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Original Paper

A Sustainability Model for Continental Hybridization of High Performance Computing (HPC) in Africa

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Abstract

The potential for High-Performance Computing (HPC) opportunities in the areas of health, environment, energy, climate change, business and livelihood are immense in Africa. However, the lack of sufficient HPC facilities and capacity skills deficiencies continue to curtail its growth. This paper maps the status of HPC facilities in Africa. Thereafter based on a review of various business and funding models, it suggests a hybridization model as a way for building sustainable HPC infrastructures across the continent to provide support for teaching and learning, research and education. The main contribution of this paper is the anchoring of hybridization as a sustainable business model for improving the access and establishment of HPC infrastructure in Africa.

Keywords

HPC, IoT, Big data, analytics, hybridization, sustainability

1. Introduction

High-Performance Computing (HPC) also referred to as supercomputing may be considered the applicative use of parallel processing to run advanced algorithms which perform advanced experimental research and innovation. HPC aggregates computing power to enable delivery of high-performance computing power to find solutions for problems in science, engineering, or business that is achievable by workstations. HPC systems would typically function at above a teraflop or floating-point operations per second. An intimate link exists between HPC, big data and development. Globally, computational science relying on HPC has leveraged big data in Artificial Intelligence (AI) and Machine Learning (ML) to deliver advances in sciences, technological and social life. These advances have led to unheralded inventions, innovations and creativity. In this regard, the European Commission (EC) notes a number of fundamental issues in its Digital single market policy on HPC

(EU, 2018):

i. That by 2020, 