finish and I couldn't get in line. Then, I decided to create my own workstation and my own system.*

Computation requests by different researchers are queued at the central source. If the computation requires a high level of resources, researchers in Turkey have no choice but to wait in the queue at the central resources. There is no way to run such computations at a local center. Because of this, in a crowded queue at central resources, researchers wait for their high-level computations to be run. The experience of i-14 indicates this problem:

> *Since TRUBA has a more powerful processor, we can obtain better results in the long run by uploading the simulations that we use in local [workstations] to TRUBA. It is advantageous to use TRUBA as it produces faster and more effective results. However, I can directly run a computation here in a local HPC, which is a significant benefit. When I give it to TRUBA, I have to wait for days. For instance, I have two analysis right now; one is in a local HPC and the other is in TRUBA. The former is running now and I can follow it; however, I have to wait for the latter, which slows me down.*

To avoid the risk of getting an incorrect result after waiting in long queues, researchers are under tremendous stress of prepping before running their computations in the central resource. The statement of i-13 reveals this stress:

> *We do large scale computations in TRUBA. After the pandemic, the waiting period increased there; thus, we don't have the opportunity to change the simulations. We need to enter it when we are really ready.*

Researchers in Turkey use local resources to avoid the crowds of the central resources, as revealed in this study. Although local centers seem to be an escape from central resources' queues, they can only be used in small-scale projects. This is an obstacle to large-scale collaborations. As revealed in the analysis, many researchers from different fields come together in large-scale research which require high-level computing. For large-scale collaborations, central resources are insufficient. Waiting in long queues for centralized resources used for large-scale research and running only small-scale computations on local resources put researchers in a dead end regarding collaboration.

In order to get out of this impasse and to somehow carry out their research and collaborations, researchers are trying to establish local centers with great difficulty. For instance, the interviewees stated that they made the first installations of local centers on their own. They tought themselves the installation of the center that required a different technical expertise. i-5 and i-15 talked about how, although they are scientists, they set up their own HPC systems like technical staff since there was no policy for HPC resource allocation:

> *We built a small HPC system then. Of course, there was nobody around who knew this. The sellers didn't know it, either. They sold us the system, yet we couldn't use it very efficiently. I somehow started to do it on my own; I built HPC system by compiling the information available in the library and online at that time.* i-5

> *Our managed told us how much money we had and he asked us to buy clusters or whatever we wanted. I said okay but I was only a user until then. It wasn't like buying a laptop; we didn't have any information online or on forums. I first asked a few acquaintances for advice. Then I examined TRUBA to have an idea. I didn't want to do anything without having enough knowledge. I knew that we can't have such amount of money often. We are a state institution and it was an important investment. We had to find the answers to a lot of questions*

> *like "Is there a course for this?", "How can we buy it?", "Who can we bargain? ", "How are we going to manage it?" and "How are we going to provide electricity for it?"* i-15

Not only during the initial setup but also when operating the local center, there is a problem of lack of technical staff. Researchers try to find solutions on their own when they encounter technical problems. Local centers are mostly computing centers equipped with a few servers that researchers have purchased. Most of these researchers are not computer scientists. Even when they are, a different expertise is required to solve the technical problems. In this case, there is a huge technical burden on researchers who want to preserve the local computational resource they want to use for science. The responsibility taken by i-9 in this regard is striking:

> *I even don't want the cleaning staff to enter that place. Nobody has the key to that room except one of the instructors because a problem with a cable prevents me from sending computations from home.*

In local centers in Turkey, a certain group tries to deal with all the problems to keep the system running. Hence, these local centers are unlikely to be used by a foreign user lacking resources. These situations hinder collaborations where HPC is used. Because local centers in Turkey do not provide a collaborative environment, they push researchers to individual and small-scale studies. i-9, whose resources were insufficient despite having access to various resources, cited difficulties while using another university's center:

> *Actually, it was possible to have access to N [name of the university, anonimized] university's resource from outside, but as I was in F [name of the university, anonimized] university, they didn't want it. As a result, I used to enter it using the account opened at N by the instructor, run my computation and come back, which was exhausting. It was always difficult for me to access computers.*

For all these reasons, some users are particularly against the allocation of local centers. i-10 summarized all these difficulties and explained why they are opposed to the establishment of local centers in their own universities:

This means that first you have to create a physical place in the university. I mean where are you going to put those computers? Second, you need to do maintenance. Finally, you need to hire personnel who will help you catch up with the ever changing technology. For example, computers can't run in the room temperature. You need to have cooling systems, which is expensive. And every university has to do it. Instead, it is better to have one central HPC system. Since we do simulations online – all of our work is online -, we don't have to see or touch that device to feel its existence.

In this section, I addressed the findings related to the allocation of a resource. Apart from that, the issue of allocation of a resource, whether it is local or central, is also analyzed. The findings of the allocation of a resource to users are analyzed in the following section.

4.3.3. Allocation of a Resource to Users

Although sustainable local or central HPC centers are established, there are problems in terms of management of the system and allocation to users.

At this point, it is necessary to mention the importance of efficiently allocating a resource to users. Big collaborations involving the use of HPC require efficient use of resources. Different policies exist for allocating a particular HPC resource to users with a wide variety of needs. In Turkey, allocating resources to everyone without any pre-qualification requirements seems to be a severe policy deficiency. Turkey's central HPC resource is free to any user and does not require any pre-qualification, as i-3 mentioned, "*An advantage of TRUBA is that it gives you free CPU-hour*[12] *because there is government subsidy. But, you have to wait in the queue for a long period of time."* However, as it turns out, researchers not only have to wait in crowded queues due to a lack of resources but there are also problems because a single resource is unconditionally available to everyone. The absence of any pre-qualification results in user density and leads to waste of HPC resources, which are already scarce.

It is seen that that just increasing the HPC resources is not enough to solve problems. No matter how good the infrastructure is, resources are still wasted due to a lack of usage allocation policy; therefore, researchers have to endure long q-times stemming

[12] HPC Resource usage time (GPU/CPU-hour).

from the crowd. i-7 emphasized that the reason why she talked about usage allocation policy intentionally as the investment would be wasted without such a policy.

> *If we do it with this policy, we waste the investment. Turkey doesn't have a computer system ranked on the TOP500 list, which is the most concrete example of our insufficiency. However, we also need some regulations to effectively manage the use of resources while investing in it. Resources will not be enough if you open it to everyone. In this case, we will have to wait in the queue again. Although you invest in it, the result will be the same. We have to increase resources but with the necessary regulations. That's why I talked about the need for regulations first. Even if we increase resources with the current policy, it won't be efficient.*

This situation shows us that no matter how much capacity increase is made, unless it is implemented with a certain policy, it will be nothing but a waste of investment. It turns out that researchers do not have a blind need for capacity size. What is really necessary is to identify and meet the real needs with an effective policy. Hence, as stated by i-7, there is a need for policies that will ensure the effective use of existing resources:

> *I think we can no longer say, "Let's open the resources to everyone and let people meet each other in it." We need to start using it effectively. We need to ask the question how HPC can be used effectively to help us achieve our goals.*

The egalitarian approach hinders a productive research environment. It is an indisputable necessity for a country to facilitate equal distribution of the HPC resources for opportunity equality, as i-2 said "*Everyone should have access to it. Every university needs to be able to access it."* The interviewees noted that it should be ensured that universities in Turkey that do not have substantial financing have access to quality HPC resources. Providing disadvantaged groups with access to HPC resources contributes to the development of the research environment. In this regard, i-25 made the following comment: "*Because the government is like a father. As it is a father, it wants to fund scientists in different cities like Bitlis, İzmir, Ankara or Giresun".*

However, it is also necessary to make HPC resources available to users without wasting them. Efficient allocation of HPC resources is essential for a productive research environment. The creation of many low-quality idle centers to provide resources for all is also a policy deficiency. i-17, who had to use only central resources, made statements supporting this:

> *I also saw that in some places computational laboratories had been built but they hadn't been used for years. I need [computing] time and if those computers had been in Ankara, (in the central resource) I could have used them when the researcher wasn't using them.*

Opening the resource to everyone without any pre-qualification requirements to enable disadvantaged groups to access HPC resources is not a solution. Thus, there are policy shortcomings regarding the efficient allocation of a single resource to users. The policies are analyzed under two headings: prioritization and commission.

4.3.3.1. Prioritization

The use of an HPC center can be prioritized for specific studies such as high energy physics (Ahn, 2017) and bioinformatics (Pérez-Wohlfeil et al., 2018), or for basic training in HPC use (Holmes & Kureshi, 2015).

Researchers expect large-scale projects to be carried out in central resources like hubs. Central HPC resources differ from local centers in this regard. However, the use of a central resource for training or out of curiosity poses difficulties by causing long queues. The prominent point in the complaints of the interviewees is that the resources are not used by real users. What is meant by a real user is that it is the user who uses HPC for its intended purpose. Computations that can be completed even on laptops done in an HPC center are a big problem as i-4 said: "*I have also seen works with two or five processors, which isn't what that machine should be used for*." These small-scale computations cause long queues in the central resource designed to be used in large-scale collaborations.

Due to the absence of a prioritization policy and the insistence on an egalitarian approach, users who have different needs cannot benefit from central resources. i-8 explained this problem by giving an example:

> *If some people use that machine for another purpose like "let me try it", they will steal the resources of others trying to do computation there. I mean the resources of people who really need to work on HPC will be spread to more people. For instance, if I need to use 10-20 nodes and if you give everyone one node, it's impossible for me to find 10-20 nodes to finish my work.*

Having used one of the top-10 supercomputers in the TOP-500 list in a large-scale project with multi-collaborator, i-1 explained that it is possible to eliminate the q-time problem even in such large scale projects by prioritization*:*

> *For example, we have such an account in the project abroad where I work. Our q-time is very low. That is, in such big systems, it's normal to wait for several days or weeks since there are already simulations running there. There are priorities regarding which projects will run first. We generally wait for one day. When you want to do an analysis, q-time is less than a day in the number one system in the world.*

There are ways to prioritize users. One way is that the common HPC resource is prioritized according to publications generated after it is used. As it turned out, a prioritization method can be applied according to whether or not there will be a publication after the HPC resource usage. i-2 stated that researchers who do not publish use the resource unfairly:

> *For instance, I have 15 articles but I have a limited number of computers. The same number of computers are given to researchers whom I think do not work [as hard as I do]. They have the same number of computers cores as me. We should have the equal number of resources in the beginning; however, I work much more than them, so if they give me more resources, I can do more [publish].*

Emphasizing that the use of resources is not allowed anywhere in the world without questioning, i-7 claims that it is appropriate to question whether there will be any publication after HPC is used in Turkey*:*

> *They should also give it for free, but they also do not ask what is done with the resources. They should ask "You have been using our resources for one year, so what have you done?" Do they have a report? No.*

However, there is one more point to be noted in this regard. Researchers are not wasting resources just because they do not publish. In some cases, there is no publication as a result but researchers use the HPC resource fruitfully. In this regard, i-2 is of the opinion that who unnecessarily use the HPC resource do not deserve to have an account:

> *Actually, we shouldn't open an account to those who use it and produce nothing, or we can cancel the accounts of those who use it to run unnecessary computations without getting any beneficial results.*

Considering this, there is also a lack of prioritization that can be done with a usage-oriented approach. The wasteful uses such as trying some low-level computations and computations outside the scope of the projects are common problems. i-4 exemplifies how easy it is to occupy HPC resources unnecessarily in her own field:

> *I go to TRUBA. There are some programs there which we installed. For instance, if I run the tutorial case of this with 500 processors, the result means nothing [in terms of writing scientific articles and project output]. I don't know, do you do engineering? [addressing the interviewer] I can teach you how to run it in one hour and then you can run it in that processor. You can create huge files that has terabytes of data and then you can create beautiful pictures with them, which means nothing.*

Another approach is to prioritize via the importance of the topic. The main reason for this need is that some studies are given priority in terms of time or requirements. Groundbreaking research needs to be given priority. There are researchers in Turkey who have superiority at the central HPC center according to the topic of their research. For instance, stating that Covid-19 research is prioritized, i-14 told that she benefited from this as follows:

> *During the Covid pandemic, we were given priority, but I generally used the HPC here then. However, there were times when I used that priority to finish [my analysis faster] during the pandemic.*

Likewise, i-3 shared her experience: "*I gave a seminar recently. They asked me to do a reserved queue tutorial there. They made a reservation and I used it there, which was good. It works fast when you upload"* She was so pleased with this experience that she argued that the computations she made without prioritization made her wait incomparably longer:

> *However, I don't know whether or not it will work as smoothly as the last time when I make a reservation again. You need to wait for a long time in an unreserved queue. It takes such a long time that you forget about it.*

4.3.3.2. Commission

The need for prioritization has been analyzed so far. In this section, the need for a commission, a group of people who are officially charged for HPC center management to provide prioritization, is mentioned. It can also act as the body that determines and implements policies for research with HPC. i-4 stated that a commission is a primary need and stresses that it should prioritize research in HPC centers:

> *There is no scientific commission. To me, this is what we really need. There must be a commission whose members have a lot of publications in this field. They need to contribute [to this process] by putting these [studies applied for using HPC resource] in order of priority. This is one of the two things that they should do.*

As it is revealed, the existence of a commission that implements these policies is essential. Stating that the resource she used abroad had been approved by a board, i-8 emphasized that this is a need more important than resource enhancement:

> *We are not authorized to give orders, tell people what to do. They established an independent organ there. You send it to a commission and they discuss it and tell you in detail whether they can do it or not. It's very important to have such policies. Otherwise, we cannot solve this problem by purchasing 100 or 500 nodes and doing something with each of them.*

According to interviewees, the commission should decide what should be given priority, but also who should use the precious and scarce HPC resource. The commission can review the preliminary work and decide whether the individual or the group can do the job. i-7 supported the need for a commission as:

> *When I say that I have an idea and need certain amount of computer power, somebody should evaluate it and tell me that my project is logical. If it is possible to obtain scientific results with my project, they should let me use the resources. If my project is not funded, then I shouldn't be able to use them.*

The commission can decide on both the suitability of the project and the competence of the researchers. Therefore, there is also a need for the commission to consist of researchers using HPC. A researcher with HPC awareness can respond to the needs of researchers using HPC. The commission should include people who have experienced difficulties in the publication process and who are aware of the difficulties that a researcher may face while using HPC. As it is revealed, Turkey's research community will trust a commission who composed of competent people who use HPC and publish with it more. i-4 stated that without the commission, no one could tell researchers who can and cannot use the center. She mentioned that researchers can claim that they allow others to use it and prevent them from using it in this case. Moreover, she explained that the presence of well-known researchers in the commission would provide confidence and increases trust. i-4 stated that commission should consist of researchers who have articles with HPC and who could examine the preliminary studies of researchers who want to use HPC resource. She gave examples on software development as follows:

> *Our friends at TRUBA cannot tell the researcher that they don't have any studies on that subject. If they say that, the researcher will react by saying "You let other researchers use it; why don't you allow us to use it?" There should be a commission, the members of which should be experts on this subject. They should have published an article about HPC and be a member of TRUBA. Such a commission can tell the researcher "You're going to use it but first show us a code that you have developed and show us that the results of your code have priority.*

Another requirement that arises is penalties to prevent the problems experienced in the implementation of the policies the interviewees mentioned. Some interviewees also shared their experiences abroad in this sense. i-2 emphasized the necessity of an audit process after the use of the HPC resource: "*You have a dream but you can't realize it. As a result, you [waste the resources and] harm the state, which should be kindly punished in my opinion".*

4.3.4. Field-specific Center

One of the findings is that the allocation needs differ according to the fields of the researchers. Researchers' need for hardware and software resources varies significantly according to the fields and the type of the research. For instance, a large storage capacity is needed in some fields, while computations require high processing power in others. Researchers want to choose HPC centers, which act as hubs in their collaboration, according to their needs. Researchers in certain fields want to collaborate in HPC centers that they know can meet their needs. In this regard, the necessity of determining which fields it is used in come to the fore. i-8 explained with examples that different fields have different needs regarding HPC resources:

> *When it comes to "capacity", my definition of this term is very different as I am a physicists. My definition differs from a theoretical chemist's definition. For instance, if you increase the capacity for a physician, a chemist will say that money is wasted. If you increase the capacity for a chemist, an engineer will say that it is unnecessary. For instance, while chemists do not need a lot of nodes in the clusters that they generally use, they need a huge amount of RAM in a node so as to make contraction matrices. On the other hand, I don't need to make contraction matrices like chemists. I use a different method. I need less RAM and a great number of CPUs. As for engineers, they need nearly zero RAM and infinite number of CPUs. As a result, I say "I don't have enough RAM to run these tasks[computation tasks]".*

It is understood from these sentences that computations differ from field to field. Every field has different computational theorems and needs. Hence, needs such as storage, RAM, and CPU in an HPC center vary from area to area. From a computer scientist's perspective, i-11 explained these differences as follows:

> *If it is an engineering modelling model, then it is mostly a computational problem rather than a data-driven problem. Thus, fast parallelization is needed instead of storage areas, which changes what kind of infrastructure is needed. If the data is huge, how are we going to distribute it? Again parallelization, but a different parallelization and there must be enough storage space when you distribute it and so on.*

i-15 emphasized that they bought the system in their local centers by considering these differences as:

> *Four or five groups share it. Again, it is relatively a heterogenous group and people's computational needs are different. As we know it would happen, we bought the machines considering these different needs.*

i-8 exemplified the consequences of capacity increase without considering these differences and following a policy about it:

You want to increase your capacity and you tell it to UHEM. This is like telling them "Let chemistry, physics and engineering departments fight and I will watch them fighting.

The need for clear center usage definition and the necessity of predetermined objectives have emerged. In the HPC working environment, which brings together researchers from many different fields, it is a basic requirement to know which areas the center is aimed at. Regarding this, i-8 talked about the application in Europe as follows:

They get into bigger fights in Europe. They deal with millions of euros. There is such a method for the management of such fights. All centers publish their statistics at least for their users. In this way, they show how many computers and what kind of computers they have and what they are used for. As this is made public, when chemists claim they can't use these machines for their computations, they can say the machines are not designed that way. This becomes a personal request from the chemist.

As for the clear usage definitions, i-4 stated that a commission could also play a role in defining the center's usage and its objectives:

That commission can also do allocate hours. For instance, they can allocate 20 million CPU hours to fluid dynamics this year. They can allocate 30 million CPU hours for molecular dynamics. When people clearly define their work and tell them what they need to use it for, the commission can allocate hours to them. This also be good for the users as well.

These field-specific centers can be institutionalized within a certain institute. These institutes aim to increase collaboration in certain fields and to become a relevant hub in these studies. On this subject, i-12 talked about an institute abroad that she is a member of:

I was a member of the institute there. While we were working there, we were able to enter supercomputing centers with a special permission. They allowed us to access such an institute's computers externally. This will increase collaborations, of course.

This experience of i-12 is an example of reaching potential collaborators via access to a field-specific center. These centers can function as collaboration hubs in certain field activities. The access of the HPC resources in such centers can also enable researchers to participate in the interdisciplinary collaborations. The privileged and authorized access of i-12 opened the door to collaboration for her. Moreover, i-4 stated that:

> *That commission can also do allocate hours. For instance, they can allocate 20 million CPU hours to fluid dynamics this year. They can allocate 30 million CPU hours for molecular dynamics. When people clearly define their work and tell them what they need to use it for, the commission can allocate hours to them. This also be good for the users as well.*

4.3.5. Allocation with Support

Researchers using HPC can come together through project calls and research incentives. However, researchers in Turkey are so afflicted by resource scarcity that they use these grants to create HPC resources. This can happen in two ways. The first is to get local HPC resources with project support. Interviewees stated that obtaining local resources with project funding or strengthening the existing local resources is very common in Turkey.

The second is that the researcher can purchase hour-based usage with a fee from central resources. If there is no project support, these fees create a burden on researchers. They have to endure long q-times while using free resources. That's why i-7 prefers to pay fee to get rid of long queues:

> *For instance, I pay to use [HPC centers]. I include the cost of service under expanses in my project so that I have a budget to buy CPU time when the project is funded. Then, they allocate that time to me, which I think is a much better method.*

i-8 stated that it is almost impossible to run computations in central resources without project support or without buying processor-hours:

> *Neither [project support and processor-hour] was given to me. My situation is really sad. They told me "You have just come; we're going to give you a start-up project in a month or two. Then, we're going to give you money." I thought I can buy CPU time using that money and start working with the kids [students]. They didn't give me project money. It has been seven-eight months;*

> *they have just told me that they're going to pay me. They open an account in TRUBA for new users. I tried using that account and submitted my work; I waited for two months; then, I cancelled it. You cannot do anything in TRUBA unless you pay them. UHEM also requires you to pay for the service.*

There is one more possibility in the central resource. A researcher who receives TÜBİTAK project support uses a priority code with a certain limit that allows her to get ahead while waiting in the queue in TRUBA resources. i-9 explained this process as follows:

> *If you have a TÜBİTAK Project and use that project code in TRUBA, they put your computations into a different area, so you have a faster computation. That is, you go up in the queue, which is an advantage.*

The project code is very valuable for researchers and they use it very sparingly as i-10 said:

> *No, I'm not using the project code. I use the code very economically in special situations. As I told you before, when I want to see the results in a very short time.*

Unfortunately, there is a problem with TÜBİTAK project applications. A preliminary study is required when applying for project support. This application can be for both the local resource acquisition and the access priority to the central resource. In order to carry out the preliminary study, the interviewees stated that a certain level of HPC resource use is required. However, this becomes an obstacle for researchers who have applied to the project to access the HPC resource and do not have a local resource for the preliminary study. i-32 explained this vicious cycle by showing her own experience as an example:

> *For instance, when we submit the project, we need to start the computations. However, if the available HPC system is not enough, I need my own computer system to do a preliminary study as the person who examines the project may ask to see a preliminary study. You need to have your own system to do it. I mean you have to use TRUBA for it. Moreover, when I submit my project proposal, TÜBİTAK says "This person already has computer nodes; then they can use their own system instead so using TRUBA is unnecessary" and rejects it.*

Furthermore, the interviewees stated that when TÜBİTAK evaluates project applications for a local resource improvement, they reject the project of a researcher who already has a local resource since they think she does not need to improve her system and she can use the central resource when necessary.

> *I write the project to improve my own system. That's my main purpose. However, they think "TRUBA is already doing it; then why should the government pay for it?" However, TRUBA gives priority to those who has a TÜBITAK project. I can't use that system if I don't have a project*. i-9

Some researchers purchase resource usage time (GPU/CPU-hour) due to the lack of resource allocation policies in Turkey which prevents researchers from using HPC easily in their collaborations. For the same reason, there are also researchers who make purchases from abroad or get the right to use foreign platforms through a membership fee. i-23 stated that she uses foreign resources with the service procurement budgets from Turkey:

> *If foreign data is to be used, we try to run computations by purchasing HPC resources or time from such places as E [foreign paid platform, anonimized] or Y [foreign paid platform, anonimized]. If it exceeds the funding of the service, we try to do it in our own local [system]. When you want to make an analysis, storage space is not what is limited. When they open an academic account to you, they give you a certain amount of credit. Your credit decreases according to the size of your analysis and the area you buy for it.*

The lack of a resource allocation policy impels researchers to go beyond accepted procedures. i-2, who uses the account of a deceased researcher, and i-26, who uses the account of her spouse, are proof of this practice:

> *We bought two more accounts on behalf of two lecturers. We bought an account for the lecturer's professor, who didn't run computations. After she died, we used it until the cota expired. We find a way*. i-2

> *I sometimes use my spouse's account as it is not used fully*. i-26

4.4. Disciplinary Gaps

In this section, the ways of filling disciplinary gaps in studies with HPC while collaborating are analyzed. The findings are grouped in four clusters: Technical support, education, human resources, and development of HPC tools. This structure is shown in Table 4.4. The codes that form the Disciplinary Gaps section are clustered as technical support, education, human resource, and development of HPC tools. The codes are listed under the clusters they belong to.

Table 4.4: The Structure of Analysis of the Disciplinary Gaps Section

Technical Support	**Education**	**Human Resource**	**Development of HPC Tools**
help of center staff	no account for students	qualified researchers	software fees
communication with staff	hands-on training	lack of staff	platforms with fees
academic staff			resource scarcity of developers

4.4.1. Technical Support

It is revealed that closing the disciplinary gaps for researchers not coming from computer science is possible with the help of the center staff. In this respect, the interaction of the center staff with researchers while using HPC affects collaborations and the research in many ways. Interaction with the center staff is critical not only in closing the disciplinary gap but also in all research using HPC. The existence of an accessible center that provides quick solutions to the problems faced by the researcher directly affects the research. In support of this, i-6 stated:

> *In our studies, speed is of utmost importance. I think I can say that for everyone who works with computers. Therefore, when we see a mistake, we want to get the answer as soon as possible, intervene and correct it and then continue. That's why fast response to our questions and needs is very important for us.*

In this respect, the experience of the center staff is essential. In solving these problems, researchers who do not come from computer science cannot be expected to learn about the technical issues and provide solutions themselves. i-7 compared this to driving a car: "*When you drive a car, you don't have to fix every problem; you take it to a mechanic. However, if you don't know anything about a car, you cannot drive it. HPC use is similar to this. You need to understand computer language enough to be able to* *do HPC"* In this regard, she stated that the center staff and researchers should work together as follows:

> *We call them admin… They are system administrators and experts in this field. They may be divided into two. We need people who know both hardware and software. Here depending on the resources and the number of users, sufficient number of people should be hired to manage this system.*

Additionally, in local centers, researchers have to work like the center staff because of the inexperienced staff. i-15 mentioned that the system administrator at the local resource is not as experienced as those at the central ones. She expressed her confidence in one of the central HPC centers as, "*Since there are no problem, either they are solved before we realize it or admins are very experienced. Thus, there's no problem."*

The centers in Turkey are inadequate in meeting unique technical needs. However, the interviewees stated that it is common to establish scientific collaborations with HPC center staff abroad. For instance, i-5 said that they received support from abroad for adding the code they needed. She stated that similar approaches do not exist in Turkey:

> *We came together with HPC experts on this issue. After one meeting, they made this addition for us in two weeks. We were able to have several different methods added to this code within the framework of our formulation, which are very difficult in our country.*

Communication, which emerged as a collaboration facilitator, is also essential in collaborations with HPC center staff. Communication with staff at these centers is invaluable to researchers. They need to work with a center they trust against the risks such as not being able to make a critical computation or not being able to publish research that is supposed to be published. According to the interviewees, the way center staff's talk to them while providing technical support affect the researcher positively or negatively.

Moreover, the researchers' relation with the center staff affects their preferences regarding centers. Interactions within HPC centers, which are analyzed as a hub for collaborations, directly affect collaborations. For instance, i-2 using TRUBA said that she preferred the center because she had good relations with the staff. The following statements by her, in which she says that the availability of the emloyees and their willingness to help, seem to be one of the significant reasons for her choosing to use that center:

> *I remember calling them [the staff] at the weekend and they helped me. I needed to submit computations but the computers were turned off. They found a way to connect from their homes and asked someone there to turn on the computers. As they always help you during holidays, I'm always pleased to work with them.*

Researchers do not want to work with whose staff they can't communicate well. As this research reveals, communication between the center staff and researcher must be strong so that the researcher can ask for help without hesitation. For example, i-15 exemplified this as "*Someone has put a lot of effort into it. I wonder whether a know-it-all will tell you something annoying, whether they think I'm stupid or whether I should write it [on a forum or a mail group when we need help].*" Hesitations like these will no doubt hamper research.

The support of the center staff is of great importance for researchers who use HPC as a tool in research. In this regard, an HPC center is an essential element in the formation of strong and close relations of the HPC community. Assisting the researcher in technical matters not only contributes to the research, but also provides an efficient research environment by building a bridge between the center and the researcher. Researchers are moving away from centers where they feel that this bridge cannot be built. For instance, i-25 explained why she uses TRUBA as follows:

> *For example, when I ask a question to them, they respond "Everybody knows this". However, I don't know it. I ask it because I don't know it. They tell us "How can you not do it?" instead of helping us. For instance, we experienced something like this at UHEM. They told us that we could set it up ourselves. Yes, but I didn't want to waste a week doing it. While setting it up, I also need to know about computers to deal with the problems. We haven't experienced such a problem in TÜBİTAK.*

Another example from i-29 is that she prefers UHEM instead of TRUBA due to their quick responses.

> *Unfortunately, the last problem I had with TRUBA, it was late and I had to send four or five messages. Maybe it resulted from the pandemic and the limited working hours. They were faster before. I saw it was faster in UHEM. Maybe they give importance to it since they compete with TRUBA.*

Furthermore, ensuring a good communication with the center staff facilitates research. Considering this, local centers can be more advantageous. For example, i-14 said that it is easier to communicate with the admin in their local centers, as they have the opportunity to meet face-to-face. She described the communication channel as follows:

> *We get to know each other better after talking three or four times. They know who I am and where I can make mistakes. Everything is managed via email in TRUBA. I don't know the person at TRUBA at all, so it is more formal*.

The center staff's familiarity with the academic community has an enormous contribution to research with HPC. i-13 supported this with statements as "*There weren't only computer engineers; there were also scientists in addition to administrators. The scientists saw it from our perspective, the users' perspective. As a result, it was very useful."*

In addition, talking about her experiences abroad, i-5 stated "*There were highly qualified researchers among the HPC personnel who do quality research in the models that I know. They are researchers with a doctorate degree and they help the professors to solve the problems."* In this regard, there is no requirement that some of the employees working in any center in Turkey should be researchers with doctoral degrees. In the absence of this kind of staff, it can be understood from the following sentences of i-13 what kind of problems the researcher using the HPC center may experience:

> *The administrator of our computer is a young student studying in the engineering department. I mean it's impossible for him to know this [needs for certain scientific fields]. When he comes here, I show him [the computers and software we use in our study] and we discover how to be an admin together*.

Such extra technical burdens undermine the research environment by wasting the researcher's time. In this regard, i-20 shared her experience when she wished a scientist was among the team:

> *For instance, the software doesn't show you the error. It just doesn't produce any results. There are subtle things like this. If there were scientists in that team, I wouldn't have to deal with these problems.*

Another experience told by i-32 shows the IT support team's lack of HPC awareness in their local center:

> *One day, they locked one of our professors' account. Why? She transferred a lot of data. That is, she worked too much! [laughter] They told us that she was transferring too much data and they didn't understand what she transferred. We need to solve such problems.*

4.4.2. Education

One of the emerging types of collaboration in Turkey is student-instructor collaboration. However, Turkey's HPC research environment is problematic regarding student involvement in projects. There are difficulties in students' use of central HPC resources. Some centers do not open accounts for undergraduate students. For example, i-2 stated "*Even undergraduate students can do computations, but they don't have accounts. Since the number of users have increased, TRUBA doesn't open accounts for undergraduate students anymore.*" Considering the collaborations established with students in research with HPC, this creates a big problem. In this respect, the tendency towards local centers is increasing. Hence, researchers act against the procedure to educate their students, as i-2 said "*They didn't give our students accounts but we found a way. They used my account or other accounts that belong to people who weren't using them.*"

The constraints of student usage of HPC are not limited to central resources. There are also difficulties in opening an account for students in local university resources, which causes practices outside the norms in both local and central resources. i-9 shared her experiences in this regard as follows:

The university says that they can open external VPN access only to personnel. We can't make them understand that we can access our system externally but our students cannot access it externally. They can access it using wi-fi in the university campus. I can access it from my home but they can't. They don't give this freedom to students. During the pandemic, I had to give this freedom to my students by letting them use my accounts.

The inability of students to participate in HPC studies causes educational problems in the Turkish HPC community which will cause the disciplinary gap to grow in the future. There are other obstacles in education and closing disciplinary gaps. Researchers use their project grants to strengthen their local resources in order to include their students in their project groups and to increase their educational opportunities because a central HPC center does not open accounts for undergraduate students. However, applications for funding by researchers who already have local resources are rejected. Thereupon, the resources that they can use for their students cannot be improved. This vicious cycle is undermining research with HPC in Turkey. i-32 described the situation as follows:

I allow my undergraduate students to use that system. I can't write in [in the project] that my students will use them. The existence of such a center (TRUBA) is bad for me in this respect. I want to strengthen the system [the local HPC system] that my students use. I want to include more people in the group. I want to improve my system to be able to include more people… I don't know how all those heads will change.

Education is essential to establish a foundation in HPC research and close the disciplinary gap before it occurs. That is why training sessions organized for HPC use in research are of great importance. Maximum benefit is obtained from the training sessions where researchers with similar problems, such as field-specific issues, come together. These events, which bring researchers together and encourage collaboration, are also very beneficial for education. i-25 gave an example supporting this as:

For certain program packages, I am an expert but the other person has no idea or vice versa. I don't know how to use Gromax[13], whereas he uses it very well. If I had known it, I could have worked with the biologist better. Maybe if they organize workshops, I can attend and tell them what I know.

[13] A software.

In addition, one-on-one hands-on training has a positive impact on researchers. This kind of HPC training environments encourages collaboration by enabling researchers to meet potential collaborators simultaneously. In supporting this, i-2 gave an example from abroad as:

> *Half of my collaborations are the collaborator friends I made during my travels abroad. I listened to their talks, met them, talked to them face to face, persuaded them and gave them ideas, which is very important. We need to do this. For instance, there are theoretical physics or mathematics institutes in Italy and Spain. They open winter, spring and summer schools. Since computational science and engineering is so important, we need to fund our students and send them to these schools where they teach it hands-on.*

In the analysis, student-instructor collaboration havestood out. However, it is revealed that students' access to HPC resources is quite limited. Training opportunities are improving, but this is an issue that needs to be addressed. Education opportunities and training quality provides us with trained human resources, which is the key to closing disciplinary gaps.

4.4.3. Human Resources

A result of educational activities on student training in research with HPC is creating qualified human resources which means training both technical center staff and computational scientists who are potential collaborators. In particular, researchers state that the area where time and money should be invested is trained human resources. These human resources are the HPC community, who will eventually implement large-scale projects. According to i-3, the most fundamental problem is human resources:

> *I mean you teach your students everything and they become independent. Then, they go abroad instead of contributing to our work. This is a human resources problem. Other problems can be solved.*

Qualified researchers are necessary for the development of Turkey's computational science research environment. The lack of human resources hinders Turkey's research with HPC. There is a lack of researchers to collaborate with for the same reason. Researchers find it difficult to find collaborators from close circles. From her perspective, i-15 said: "*It is very important that the researchers are well-trained. It's very difficult to find such people. The biggest cost is your human resource.*"

The lack of staff at HPC centers negatively affects Turkey's HPC collaboration environment. The number of staff of in both central and local HPC centers is insufficient in order to receive technical support. This means that collaborations with staff that aim to close the disciplinary gap cannot be made.

Due to the density of users in the central resources, the number of service staff may not be sufficient. According to the interviewees, employees in both central HPC centers (TRUBA and UHEM) in Turkey are doing their best to serve Turkey's scientific community with their self-sacrificing efforts. However, the low number of staff undermines Turkey's research environment using HPC. i-30 made this clear with the sentence as "*So they can't be in two places at the same time.*"

i-3 summarized these deficiencies and the negative effects as follows:

> *For instance, they hire staff and they pay them well. They also let them do scientific research while working. Since they have studied science, they know your needs. They have also used the same thing. It wasn't like this until recently. They hired few people and paid them little and we had so many problems because of this.*

The situation is worse in local centers. Researchers even provide technical support for their students themselves due to lack of technical staff, as i-9 exemplified: "*She [student] has a desktop computer, so I try to set it up. There needs to be an IT DESK. I shouldn't be dealing with such things; I should be doing research*".

4.4.4. Development of HPC Tools

Having to develop the software for their computations is a burden for researchers who are computer scientists. It is a waste of time for these researchers to spend time developing software for computations while they need to allocate time for their research. In the group interviewed, there are those who are not computer scientists but who have had to develop their own software for their research. These researchers publish on software development for the computational branch in their field. In this respect, they want other researchers to use the programs that they develop. Packaged software and interfaces that offer ease of computation are more attractive for researchers who use HPC as a tool for computing in their research. When these researchers cannot find a user-friendly solution in local or national centers, they turn to platforms with fees.

User-friendly software has a direct effect on the choice of the service offered in HPC centers. i-2 emphasized that it is not necessary to deal with software development while conducting their research:

> *We are users. We use the software. Not knowing that code or not knowing how to compile in that code is considered a shortcoming on our part. However, I think we don't need to know these as knowing them doesn't make our articles better.*

i-15 using TRUBA developed software specific to her field for a particular machine in TRUBA. Because TRUBA did not have software developed specifically for her field. There was no other option for her. She added that TRUBA could not optimize the system for every program:

> *TRUBA's wiki is very good, but they can't can't optimize [the system] for every program. We tried to do it ourselves. I had a lot of difficulty preparing documents in the beginning. We especially wanted to prepare something like this [showing a wiki of her software]. Maybe it will help someone.*

Some people are not as lucky as i-15's colleagues. In HPC centers in Turkey, every program for every field does not exist. Some researchers prefer foreign platforms when they cannot find the source they need in Turkey. For instance, i-16 emphasized that foreign platforms offer a more comfortable working environment for her because there are no programs for their field in the central HPC center in Turkey:

> *Our problem with TRUBA is that they don't have a special area for bioinformatics. As there aren't any available tools in bioinformatics, we have to create them whenever we start a project. We have some ready-made software; we also have our own software. However, whatever we do, everybody should be able to create their own area in TRUBA. Every one of the bioinformatics researchers in Turkey has to do the same thing over and over again.*

HPC interfaces are developed so as to meet the diverse needs of various fields. In this regard, there are researchers who want to modify programs by themselves according to the needs of the research, but those who do modification are primarily developers. Although these developers are not computer scientists, they produce software or optimization solutions that can meet different computing needs in their field. These developers are part of the HPC community. It turned out that it is quite common to establish collaborations over the software developed in studies using HPC in certain fields abroad. i-15 stated that there are collaborations around the developed software. She emphasized that it is important that the codes produced by the developers are used by other researchers in collaborations:

> *There are softwares that they call flagship. It is important that people can use these softwares properly without needing any experts. What is the most important thing for computational biologists? Citation. It's important that their programs are used.*

Interviewees talked about the platforms abroad that are specific to certain fields due to these software needs and the establishment of large-scale collaborations on these platforms. i-15 mentioned that the platform they used to develop software specific to their field while doing her doctorate that hosted big-scale collaborations.

> *The laboratory where I did my PhD actually both does academic research and provide open service to academy. It turned from a The Netherlands-wide consortium into a Europe-wide consortium. It was a very important investment that was made by my doctorate professor. He ported the software that he wrote into the grid and HPC, opening it to academic use. Otherwise, the clusters in your laboratory cannot be enough. In this way, he had a change to introduce his software to the world.*

However, the interviewees claimed that these kinds of platforms similar to those abroad do not exist in our country. The developers and even the users within the group interviewed state that being a developer in Turkey is difficult. An innovative software development environment that can bring researchers together does not seem possible in Turkey due to lack of resources and usage allocation policy:

> *There are 17.000 processors in Turkey now. I ran computations in 10.000 processors in France. While it is ridiculous to provide 17.000 processors in total for everybody in France, it is a start in Turkey. It is an opportunity to train people*. i-4

The importance of software development for the HPC research environment and its contribution to the scientific community has come to light. At this point, platforms suitable for use by developers provide an effective way to close disciplinary gaps. These platforms facilitate collaboration and contribute to the research environment.

In the next chapter, all findings in the findings chapter are discussed with studies in the literature and best practices in the world.

CHAPTER 5

DISCUSSIONS

In this part of the thesis, the findings mentioned in the literature review section and the findings of this thesis study are discussed.

5.1. Nature of Research with HPC

First, the question of why researchers in Turkey use HPC in their research was asked. The findings in this thesis show that HPC is an indispensable tool for researchers. This result supports the claims of Apon et al. (2014) that research using HPC cannot be conducted otherwise. One of the reasons for this is that, as mentioned in the literature, big data requires an advanced tool (Chen & Zhang, 2014; Patgiri & Ahmed, 2017). As presented in this thesis, the research questions of researchers using HPC are quite complex and their data is also complex and 'big'. In addition to solving a complex problem, it is revealed that researchers need to simulate real phenomena. The need for converging to reality brings the need to present simulations in the most realistic way. Moreover, the findings show that a sophisticated tool, that is HPC, is needed to get the most precise and accurate results, as Götz (2017) mentioned.

There are findings in the literature, such as the desire to gain reputation (Katz & Martin, 1997; Price, 1963) and increasing career opportunities (Ynalvez & Shrum, 2011) in response to why researchers in Turkey collaborate. The findings of this thesis reveal that researchers use HPC to gain a scholarly reputation. It turns out that besides gaining fame by collaborating, researchers have gained fame even just by using HPC. Researchers chose computational science in their fields at the beginning of their careers. Computational science provides the opportunity to publish on popular topics, and it seems easier for researchers to gain a reputation by publishing with HPC.

The findings show that researchers using HPC support other fields with simulations or theoretical computations. It can be seen that there is a need to support the findings of experiments with HPC in such research. On the other hand, the results obtained by HPC can also be tested in the experiments. In this sense, HPC facilitates research in many different fields. Hence, researchers using HPC naturally collaborate with researchers from many various fields. While researchers can publish only an experimental study or only a computational study, they aim to produce higher-quality studies with collaboration so that they can publish them in well-known journals. HPC collaborations are not made just for fields to support each other. As demonstrated, HPC studies are inherently used to answer complex questions. The questions that are too complex for the researchers to answer alone create the need for collaboration. Therefore, collaborative work is essential in research with HPC. The findings support the literature in this regard (Hara et al., 2003; Iglič et al., 2017; Morrison, 2017).

While seeking an answer to the question of why researchers using HPC in Turkey collaborate, the desire to collaborate to access the expensive and sophisticated tools mentioned by Katz & Martin (1997) came to the fore. In support of this, it is revealed that researchers in Turkey turned to international collaboration due to the resource scarcity in Turkey. The desire to collaborate with computer scientists to access computational tools mentioned in the literature (Cowls & Schroeder; 2015) appeared in a different form in this thesis. Researchers collaborate with any researcher who has the software or hardware tools they need, regardless of what field the researcher works in. This does not just happen with someone coming from computer science. Researchers also collaborate with their colleagues in the same field if they have the tools.

5.2. Communication and Trust

Publishing is vital for researchers. They tend to collaborate with punctual collaborators that are trustworthy to publish together. Researchers want to study novel topics that can bring more citations in more attractive journals. Hence, they collaborate to improve the quality of publication in studies with HPC. In this respect, communication and trust are discussed in this section within the framework of the thesis question.

It should be noted first that in this thesis, collaboration is handled from a broad perspective. It is considered that there is collaboration in research even if there is a division of labor. Communication is of great importance in collaborations using HPC in Turkey. This result contradicts the studies in which communication appears to be unimportant in collaborations (Chompalov et al., 2002; Evans & Marvin, 2006; Lowe & Phillipson, 2009). Contrary to what Leahey and Reikowsky (2008) argue, the findings in this thesis show that even when there is a sharp division of labor, communication is vital for collaboration. Supporting Hampton and Parker's (2011) argument, it turns out that face-to-face communication strengthens collaboration.

Collaborations can be established in interdisciplinary studies with the division of labor in Turkey's HPC research environment, even if there is no synthesis (Bennett & Gadlin, 2014; Hackett et al., 2019; Hampton & Parker, 2011). It is difficult to find large-scale consortia that bring together vast sums of different collaborators in Turkey's HPC research environment. Therefore, large-scale multidisciplinary studies cannot be compared with interdisciplinary studies. However, it can be said with certainty that even if there is no interaction between researchers, communication and trust are essential in collaborations using HPC in Turkey. This finding is compatible with the study conducted by Aydinoglu (2013).

It is imperative to establish trust in collaboration via face-to-face meetings. This result is supported by many studies (Bennett & Gadlin, 2014, 2012; Disis & Slattery, 2010; Hall et al., 2012; Wagner, 2018). Moreover, as revealed in this thesis, the desire to collaborate with people whose contacts were previously trusted is intense among researchers. This result is in contrast to the arguments by Shrum et al. (2001) and Iglič et al. (2017). Researchers are more likely to collaborate with people they already know (Harris & Lyon, 2013; Maglaughlin & Sonnenwald, 2005; Sonnenwald, 2007), according to the findings.

Another factor that determines the fate of the collaboration is that the interests of the researchers must coincide (Atkinson et al., 1998; Kim, 2017). All four types of collaborations analyzed in this thesis (needs-based, topic-based, complementary, and student-instructor collaborations) depend on mutual interests in Turkey's HPC research environment. In needs-based collaborations, mutual needs are met (Sarma et al., 2004). Topic-based collaboration tries to explore a common issue (Richards & Farrell, 2005, p. 56). Complementary collaborations support mutual work to produce better publications. These results support the study of Hara et al. (2003), which states that theorists and experimentalists form complementary collaborations due to needs such as computer simulation. Student-instructor collaborations contribute to the student's education life and the instructor's career (Shein & Tsai, 2015; Yan, 2017). This type of collaboration falls under the 'learning opportunities through colleagues regarding teaching' category that Hara et al. (2003) mentioned. These four types of collaborations are all based on mutual interests. Researchers using HPC in Turkey seek reciprocity in their collaboration. This result supports the necessity of reciprocity in collaboration stated by Morrison (2017).

Apart from these, different factors have emerged in this thesis that affects the communication of researchers in their collaborations. One of them is participation in scientific events such as conferences and congresses, which create an environment for meeting researchers from different fields. The social environment and personal relations have an important place in this regard. Thus, it is inferred that the mobility of researchers in the HPC research environment in Turkey should be promoted so that they can easily find potential collaborators (Nuhoğlu & Aydinoglu, 2021). These potential collaborators can find an answer to part of a complex research question, come up with a novel idea about their field, satisfy a need from the same discipline, satisfy the reciprocity, or meet the need for sophisticated tools. The importance of finding potential collaborators is demonstrated in this thesis with many different solid examples.

5.2.1. Conflicts in Collaboration

Considering the collaborations established in researches using HPC in Turkey, author conflicts negatively affect the collaborations. This result supports the studies of Cronin (2001) and Smith et al. (2020). Due to the nature of research with HPC, there are publications with multiple authors. It is debatable who actually contributed to the studies involving many authors. As revealed in this thesis, unethical practices such as writing the name of the person who made no contribution occur.

Additionally, changing interests of researchers can lead to conflict and even end the collaboration before it reaches a conclusion. The importance of interests of researchers (Kim, 2017) and the work presented by Atkinson et al. (1998) on this issue is entirely compatible with the findings. The reciprocity demonstrated by Morrison (2017) is also essential for collaboration in research using HPC in Turkey. Moreover, trust is vital (Bennett & Gadlin, 2012; Wagner, 2018). Contrary to what Centellas et al. (2014) mentioned, conflicts do not feed the HPC research environment in Turkey and do not lead to better results.

5.3. Resource Allocation Policies

While searching for an answer to the question of what kind of barriers exist in collaborations using HPC, it turns out that resource access has an impact above all else. Resource access is a big challenge naturally when searching for answers to complex questions in big data studies (Chen & Zhang, 2014; Metzler et al., 2016). However, the HPC resource access problem in Turkey is not similar to the problems mentioned in the literature. While searching for an answer to the question of how researchers access HPC tools in Turkey while collaborating, the profound impact of the lack of resources emerged. Access to HPC resources in Turkey is problematic to the extent that it affects the entire HPC research environment.

Although it is found in this thesis that the researchers want to do novel and popular studies when collaborating, the lack of HPC resources is a major obstacle to this goal. Researchers in Turkey eliminate extraordinary research questions due to the HPC resource scarcity as a more complex question means, more powerful resources are needed. Moreover, researchers who plan their collaborations on publications have a hard time publishing their findings due to the lack of resources. Researchers using HPC in Turkey, who are mainly publication-oriented, encounter obstacles in the issue they care most.

Departments with local resources due to high demand, as shown in the study of (Apon et al., 2014), are also available in Turkey. Although it may seem beneficial for local centers to serve as a substitute, their scattered structure leads to a waste of resources in Turkey. Moreover, the situation where scientists bear the burden ofinfrastructure problems in Turkey is an evidence of the lack of a comprehensive policy. On the contrary, there are examples abroad that connect local centers in different locations with efficient HPC infrastructure deployment to facilitate collaboration (Alvarez et al., 2007; Fitzgerald et al., 2007; Khan et al., 2019; Kuraishi et al., 2014; Navarro et al., 2017).

Considering that the findings in this thesis have clearly revealed the lack of resources, it is straightforward that making HPC investments will bring benefits. The necessity of HPC investments can support the study of Apon et al. (2010), which claims that investments increase the competitiveness of scientists. However, the support for this issue, which goes beyond the research question of this thesis, is relatively weak.

Virtualization (Ursuleanu et al., 2010), HPC platforms where scientists come together on the same network (Z. Zhao et al., 2005; McGregor et al., 2015), and cloud infrastructures are provided in the literature as a solution to problems similar to the problems emerged in this thesis (Lynn et al., 2020; Mauch et al., 2013; Xia et al., 2016). Resource quality and service quality are improving by the cloud. The emergence of the convenience of cloud use and researchers' preference for common virtual platforms in this thesis support the cloud solution in the literature.

Another situation that arises from analyses related to resource allocation applications is field-specific center allocations. As this thesis reveals, different areas may have different hardware and software needs. Bearing this in mind, field-specific center allocations have examples in the world. Japan's K supercomputer is dedicated to the fields of nanotechnology and life science (Yonezawa et al., 2011). Brazil's national High-Performance computing network focused solely on bioinformatics is BioinfoPortal (Ocaña et al., 2020). Technical capabilities and application areas of supercomputers within EuroHPC JU are publicly announced. European users know which computations can be performed within which supercomputer (EuroHPC JU, 2021). It is also observed that field-specific centers are established within the institutes specific to the same field, and thus, scientific studies in the field are facilitated by encouraging collaborations (Rathje et al., 2020; Zafeiropoulos et al., 2021).

EuroHPC JU does not have any supercomputers outside the territory of the EU member states andthe priority is given to the EU and member countries in its central management (European Union, 2018). This joint undertaking can only be an alternative resource other than a solution to the problems revealed in this thesis.

Additionally, there are prioritization policies in the world for the allocation of an HPC resource to users. The findings of the thesis dovetail with these policies. The prioritizations are made in line with the decisions of a competent committee. For instance, Japan's K supercomputer is prioritized for use by the Japanese Ministry of Education, Culture, Sports, Science, and Technology (MEXT) committee (Yonezawa et al., 2011). Another example is China. In addition to the classical HPC central allocation, China allocates resources to users with prioritization among different allocation methods. Furthermore, the service offering of additional resources on interconnected platforms in a way that encourages collaboration is among these different allocation methods (Xu et al., 2016).

5.4. Efforts to Fill Disciplinary Gaps

Collaborations in research using HPC in Turkey are not only established with computer scientists to bridge the disciplinary gaps as mentioned in the literature (Hu & Zhang, 2017; Lazer et al., 2009). Collaborations are generally established in an interdisciplinary manner due to the nature of HPC, as analyzed in the thesis. In this environment where science requires joint effort, the disciplinary gaps in Turkey are tried to be closed with many different efforts. As a result of the analysis, disciplinary gaps in Turkey are closed with the support of the center staff, educational activities, and the development of user-friendly HPC tools. It is explained in the findings chapter that there are many obstacles to their realization. These obstacles seems to result from lack of resources and lack of policy.

Student-collaborator type collaboration, one of the collaboration types that emerged in the collaboration section, is undermined due to wrong policies. This type of collaboration forms the basis of education, which is the most important for bridging the gap between disciplines before the gap even forms. As revealed in the findings, students learn while working hands-on. Their lack of access to HPC resources causes them to be excluded from big projects and hinders collaboration.

In addition, the importance of getting help from the center staff has emerged in the findings. Policies abroad in this regard are implemented in such a way that the center staff also includes scientists. Considering the problems such as the shortage of personnel in central resources and even the fact that students take charge as admins in local resources in Turkey, the vital problem of policy deficiencies emerges.

Problems with human resources and policy deficiencies of their training harm the scientific community and hinder the development of the research environment. These results coincide with the claims of Hey and Trefethen (2005), who emphasize the need for a joint effort to close the disciplinary gaps and state that the infrastructures that enable researchers to come together are the solution.

In order to close the disciplinary gaps, the importance of the center staff and the human resources in the scientific community in general has emerged in this thesis. The findings support the literature regarding the establishment of platforms to encourage collaboration in HPC centers, including the staff of the centers (Connor et al., 2016; Goscinski et al., 2015; Nystrom et al., 2015).

In this thesis, the findings on human resources have come to the fore. Looking at examples of solving this problem, US National Strategic Computing Initiative Strategic Plan it stands out. The USA, which has a dominant place in the TOP500 list and is at the forefront of scientific productivity, can be an example in this regard. It is seen that the national HPC ecosystem is considered as a whole with its users, including scientists and workers in the US National Strategic Computing Initiative Strategic Plan. It has put education and training at the forefront regarding the workforce and users (The National Strategic Computing Initiative Executive Council, 2016). Considering the lack of policies towards human resources detected from the analysis, this human-centered approach can be a solution for Turkey.

TRUBA and UHEM play a key role in solving Turkey's problems, especially in education and human training. As revealed in the findings, training through TRUBA and UHEM provide solutions to many issues with the experiences of the center staff and the provision of EU support programs. In terms of EU programs, UHEM is a member of PRACE (Partnership for Advanced Computing in Europe)[14] (PRACE, 2020) and TRUBA is a member of EuroHPC JU (European Comission, 2019). However, the findings show that the number of center staff is insufficient. There is also a lack of a nation-wide policy for education in the use of HPC, including resource allocation in line with the evaluations of a particular commission or council. It is vital to evaluate well-trained human resource and to provide training and support from a common platform in line with specific policies.

5.5. Future Studies and Limitations

Collaboration in research with HPC in Turkey is analyzed from the eyes of the HPC community in Turkey. A more detailed cause-effect relationship can be examined regarding the nature of HPC research with quantitative data. In order not to go beyond the framework of the thesis question, I put forward the relationship based on collaboration. The relationship between HPC and scientific productivity and the use of HPC by fields can be examined statistically if the HPC center data can be accessed, standartized, and analyzed. However, centers in Turkey are reluctant about sharing their usage data and most use lab-cooked metadata which is not easy to standardize.

Additionaly, bibliometric analysis can be done in future studies. Although UHEM provides citation information within HPC centres, citation information of research conducted using local resources and TRUBA is not published. It is necessary to conduct a detailed research in Web of Science and other databases. However, there is also limitations for this. HPC research in computer science should be differentiated from studies in areas that use HPC as an infrastructure. Furthermore, each discipline that utilizes HPC has a different scholarly publishing practice. The results would not be comparable to each other. All these complex problems are limiting factors. It should

[14] PRACE is a partnership with 26 member states providing access to computing resources for large-scale applications forming the pan-European supercomputer infrastructure. It offers services such as free seminars, training, and seasonal schools. UHEM announces PRACE calls.

also be noted that the bibliometric results may include authors who did not actually contribute to the collaboration as there are controversies in academic authorship practices. In order to prevent this bias, future bibliometric studies alone will not be sufficient and should be supported by qualitative studies.

In terms of HPC resources, this study presents the experiences of researchers in Turkey in detail. It becomes clear how needs and gaps, policy deficiencies, and infrastructure problems affect researchers regarding collaboration. Apart from collaboration, infrastructure problems of local and central HPC resources in Turkey can be handled technically. Within the framework of the data center, the energy use efficiency of local and central resources in Turkey can be examined. Similarly, investments on HPC can be handled from an economic and statistical point of view specifically to Turkey in future studies. The software issues can be examined in a separate study specific to Turkey's HPC research environment.

The issue of HPC and project supports can also be handled in an economic context. This could make enourmous contributions to Turkey's HPC community and research environment.

In this thesis, I aimed to present policy recommendations in the focus of the research question. I made analyses by extracting the experiences of the interviewees for strong policy recommendations. I offer my suggestions in the policy chapter.

CHAPTER 6

POLICY

Up until this chapter, many deficiencies in Turkey’s HPC research environment, from resources to personnel, from training opportunities to the lack of communication channels between researchers, have been analyzed. Eliminating these deficiencies alone are not enough. Therefore, a comprehensive policy is essential for a sustainable HPC research environment regarding collaboration. Within the framework of the nature of HPC, a policy structure that supports the production of competent human resources and builds a collaborative community is suggested.

Considering the framework of the nature of research with HPC, collaboration naturally arises, and interdisciplinarity is inherent. The support of a research using HPC or the need for researchers from many fields to find a solution to a new and complex problem indicates the natural occurrence of collaboration and interdisciplinarity. These natural occurences has been analyzed in this thesis.

The effectiveness of HPC studies depends on establishing a collaborative environment on the basis of trust. In order to strengthen this, it has come to the fore to provide environments where researchers come together. It has been seen that there are HPC centers on the basis of this. Thus, it is essential for researchers to come together around the centers.

Providing HPC resources through centers entails profound policy implications. It has been revealed that local resources have problems such as the technical burden on researchers, infrastructure problems, and the inability to carry out large-scale projects due to small capacity. Despite all this, local resources are highly preferred to avoid the long q-time problem in central resources in Turkey. The way out of this vicious cycle is to implement effective HPC allocation policies as well as consolidation of the resources. Moreover, collaboration in research with HPC suffers from policy deficiencies in Turkey. Researchers lack productive environments where they can gather. The causes of all these problems have been addressed in this thesis. In this chapter, policy suggestions are made as a solution to these problems. Proposed policies are built on a common platform basis.

The findings in this thesis demonstrate that the establishment of field-specific centers ensures that the need for resources is met correctly and that researchers with the same problem come together. A center design that is free from the problems of disciplinary gaps within specific fields includes a center staff composed of people who are competent in their area.

These field-specific centers should be connected to a common platform that will encourage interdisciplinary studies. This platform, which is physically connected with an interconnected infrastructure in environments such as the cloud, also serves as an upper platform that organizes events where researchers come together. One of the most significant contributions that can be made to the research environment is to build community. This purpose can be achieved by this platform.

To sum up, the structure of the proposed policies is shown in Figure 6. The three pillars -consolidation, field-specific common central resources, and building community with common platform- are proposed according to the findings in this thesis. For policy recommendations, the codes and clusters in the findings are analyzed. Accordingly, the targets corresponding to each code are determined. Recommendation pillars that could achieve these targets are constructed. Each code in the Codebook is processed into this structure one by one.

Figure 6: Recommended Policy Structure

6.1. Consolidation

The construction of the recommendation pillar-one, consolidation, is shown in Table 6.1. Adequate, accessible, common HPC resource for large-scale projects can be obtained by consolidation.

Table 6.1: Recommendation Pillar-One: Consolidation

CLUSTERS	CODES	TARGETS
Research	**high computational need**	High-capacity HPC source
	precision and accuracy	Powerful HPC source
	converging to reality	Sophisticated HPC source
	research facilitation	Sophisticated HPC source
	easiness of computation	Sufficient HPC source
	fierce competition	Sophisticated HPC source
Resource	**high computing power**	Powerful HPC source
	dividing computations	Sufficient HPC source
	off-peak hours	Sufficient HPC source
	q-time	Sufficient HPC source
	installations	Operable HPC source
	waste	Prevent waste of resources
	idle	Prevent waste of resources
	infrastructure	Operable HPC source
	technical staff	Operable HPC source
	certain group	Accessible HPC source
	inappropriate practices	Accessible HPC source
Disciplinary Gaps	**no account for students**	Sufficient HPC source
	software fees	Sophisticated HPC source
	platform with fees	Sophisticated HPC source
Collaboration	**student-instructor**	Accessible HPC source
	group size	Sufficient HPC source
	authorship tied to HPC ownership	Common resource

Consolidation of centers can be done to solve infrastructure problems and technical support problems in local resources. The analysis so far has shown that local center capacity is inadequate, investments are costly, and there is a risk of wasted investments. Furthermore, local centers are under the monopoly of particular groups, and external people cannot access them. Additionally, they are hard to install and maintain. Although it is quite burdensome, researchers turn to local sources because they cannot bear the density that occurs in a central resource.

Regarding efficient usage of the HPC resources, it can be thought that the small scattered centers should be in the form of consolidated centers. With consolidation, local centers in different places can be gathered under a single roof. Thus, additional infrastructure problems of scattered local centers would be reduced. Another way is that the centers in different locations can be combined over the cloud.

The aim of consolidation of local centers should not be to reduce the number of centers but to obtain efficient centers. Being dependent on only one source increases the risks such as disruption of computation tasks due to power outages. It is also necessary to increase the number of HPC centers that operate with a sustainable system to eliminate risks like a failure of a resource.

6.2. Field-specific Common Central Resources

The construction of the recommendation pillar-two, field-specific common central resources, is shown in Table 6.2. Field-specific, common, accessible, high-capacity, powerful, sophisticated, operable HPC Centers can be obtained by establishment of Field-specific Common Central Resources. These centers can meet the real needs of fields, support the priority areas, and have an effective management mechanism. Researchers can demonstrate their competencies, communicate, collaborate, and publish easily while using these resources. In a Field-specific Common Central Resource environment, technical support can be at a level that encourages academic activity. This environonement can facilitate projects with great impact and scale.

Table 6.2: Recommendation Pillar-Two: Field-specific Common Central Resources

CLUSTERS	CODES	TARGETS
Research	**research question**	Gather around research question
	high computational need	High-capacity HPC source
	precision and accuracy	Powerful HPC source
	converging to reality	Sophisticated HPC source

Table 6.2 (cont'd)

CLUSTERS	CODES	TARGETS
Research	research facilitation	Sophisticated HPC source
	easiness of computation	Sufficient HPC source
	popularity of HPC	Easy publishing
	reputation	Demonstrate expertise
	fierce competition	High quality publications
Resource	TOP-500	Powerful HPC source
	exascale	Powerful HPC source
	high computing power	Powerful HPC source
	q-time	Sufficient HPC source
	dividing computations	Sufficient HPC source
	off-peak hours	Sufficient HPC source
	huge investment	Sophisticated HPC source
	prioritization	Meet real needs, Support priority fields
	commission	Efficient management
	specify fields	Identify & meet real needs
	infrastructure	Operable HPC source
	technical staff	Operable HPC source
	certain group	Accessible HPC source
	hour-based usage	Sufficient HPC source
	priority code	Support priority fields
	membership fee	Accessible HPC source
	inappropriate practices	Accessible HPC source
Disciplinary Gaps	help of center staff	Close gaps between researcher and staff regarding technical support
	communication with staff	Facilitate communication between researcher and staff
	academic staff	Technical support that contributes to academic actions
	no account for students	Accessible HPC source
	hands-on training	Qualified human resources

Table 6.2 (cont'd)

CLUSTERS	CODES	TARGETS
Disciplinary Gaps	qualified researchers	Qualified human resources
	lack of staff	Operable HPC source
	software fees	Sophisticated HPC source
	platform with fees	Sophisticated HPC source
	resource scarcity of developers	Sufficient HPC source
Collaboration	topic-based	Collaborate based on topic
	needs-based	Collaborate based on needs
	complementary	Develop complementary collaborations
	student-instructor	Collaborate during education period
	Output-oriented approach	Easy publishing
	group size	Large scale projects
	authorship tied to HPC ownership	Accessible HPC source
	international collaboration	Projects with great impact

The need for a centralized system is evident. The existence of a robust centralized system is essential to meet the high computational needs of researchers. Allocating a central and powerful resource is vital for the research environment in jobs with a high computational need that cannot be done in small local centers. It is essential to facilitate access to high-capacity resources for those who really need them. The interviewees shared their experiences of using centralized common sourcing by exemplifying their use abroad and in Turkey regarding common central resource allocation.

Researchers wait in crowded lines at the central resources in Turkey. They have to endure long q-times. The main reason is the policy deficiency applied in the allocation of available resources. The public central system does not mean that unlimited resources are offered to everyone unconditionally. In this context, prioritization, prequalification, and in-use inspection processes should be applied to reduce q-time lengths and to prevent waste of resources.

These common central resources must be field-specific. The importance and the necessity of clarity of center definition and predetermined objectives are clearly laid out in the analysis, in section 4.3.4. The allocation of field-specific centers not only provides solutions to technical capacity and resource access problems but also bridges disciplinary gaps. For instance, providing researchers with an environment where there is academic center staff specialized in a specific field and where they can collaborate with them can remove barriers of the disciplinary gaps and facilitate collaboration.

The recommended roles of field-specific centers are summarized below:

- Ensuring access to these centers by every scientist in the field
- Having a committee consisting of experienced scientists in the field
- The committee acting as a decision-making body that users are subject to for evaluation on access to centers
- The committee acting as a decision-making body on the processes of pre-qualification, evaluation, in-use inspection, and punishment
- Cooperation of centers serving in these designated areas with international collaboration platforms in their fields
- Organizing field-specific events, developing communication and collaboration mechanisms
- Conducting field-specific educational activities
- Providing support mechanisms like project calls through these centers in these designated areas
- Conducting training activities in these designated areas
- Employing qualified and experienced technical personnel capable of collaborating with scientists in these centers.

6.3. Building Community with Common Platform

The construction of the recommendation pillar-three, building community with common platform, is shown in Table 6.3. Building a community with a common platform can promote collaboration and removing its barriers. This platform acts as a hub regarding professional socialization. It increases HPC awareness and human resources trained in the HPC field. This pillar provides an effective mechanism for accessing the necessary resources for projects with greater impact and scale.

Table 6.3: Recommendation Pillar-Three: Building Community with Common Platform

CLUSTERS	CODES	TARGETS
Research	**research question**	Gather around research question
	fierce competition	High-capacity HPC source
	research facilitation	Powerful HPC source
	popularity of HPC	Sophisticated HPC source
	reputation	Sufficient HPC source
Collaboration	**topic-based**	Collaborate based on topic
	needs-based	Collaborate based on needs
	complementary	Develop complementary collaborations
	student-instructor	Collaborate during education period
	expert collaborator	Connect researchers with suitable collaborators
	output-oriented approach	
	punctual collaborator	
	previously known collaborator	
	face-to-face communication	Facilitate face-to-face communication
	wide social network	Expand social network
	congresses	Facilitate collaborations
	virtual tools	Facilitate communication
	lack of HPC awareness	Increase HPC awareness
	authorship disputes	Prevent authorship disputes
	lack of a common scientific language	Establish common scientific language
	lack of mutual interest	Platform where mutual interests meet
	lack of mobility	Facilitate collaborations
	international collaboration	Projects with great impact
	group size	Large scale projects

Table 6.3 (cont'd)

CLUSTERS	CODES	TARGETS
Resource	certain group	Accessible HPC source
	prioritization	Meet real needs, Support priority fields
	commission	Efficient management
	priority code	Support priority fields
	membership fee	Accessible HPC source
	inappropriate practices	Accessible HPC source
Disciplinary Gaps	communication with staff	Facilitate communication between researcher and staff
	academic staff	Technical support that contributes to academic actions
	hands-on training	Qualified human resources
	qualified researchers	Qualified human resources
	platform with fees	Sophisticated HPC source

Building a community and deploying communication channels within this community is a solid answer to the main research question of this thesis. The necessity of communication in order to receive support is not limited to the employees of the center. It is vital to create a community with a strong communication language for researchers. The common platform can trigger collaboration and remove barriers to it. With a common platform, an environment of trust can be established by improving communication between researchers.

The recommended roles of common platform are summarized as below:

- Enabling activities such as targeted workshops, congresses, and conferences to facilitate collaboration among scientists with each other through this platform; acting as a hub
- Having a qualified supreme board responsible for the management of the platform
- Determining the priority areas of field-specific centers by the supreme board and determining services to be provided by these centers

- Determining HPC strategy throughout the country
- Cooperating with field-specific centers on issues such as project supports and prioritization
- Developing mechanisms to encourage collaboration between field-specific centers
- Cooperating with international institutions, organizing events and congresses, and providing mobility incentives for scientists in Turkey to participate in international events
- Conducting projects involving multiple local or field-specific centers across the country
- Providing educational activities throughout the country.

This qualitative study emerged in which the researchers established their collaboration with their own efforts without the help of a common platform. Scientists who use HPC should be provided with a collaborative environment. Researchers who come together on a common platform around a specific topic will trigger successful collaborations.

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APPENDICES

A. APPROVAL OF THE METU HUMAN SUBJECTS ETHICS COMMITTEE

UYGULAMALI ETİK ARAŞTIRMA MERKEZİ
APPLIED ETHICS RESEARCH CENTER

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04 AĞUSTOS 2020

Konu: Değerlendirme Sonucu

Gönderen: ODTÜ İnsan Araştırmaları Etik Kurulu (İAEK)

İlgi: İnsan Araştırmaları Etik Kurulu Başvurusu

Sayın Dr.Öğretim Üyesi Arsev Umur AYDINOĞLU

Danışmanlığını yaptığınız **Gökçe NUHOĞLU'nun "Türkiye'nin Bilimsel Araştırımlarında Yüksek Başarımlı Hesaplama Kullanımına İlişkin Politika Önerileri"** başlıklı araştırması İnsan Araştırmaları Etik Kurulu tarafından uygun görülmüş ve **241 ODTU 2020** protokol numarası ile onaylanmıştır.

Saygılarımızla bilgilerinize sunarız.

Prof.Dr. Mine MISIRLISOY
Başkan

Prof. Dr. Tolga CAN
Üye

Doç.Dr. Pınar KAYGAN
Üye

Dr. Öğr. Üyesi Ali Emre TURGUT
Üye

Dr. Öğr. Üyesi Şerife SEVİNÇ
Üye

Dr. Öğr. Üyesi Müge GÜNDÜZ
Üye

Dr. Öğr. Üyesi Süreyya Özcan KABASAKAL
Üye

B. INTERVIEW GUIDE FIRST VERSION

1. Ne kadar zamandır araştırmalarınızda HPC (Yüksek Başarımlı Hesaplama) kullanıyorsunuz?
2. HPC ilk defa kullandığınız zamanı hatırlamaya çalışırsanız; o zamanki araştırma ortamınızdan biraz bahseder misiniz? Nasıl deneyimler edinmiştiniz? Nelerle karşılaşmıştınız?
3. HPC kullanarak yayınlanmış olan makaleleriniz veya bildirilerinizden birkaç örnekle bahseder misiniz?
4. Bu çalışmalarınızda sizi HPC aracını kullanmaya iten şeyler nelerdi?
5. HPC yerine başka bir araç kullanabilir miydiniz? Böyle bir imkân var mıydı?
6. Çalışmalarınızdaki araştırma ortamınızı merak ediyorum. Diğer araştırmacılar ile nasıl bir araya geliyorsunuz? Sizi bu çalışmalarda bir araya getiren etmenler neler?
7. Ne tür kütüphaneler ve diller kullandınız?
8. Bu dilleri ve kaynakları kullanmayı nasıl öğrendiniz?
9. Hiç ulusal merkezlerin kaynaklarını kullandınız mı? Evet ise, lütfen onlara nasıl eriştiğinizi söyler misiniz? Neden bu kaynağı kullanmayı seçtiniz? Bu kaynaklardan nasıl yararlandınız? Ulusal merkezlere erişim konusunda en çok ne hoşunuza gitti?
10. Hiç yerel kaynakları kullandınız mı? Evet ise, lütfen onlara nasıl eriştiğinizi söyler misiniz? Neden bu kaynağı kullanmayı seçtiniz? Bu kaynaklardan nasıl yararlandınız? Yerel kaynaklara erişim konusunda en çok ne hoşunuza gitti?
11. Hiç yurtdışı kaynaklarını kullandınız mı? Evet ise, lütfen onlara nasıl eriştiğinizi söyler misiniz? Neden bu kaynağı kullanmayı seçtiniz? Bu kaynaklardan nasıl yararlandınız? Yurtdışı kaynaklarına erişim konusunda en çok ne hoşunuza gitti?
12. Gelecekteki çalışmalarınızda kaynaklar, erişim, işbirliği gibi konularda neler dilerdiniz/nasıl ortamlar, durumlar, kaynaklar olsun isterdiniz?

C. INTERVIEW GUIDE SECOND VERSION

1. Ne kadar zamandır araştırmalarınızda HPC (Yüksek Başarımlı Hesaplama) kullanıyorsunuz?
2. HPC ilk defa kullandığınız zamanı hatırlamaya çalışırsanız; o zamanki araştırma ortamınızdan biraz bahseder misiniz? Nasıl deneyimler edinmiştiniz? Nelerle karşılaşmıştınız?
3. HPC kullanarak yayınlanmış olan makaleleriniz veya bildirilerinizden birkaç örnekle bahseder misiniz?
4. Bu çalışmalarınızda sizi HPC aracını kullanmaya iten şeyler nelerdi?
5. HPC yerine başka bir araç kullanabilir miydiniz? Böyle bir imkân var mıydı?
6. Çalışmalarınızdaki araştırma ortamınızı merak ediyorum. Diğer araştırmacılar ile nasıl bir araya geliyorsunuz? Sizi bu çalışmalarda bir araya getiren etmenler neler?
7. İşbirliğinizin test edildiği oldu mu? Kötü giden durumlarla nasıl başa çıktınız?
8. Kişisel olarak neye göre collaborator seçiyorsunuz?
9. Hiç ulusal merkezlerin kaynaklarını kullandınız mı? Evet ise, lütfen onlara nasıl eriştiğinizi söyler misiniz? Neden bu kaynağı kullanmayı seçtiniz? Bu kaynaklardan nasıl yararlandınız? Ulusal merkezlere erişim konusunda en çok ne hoşunuza gitti?
10. Hiç yerel kaynakları kullandınız mı? Evet ise, lütfen onlara nasıl eriştiğinizi söyler misiniz? Neden bu kaynağı kullanmayı seçtiniz? Bu kaynaklardan nasıl yararlandınız? Yerel kaynaklara erişim konusunda en çok ne hoşunuza gitti?
11. Hiç yurtdışı kaynaklarını kullandınız mı? Evet ise, lütfen onlara nasıl eriştiğinizi söyler misiniz? Neden bu kaynağı kullanmayı seçtiniz? Bu kaynaklardan nasıl yararlandınız? Yurtdışı kaynaklarına erişim konusunda en çok ne hoşunuza gitti?
12. HPC kaynaklarına erişimde veya kullanımda yardım aldınız mı? Evet ise, neden ihtiyaç duydunuz? Yardım alma süreciniz nasıldı?

13. Proje fonları, destekleri gibi başvurularınız oluyor mu? Bunun kaynak erişimine etkisi nasıldır? Bunun işbirliklerinize etkisi nasıldır?
14. Kullandığınız kaynakların işbirliklerinize etkisi nasıldır?
15. Uluslarası rekabette sizce HPC'nin rolü nedir?
16. Gelecekteki çalışmalarınızda kaynaklar, erişim, işbirliği gibi konularda neler dilerdiniz/nasıl ortamlar, durumlar, kaynaklar olsun isterdiniz?

D. CODEBOOK

1. Research
    - Motivations
        - research question
        - high computational need
        - precision and accuracy
        - converging to reality
    - Benefits
        - research facilitation
        - popularity of HPC
        - easiness of computation
        - reputation
    - Challenges
        - fierce competition
2. Collaboration
    - Types of Collaboration
        - topic-based
        - needs-based
        - complementary
        - student-instructor
    - Facilitators
        - expert collaborator
        - Output-oriented approach
        - punctual collaborator
        - previously known collaborator
        - wide social network
        - congresses
        - virtual tools

- Barriers
    - lack of HPC awareness
    - authorship disputes
    - lack of a common scientific language
    - lack of mutual interest
    - lack of mobility
- Effects of Resource on Collaboration
    - group size
    - international collaboration
    - authorship tied to HPC ownership

3. Resource
    - Turkey's HPC Power
        - TOP-500
        - exascale
        - huge investment
    - Local and Central Resource Allocation
        - high computing power
        - q-time
        - dividing computations
        - off-peak hours
        - installations
        - technical staff
        - infrastructure
        - idle
        - certain group
    - Allocation of a Resource to Users
        - prioritization
        - commission
    - Field-specific Center
        - specify fields
    - Allocation with Supports
        - hour-based usage
        - priority code

    - membership fee
    - inapproriate practices

4. Disciplinary Gaps
    - Technical Support
        - help of center staff
        - communication with staff
        - academic staff
    - Education
        - no account for students
        - hands-on training
    - Human Resource
        - Qualified researchers
        - lack of staff
    - Development of HPC tools
        - software fees
        - platforms with fees
        - resource scarcity of developers

E. TURKISH SUMMARY / TÜRKÇE ÖZET

Literatürde, büyük veri araştırmalarındaki işbirliklerine ilişkin birçok çalışma bulunmaktadır. Büyük verinin özellikleri birçok gelişmiş araçların kullanılması gibi birçok zorluğu beraberinde getirir (Chen ve Zhang, 2014; Patgiri ve Ahmed, 2017). Bu zorlukları giderebilecek araçlardan biri Yüksek Başarımlı Hesaplamadır (HPC). HPC, aynı anda gerçekleştirilecek bir dizi hesaplama işlemini veya karmaşık bir sorunu, işlemciler ve bellek gibi temel fiziksel bileşenler üzerinde işler. Bir HPC sisteminin yönetimini sağlayan sistem yazılımı ve programlama modelleri, paralellik ve dağıtım açısından geleneksel bilgisayardan farklılık göstermektedir (Sterling ve diğerleri, 2018).

Bilimsel araştırmaların, çığır açan projelerin ve yenilikçi icatların en büyük trendlerinden biri, Yüksek Başarımlı Hesaplama (HPC) uygulamalarıdır. HPC merkezlerine yapılan yatırımlar, Çin, Fransa, Birleşik Krallık, Amerika Birleşik Devletleri ve İtalya gibi ülkelerin bilimsel çalışmalarının mevcut verimliliğini ve ölçeğini önemli ölçüde etkilemektedir (Joseph ve diğerleri, 2013; Ludwig, 2012). Dijital ekonominin vazgeçilmezi olan dijital yenilikler için kullanılan HPC, dijital yeniliklerin birçok sektörde benimsenmesini teşvik ederek ekonomik büyümeyi ve rekabeti iyileştirmektedir (Gigler, Casorati ve Verbeek, 2018).

Halk sağlığı, iklim değişikliği, deprem gibi sosyal sorunları çözmek için HPC çalışmaları yapılmaktadır (K. Lee ve Lee, 2021). Küresel dijital dünyanın temel sorunlarına akılcı çözümler bulmak için büyük veri işlemeye olan talep artmakta ve bu talepleri karşılamak için etkili bir araç olarak HPC tercih edilmektedir (Sterling ve diğerleri, 2018). Büyük verinin hızla gelişmesine bağlı olarak birçok sektörde kullanılan HPC çalışmalarına olan ilginin daha da artması beklenmektedir (Gigler, Casorati ve Verbeek, 2018).

HPC ile yapılan çalışmalar oldukça rekabetçi bir ortamda gerçekleşmektedir (Usman ve diğerleri, 2018). Bu ortamda çeşitli alanlardan araştırmacılar bir araya gelerek araştırma işbirlikleri kurmaktadır. Böylece HPC merkezlerinin ve araştırmacıların bir araya geldiği ortamların önemi artmıştır (Khan ve diğerleri., 2019).

Avrupa Birliği'nin 2016 HPC Strateji Uygulama Yönetmeliği'nde HPC, yeni küresel dijital ekonomiye güç veren motor olarak kabul edildi. Çeşitli uygulamaları ve sektörleri birbirine bağlayan dijital bir ekonomide büyük miktarda veri üretilir, taşınır, depolanır ve işlenir; bu da önemli bir hesaplama gücü ihtiyacını beraberinde getirir. Artan sayıda uygulama ile bilgi işlemin doğası da değişiyor. Bu nedenle, HPC ile araştırmaya yönelik verimli politikaların uygulanması büyük önem taşımaktadır (Avrupa Komisyonu, 2016).

Günümüzde karmaşık araştırmalar, çığır açan buluşlar ve büyük bilim projeleri işbirlikleriyle gerçekleştirilmektedir (Price, 1963). Bu nedenle, bu tezde işbirliğine ilişkin HPC ile araştırmanın doğası araştırılmıştır. İşbirliği, büyük verilerle araştırma ve karmaşık hesaplama ihtiyacını karşılayan HPC'nin doğasında vardır. HPC ile araştırma yapan bilim toplulukları bir araya gelmektedir. Aynı zamanda araştırmalarını yayınlayabilecekleri ve proje yapabilecekleri verimli ortamlarda buluşmaktadırlar. Bu verimli ortamlar HPC kullanımını kolaylaştırır.

Bu tezde HPC kullanılan araştırma ortamı, işbirliği çerçevesinde incelenmektedir. HPC kullanılarak çok sayıda karmaşık veri kullanılarak veya birçok farklı disiplinden çeşitli formlarda veriler kullanılarak araştırmalar yapılabilir. HPC, simülasyon ve veri madenciliği gibi birçok farklı amaç için çeşitli bilimsel alanlarda kullanılmaktadır (Götz, 2017).

Bu tezde işbirliği konusunda Türkiye'nin HPC araştırma ortamı tartışılmaktadır. Ancak, işbirliği kapsamlı bir kavramdır. HPC ile yapılan araştırmalarda birçok farklı boyutta işbirliği ile karşılaşılabilmektedir. İşbirliği alandan alana farklılık göstermektedir. Örneğin, HPC'nin yoğun olarak kullanıldığı fizik alanında (Götz ve diğerleri, 2017) ve biyomedikalde çok yazarlı yayınlar öne çıkıyor. Ancak bu yayınlar için yapılan çalışmaların ne kadarının "gerçek işbirliği" olarak kabul edilebileceği tartışma konusudur (Cronin, 2001). Bir yayında çok sayıda ismin olması ortak çalışma yapıldığı anlamına gelmeyebilir (Canals ve diğerleri, 2017).

Bennett'in işbirliği tanımına göre, araştırmacılar birbirleriyle etkileşime girmelidir (Bennett ve diğerleri, 2018). Bununla birlikte, HPC ile araştırma, çok farklı işbirliği ihtiyaçları gerektirebilir. Çok disiplinli çalışmalarda olduğu gibi iş bölümü veya disiplinler arası işbirliği gerektiren durumlarda bir bilgisayar bilimcisi ile işbirliği, HPC ile yapılan araştırmalarda oldukça yaygındır (Hu ve Zhang, 2017). Bu nedenle, bu tezde işbirliği kavramı çok fazla daraltılmamıştır. Sentez halinde çalışmasalar bile HPC ile işbirliği içinde iş bölümü gibi ihtiyaçlar, araştırmacıların birbirlerine olan ihtiyacının göstergesidir. Ayrıca, bilimsel işbirliğini etkileyen birçok faktör vardır. İşbirliğine dayalı bilimsel çalışmalarda güven, çatışma, rekabet ve iletişim literatürde farklı açılardan incelenmektedir.

Tüm bunlar göz önüne alınarak tezin araştırma sorusu *Türkiye'nin işbirliği bakımından HPC ortamını nasıl oluşturması gerektiği* olarak sorulmuştur. Büyük verinin doğası gereği HPC çalışmalarına ihtiyaç duyulmaktadır. Bir gereklilik olarak, karmaşık araştırma soruları, birçok farklı disiplinden araştırmacıyı bir araya getirerek işbirliğini gerektirir. Küresel bilim camiasının giderek artan işbirlikçi yapısı, HPC ekosistemlerinde aranan nitelikleri de çeşitlendirmektedir. Araştırma ortamının işbirlikçi doğası, birçok karmaşık parametreyi beraberinde getirmektedir. İnsan doğası, altyapı sorunları, kariyer hedefleri ve finansman ihtiyaçları gibi parametreler, işbirliği ortamı üzerindeki etkileri açısından literatürde birçok çalışma olmasına karşın bu tezde çalışmalar sadece araştırma sorusu doğrultusunda daraltılmıştır. Literatürde HPC ortamlarının araştırma sonuçları üzerindeki etkisi araştırılsa da, HPC'nin işbirlikçi araştırmalar üzerindeki etkisi açısından araştırmalar yetersizdir. İşbirliği temelinde HPC ekosistemleri hakkında literatürde boşluk bulunmaktadır.

Analiz süreci, istatistiksel veri elde etmek veya herhangi bir nicel bulguyu desteklemek için karşılaştırmalara dayanmıyor. Bu nedenle, analiz keşif odaklıdır. Amaç, gerçeği inşa etmek için bireylerin bakış açılarını elde etmektir. Bu nedenle nitel veri toplama için görüşme yöntemi seçilmiştir.

Görüşmeler McCracken'in (1998) “Long Interview” yöntemine göre yapılmıştır. Bu yöntem sayesinde araştırmacılar deneyimlerini, ilişkilerini ve algılarını kendi bakış açılarından kendi sözcükleriyle aktarabilmektedirler. Böylece, Türkiye'deki HPC araştırmalarının eğilimleri hakkında yoğun veri toplanması amaçlanmaktadır.

Örneklemdeki temel ölçüt, araştırmalarında HPC kullanan Türkiye'deki bir üniversiteye bağlı araştırmacılardır. Bilimsel kullanım için iki ulusal HPC kaynağı vardır: UHEM (Ulusal Yüksek Başarımlı Hesaplama Merkezi) ve TRUBA (Türkiye Ulusal e-Bilim e-Altyapısı). TRUBA, kullanıcıların çalışmalarını içeren kitapçıklar yayınlamaktadır. UHEM kullanılarak yapılan yayınlar, UHEM'in web sitesinde (UHEM (National Center for High Performance Computing), 2022) atıf bilgileriyle birlikte listelenmektedir. Örnekleme için, ulusal HPC kaynaklarını kullanarak yayın yapan araştırmacılar rastgele seçilmiş ve e-posta ile görüşme daveti gönderilmiştir. Ayrıca, katıldığım çalıştay ve konferans katılımcılarına da rastgele e-postalar gönderdim. Geri dönenlerle görüşmeler yapılmış ve ardından diğer görüşmecileri bulmak için kartopu örnekleme yöntemi uygulanmıştır. Ancak TRUBA ve UHEM dışındaki HPC kaynaklarını kullanan araştırmacılarla görüşme ihtiyacı doğmuştur. Ayrıca, kartopu örneklemesinde yanlılığı önlemek için farklı alanlardan araştırmacılarla görüşme yapılması gerekliliği göz önünde bulundurulmuştur.

16 araştırmacı ile görüşmeler yapılmıştır. Görüşülen kişilerin araştırma alanları Fizik, Makine Mühendisliği, Havacılık ve Uzay Mühendisliği, Bilgisayar Mühendisliği, Biyofizik, Biyokimya, Biyoinformatiktir. Görüşülen kişiler, araştırma görevlilerinden profesörlere kadar değişiyordu.

Görüşmelerden biri 24 dakika sürmüştür. Diğer görüşmelerin uzunlukları 35 dakika ile 75 dakika arasında değişmektedir. Ortalama olarak, görüşmeler yaklaşık 50 dakika sürmüştür. Mülakatları hem görüşmecilerin hem de kendi anadilim olan Türkçe yaptım. Ana dilde konuşmanın avantajı olarak herhangi bir anlaşmazlık veya karışıklık ortaya çıkmadı. Görüşmeler Ocak 2021'den Mayıs 2021'e kadar gerçekleşti.

Tüm görüşmeleri kelimesi kelimesine işledim. Veri kodlama işlemi için Saldaña'nın (2013) birinci ve ikinci döngü kodlama yöntemlerini uyguladım. Tümevarımsal yaklaşıma bağlı kalarak kodları analiz ettim ve notlar ile kümeledim.

Türkiye bağlamında verilerin çok çeşitli olmasına dikkat ettim. Kartopu yöntemi uygularken bazı kriterleri göz önüne aldım. Belirli bir alanda çalışmış olan araştırmacılar bir önyargı yaratabilmektedir. Bu nedenle farklı alanlardan araştırmacılar seçilmiştir. Görüşmeler gerçekleştikçe kaynak kullanımı ön plana çıkmıştır. Araştırmacılarla belirli bir kaynak etrafında görüşme yapmak yanlılığa neden olabilir. Bu nedenle, farklı kaynaklar kullanan araştırmacılar kartopu yönteminde göz önüne alındı. Sadece Türkiye'nin büyük ve köklü üniversitelerindeki araştırmacılarla görüşmek de bir yanlılık yaratacaktı. Bu önyargı, özellikle politika oluşturma açısından ciddi eşitsizlik yaratabilir. Bu önyargıyı ortadan kaldırmak için Anadolu'daki birçok farklı üniversiteden araştırmacılar kartopu yöntemi uygularken göz önüne alındı.

Tezde toplanan verilerin değerini göstermesi açısından bahsetmek gerekir ki görüşülen araştırmacıların çoğu HPC merkezi yönetiminde deneyime sahiptir. TOP500 listesinin ilk 10'unda yer alan süper bilgisayarları kullananlar, Avrupa'daki HPC merkezlerinin komisyonlarında yer alanlar ve dünyanın birçok ülkesindeki HPC merkezlerinde yönetici pozisyonunda çalışmış olan araştırmacılar görüşülen kişiler arasında yer almıştır. Görüşülen topluluk o kadar kalifiyeydi ki, veri üretirken çözümler de sundular. Tümevarımsal oluşum yaklaşımı, araştırmacıların deneyimlerini analiz ederken verimli politika önerileri oluşturulmasına yardımcı oldu.

Bulgular dört ana başlık altında toplanmıştır: Araştırma, İşbirliği, Kaynak ve Disiplinlerarası Boşluklar. Türkiye'deki araştırmacıların neden HPC kullandığı sorusunun bulguları Araştırma kümesinde analiz edilmektedir. Motivasyonlar, faydalar ve zorluklar olarak kodlar Araştırma kümesini oluşturmaktadır.

Araştırma başlığında bahsedildiği üzere, HPC ile araştırma yapma motivasyonları ile bağlantılı olarak işbirlikleri kurulur. Karmaşık problemler ve bu problemlerden kaynaklanan yüksek hesaplama ihtiyaçları işbirliklerini gerektirmektedir. Karmaşık problemlerin çözümünde kullanılan HPC, doğal olarak birçok araştırmacının, hatta birçok farklı disiplinden araştırmacının karmaşık problem çözmede bir araya gelmesini sağlar.

İşbirliği, HPC ile araştırmanın doğasında vardır. HPC ile araştırma soruları ve araştırma ortamı doğal olarak işbirliği gerektirir. HPC ile işbirliklerinin tipleri, kolaylaştırıcı ve engelleyici faktörleri, ve HPC kaynağının işbirliğine etkisi kodlarıyla kümelendirilerek analiz edilmiştir.

Türkiye'deki sınırlı HPC kaynak kapasitesi, araştırmacıları uluslararası işbirliğine iterek başka birçok soruna neden oluyor. Bu sorunlar Kaynak başlığında detaylıca analiz edilmiştir. Türkiye'deki HPC kaynak kıtlığının Türkiye'nin araştırma ortamı üzerindeki derin etkileri bu çalışmada ortaya çıkmıştır.

HPC ile yapılan çalışmalar, yüksek hesaplama ihtiyaçlarını karşılayabilecek kaynaklara erişim ihtiyacı doğurur. Türkiye'nin HPC kaynakları araştırma üretimi açısından kısıtlıdır. Türkiye'deki araştırmacılar, araştırma sorularını ve projelerini yetersiz kapasiteye göre seçip yeni proje ve araştırmaları elemektedir. Bu, araştırmacıların popüler konularda yayın yapmasını engellemektedir. Türkiye'deki HPC kaynakları göz önüne alındığında, uluslararası rekabette Türkiye HPC araştırma ortamı rekabette geri kalmıştır.

Türkiye'deki araştırmacıların HPC araştırmalarındaki disiplinlerarası boşlukları nasıl kapattıkları sorusuna da yanıt aranmıştır. Mülakatlardan elde edilen bulgular bu soruya özel olarak analiz edilip dört kümede toplandı: Teknik destek, eğitim, insan kaynakları ve HPC araçlarının geliştirilmesi. Görüşülen kişiler, yazılım ihtiyaçları nedeniyle yurt dışında belirli alanlara özel platformların kurulmasından ve bu platformlar üzerinde büyük ölçekli işbirliklerinin kurulmasından bahsetti. Görüşmeciler, kendi alanlarına özel yazılımlar geliştirmek için kullandıkları platformların büyük ölçekli işbirliklerine ev sahipliği yaptığını belirtti. Ancak görüşülen kişiler, yurtdışındakilere benzer bu tür platformların ülkemizde olmadığını iddia etti. Geliştiriciler ve hatta görüşülen gruptaki geliştirici olmayan kullanıcılar, Türkiye'de geliştirici olmanın zor olduğunu belirtiyor. HPC'ye olan ihtiyaç artıyor. Dünya çapında durum böyleyken, araştırmacıları bir araya getirebilecek yenilikçi bir yazılım geliştirme ortamı, politika eksikliği ve kaynak kıtlığı nedeniyle Türkiye'de mümkün görünmemektedir.

HPC araştırma ortamı için yazılım geliştirmenin önemi ve bilim camiasına katkısı gün ışığına çıktı. Bu noktada geliştiricilerin kullanımına uygun platformlar, disiplin boşluklarını kapatmak için etkili bir yol sağlar. Bu platformlar işbirliğini kolaylaştırır ve araştırma ortamına katkıda bulunur.

Literatürde Türkiye'deki araştırmacıların neden işbirliği yaptığına ilişkin olarak itibar kazanma arzusu (Katz ve Martin, 1997; Price, 1963) ve artan kariyer fırsatları (Ynalvez ve Shrum, 2011) gibi bulgular bulunmaktadır. Bu tezin bulguları, araştırmacıların itibar kazanmak için HPC'yi kullandıklarını ortaya koymaktadır. Araştırmacıların işbirliği yaparak ün kazanmanın yanı sıra sadece HPC kullanarak bile ün kazandıkları ortaya çıktı.

Bulgular, HPC kullanan araştırmacıların simülasyonlar veya teorik hesaplamalar ile diğer alanları desteklediğini göstermektedir. Bu araştırmalarda HPC deneyinin bulgularını desteklemeye ihtiyaç olduğu görülmektedir. Öte yandan, HPC ile elde edilen sonuçlar deneylerle de test edilebilir. Bu anlamda HPC, birçok farklı alanda araştırmayı kolaylaştırmaktadır. Bu nedenle, HPC kullanan araştırmacılar, doğal olarak birçok farklı alandan araştırmacılarla işbirliği yapmaktadır. Araştırmacılar yalnızca deneysel bir çalışma veya yalnızca hesaplamalı bir çalışma yayınlayabilirken, işbirliği ile daha kaliteli çalışmalar üretmeyi ve böylece tanınmış dergilerde yayınlayabilmeyi amaçlamaktadırlar. HPC işbirlikleri sadece alanların birbirini desteklemesi için yapılmıyor. HPC çalışmaları doğası gereği karmaşık soruları yanıtlamak için kullanılır. Araştırmacıların tek başına yanıtlayamayacağı kadar karmaşık olan sorular, işbirliği ihtiyacını doğuruyor. Bu nedenle, HPC ile yapılan araştırmalarda disiplinler arası çalışma esastır. Bulgular bu konuda literatürü desteklemektedir (Hara ve diğerleri, 2003; Iglič ve diğerleri, 2017; Morrison, 2017).

Öncelikle bu tezde işbirliğinin geniş bir perspektiften ele alındığını belirtmek gerekir. Araştırmada işbölümü olsa da işbirliği olduğu düşünülmektedir. Türkiye'de HPC kullanan işbirliklerinde iletişim büyük önem taşımaktadır. Bu sonuç, işbirliklerinde iletişimin önemsiz görüldüğü çalışmalarla çelişmektedir (Chompalov ve diğerleri, 2002; Evans ve Marvin, 2006; Lowe ve Phillipson, 2009). Leahey ve Reikowsky'nin (2008) iddiasının aksine, bu tezdeki bulgular, keskin bir işbölümü olduğunda bile iletişimin işbirliği için önemli olduğunu ortaya koyuyor. Hampton ve Parker'ın (2011) argümanını destekleyerek, yüz yüze iletişimin işbirliğini güçlendirdiği ortaya çıkmıştır.

Türkiye'nin HPC araştırma ortamında sentez çalışma ortamı olmasa da iş bölümü ile disiplinler arası çalışmalarda işbirlikleri kurulabilir (Bennett ve Gadlin, 2014; Hackett ve diğerleri, 2019; Hampton ve Parker, 2011). Türkiye'nin HPC araştırma ortamında çok sayıda farklı işbirlikçiyi bir araya getiren büyük ölçekli konsorsiyumlar bulmak zordur. Bu nedenle, büyük ölçekli multidisipliner çalışmalar disiplinler arası çalışmalarla karşılaştırılamaz. Ancak, Türkiye'de HPC kullanan işbirliklerinde sentez çalışma ortamı olmasa da iletişim ve güvenin esas olduğu kesin olarak söylenebilir. Bu bulgu Aydınoğlu (2013) tarafından yapılan çalışma ile uyumludur.

Yüz yüze görüşmeler yoluyla işbirliğinde güven oluşturmak çok önemlidir. Bu sonuç birçok çalışma tarafından desteklenmektedir (Bennett ve Gadlin, 2014; Bennett ve Gadlin, 2012; Disis ve Slattery, 2010; Hall ve diğerleri, 2012; Wagner, 2018). Ayrıca, bu tezde de ortaya konduğu gibi, daha önce güvenilen insanlarla işbirliği yapma arzusu, araştırmacılar arasında yaygındır. Bu sonuç, Shrum et al. (2001) ve Iglič et al. (2017) argümanlarına tezat oluşturur. Bulgulara göre, araştırmacıların zaten tanıdıkları insanlarla (Harris ve Lyon, 2013; Maglaughlin ve Sonnenwald, 2005; Sonnenwald, 2007) işbirliği yapma olasılıkları daha yüksektir. İşbirliği yaptıkları insanlarla tekrar tekrar işbirlikleri kurarlar.

Ek olarak, araştırmacıların değişen çıkarları çatışmaya yol açabilir ve hatta bir sonuca varmadan işbirliğini sonlandırabilir. Araştırmacıların ilgilerinin önemi Kim (2017) ve Atkinson ve diğerleri. (1998) çalışmalarıyla tamamen uyumludur. Morrison (2017) tarafından gösterilen mütekabiliyet, Türkiye'de HPC kullanılarak yapılan araştırmalarda işbirliği için de esastır. Ayrıca, güven hususu işbirliklerinde kritiktir (Bennett ve Gadlin, 2012; Wagner, 2018). Çatışmalar Türkiye'deki HPC araştırma ortamını beslemiyor ve daha iyi sonuçlara yol açmıyor (Centellas ve diğerleri, 2014).

Bu tezde, araştırmacıların işbirliği yaparken yeni ve popüler çalışmalar yapmak istedikleri tespit edilse de, HPC kaynaklarının eksikliği bu hedefin önünde önemli bir engeldir. Türkiye'deki araştırmacılar, HPC kaynak kıtlığı nedeniyle yenilikçi araştırma sorularını ortadan kaldırıyor. Çünkü soru ne kadar karmaşıksa, o kadar güçlü kaynaklara ihtiyaç duyuluyor. Ayrıca işbirliklerini yayınlar üzerine planlayan araştırmacı, kaynak yetersizliğinden dolayı bulgularını yayımlamakta zorlanıyor. Türkiye'de ağırlıklı olarak yayın odaklı HPC kullanan araştırmacılar, en çok önemsedikleri konuda engellerle karşılaşmaktadır.

Apon ve diğerleri. (2014) çalışmasında da görüldüğü gibi yüksek talep nedeniyle yerel kaynaklara sahip merkezler Türkiye'de de mevcuttur. Yerel merkezlerin tahsisi faydalı görünse de dağınık yapıları Türkiye'de kaynak israfına yol açmaktadır. Ayrıca Türkiye'de yerel merkezlerin altyapı yükünü bilim insanlarının üstlenmesi durumu, kapsayıcı bir politikanın olmadığının kanıtıdır. Aksine, işbirliğini kolaylaştırmak için farklı konumlardaki yerel merkezleri verimli HPC altyapısı dağıtımıyla birbirine bağlayan yurt dışında örnekler vardır (Alvarez ve diğerleri, 2007; Fitzgerald ve diğerleri, 2007, pp. 55–113; Khan ve diğerleri, 2019). ; Kuraishi ve diğerleri, 2014; Navarro ve diğerleri, 2017).

Kaynak tahsisi uygulamaları ile ilgili analizlerde ortaya çıkan bir diğer durum ise alana özel merkez tahsisleridir. Bu tezin de ortaya koyduğu gibi, farklı alanların farklı donanım ve yazılım ihtiyaçları olabilir. Alana özgü merkez tahsislerinin dünyada örnekleri vardır. Japonya'nın K süperbilgisayarı, nanoteknoloji ve yaşam bilimi alanlarına adanmıştır (Yonezawa ve diğerleri, 2011). Brezilya'nın yalnızca biyoinformatik odaklı ulusal HPC ağı BioinfoPortal'dır (Ocaña ve diğerleri, 2020). EuroHPC JU bünyesindeki süperbilgisayarların teknik yetenekleri ve uygulama alanları kamuya duyurulmaktadır. Avrupalı kullanıcılar, hangi süper bilgisayarda hangi hesaplamaların yapılabileceğini bilerek çalışmaları için ilgili merkezlere yönelmektedir (EuroHPC JU, 2021). Aynı alana özgü enstitüler bünyesinde alana özgü merkezlerin kurulduğu ve bu sayede işbirliklerinin teşvik edilerek alandaki bilimsel çalışmaların kolaylaştırıldığı görülmektedir (Rathje ve diğerleri, 2020; Zafeiropoulos ve diğerleri, 2021).

Ek olarak, bir HPC kaynağının kullanıcılara tahsisi için dünyada önceliklendirme politikaları vardır. Tezin bulguları bu politikalarla örtüşmektedir. Önceliklendirmeler, yetkin bir komitenin kararları doğrultusunda yapılır. Örneğin, Japonya'nın K süper bilgisayarı, Japon Eğitim, Kültür, Spor, Bilim ve Teknoloji Bakanlığı (MEXT) komitesi tarafından kullanım için önceliklendirilmiştir (Yonezawa ve diğerleri, 2011). Bir başka örnek vermek gerekirse, Çin, klasik HPC merkezi tahsisine ek olarak önceliklendirme ile kullanıcılara kaynak tahsis etmektedir. Ayrıca ek kaynakların birbirine bağlı platformlar üzerinde işbirliğini teşvik edecek şekilde sunulması da tahsis yöntemleri arasında yer almaktadır (Xu ve diğerleri., 2016).

Disiplinlerarası boşlukları kapatmak için genel olarak bilim camiasında merkez personelinin ve insan kaynaklarının önemi bu tezde ortaya çıkmıştır. Bulgular, merkez personeli de dahil olmak üzere HPC merkezlerinde işbirliğini teşvik etmek için platformların kurulmasına ilişkin literatürü desteklemektedir (Connor ve diğerleri, 2016; Goscinski ve diğerleri, 2015; Nystrom ve diğerleri, 2015 Türkiye'de HPC kullanan araştırmalarda işbirlikleri, literatürde bahsedildiği gibi disiplinler arası boşlukları kapatmak için sadece bilgisayar bilimcileri ile kurulmamaktadır (Hu ve Zhang, 2017; Lazer ve diğerleri, 2009). İşbirlikleri, tezde incelendiği gibi, HPC'nin doğası gereği genellikle interdisipliner bir şekilde kurulur. Bilimin ortak çaba gerektirdiği bu ortamda, Türkiye'deki disiplinler arası boşluklar, birçok farklı çabayla kapatılmaya çalışılmaktadır. Analiz sonucunda Türkiye'de disiplinler arası boşlukların kapatılmasına yönelik çalışmaların merkez personelinin desteği, eğitim faaliyetleri ve kullanıcı dostu HPC araçlarının geliştirilmesi ile yapıldığı görülmüştür. Bunların gerçekleşmesinin önünde birçok engel olduğu bulgular bölümünde açıklanmıştır. Kaynak eksikliği bu engellerin temeli gibi görünse de, politika eksikliği her şeyin üzerindedir. İnsan kaynaklarıyla ilgili sorunlar ve eğitimlerindeki politika eksiklikleri bilim camiasına zarar vermekte ve araştırma ortamının gelişmesini engellemektedir. Bu sonuçlar Hey ve Trefethen'in (2005) iddialarıyla örtüşmektedir. Onların iddialarına göre disiplinler arası açıkları kapatmak için ortak bir çabaya ihtiyaç vardır ve araştırmacıların bir araya gelmesini sağlayan altyapıların çözüm olduğunu vurgulanmıştır.

TRUBA ve UHEM, başta eğitim ve insan yetiştirme olmak üzere Türkiye'nin sorunlarının çözümünde kilit rol oynamaktadır. Bulgularda da ortaya konduğu üzere, TRUBA ve UHEM aracılığıyla verilen eğitimler, merkez personelinin tecrübeleri ve AB destek programlarının sağlanması ile birçok konuya çözüm getirmektedir. AB programları açısından UHEM, PRACE (Partnership for Advanced Computing in Europe) (PRACE, 2020) ve TRUBA EuroHPC JU (European Comission, 2019) üyesidir. Ancak bulgular, merkez personel sayısının yetersiz olduğunu göstermektedir. Ayrıca, belirli bir komisyon veya konseyin değerlendirmeleri doğrultusunda, kaynak tahsisi de dahil olmak üzere, eğitim için ülke çapında bir politika eksikliği bulunmaktadır. İyi yetişmiş insan kaynağının değerlendirilmesi ve belirli politikalar doğrultusunda ortak bir platformdan eğitim ve desteğin sağlanması hayati önem taşımaktadır.

Bu tezde önerilen politika yapısı üç sütundan oluşur: konsolidasyon, alana özgü ortak merkezi kaynaklar, ortak platform ile topluluk oluşturma. Bu yapı, bu tezdeki analizler doğrultusunda oluşturulmuştur.

HPC kullanılan araştırmalarda işbirliği ve disiplinlerarasılık doğal olarak ortaya çıkar. Bu durum, HPC kullanan araştırmaların birbirlerinin çalışmalarını desteklemesi veya yeni ve karmaşık bir soruna çözüm bulmak için birçok alandan araştırmacılara ihtiyaç duyulması gibi sebeplerle bu tezde analiz edilmiştir.

HPC çalışmalarından verim alınması, güvene dayalı bir işbirliği ortamının oluşturulmasına bağlıdır. Bunu güçlendirmek için araştırmacıların bir araya geldiği ortamlar sağlamanın önemi ortaya çıkıyor. Bunu sağlamak için temel olarak HPC merkezleri ele alınmalıdır. Araştırmacıların merkezler etrafında bir araya gelmesi önemlidir.

Merkezler aracılığıyla HPC kaynaklarının sağlanması, derin politika çıkarımları gerektirir. Yerel kaynakların araştırmacılara teknik yük getirmesi, altyapı sorunları, küçük kapasite nedeniyle büyük ölçekli projelerin gerçekleştirilememesi gibi sorunların olduğu ortaya çıkmıştır. Tüm bunlara rağmen, Türkiye'de merkezi kaynaklarda uzun sıra sorunu yaşamamak için yerel kaynaklar daha çok tercih edilmektedir. Bu kısır döngüden çıkmanın yolu, kaynakların konsolidasyonunun yanı sıra etkin HPC tahsis politikalarının uygulanmasıdır. Ayrıca, HPC ile araştırmalarda işbirliği, Türkiye'deki politika eksikliklerinden zarar görmektedir. Araştırmacılar, araştırmacıların toplandığı üretken ortamlardan yoksundur. Tüm bu sorunların nedenleri bu tezde ele alınmıştır. Bu sorunlara çözüm olarak politika önerilerinde bulunulmaktadır. Önerilen politikalar ortak bir platform temelinde oluşturulmuştur.

Bu tezdeki analizler, alana özgü merkezlerin kurulmasının kaynak ihtiyacının doğru bir şekilde karşılanmasını ve aynı soruna sahip araştırmacıların bir araya gelmesini sağladığını göstermektedir. Belirli alanlarda disiplinlerarası boşluklardan arındırılmış merkez tasarımı, yetkin kişilerden oluşan bir merkez kadrosu içermelidir.

Alana özgü bu merkezler, disiplinler arası çalışmaları teşvik edecek ortak bir platforma bağlanmalıdır. Bulut gibi ortamlarda birbirine bağlı bir altyapı ile fiziksel olarak bağlantılı olan bu platform, araştırmacıların bir araya geldiği etkinlikleri organize eden bir üst platform görevi de görmektedir. Araştırma ortamına yapılabilecek en önemli katkılardan biri topluluk oluşturmaktır. Bu amaca, ortak platform çatısı altında ulaşılabilir.

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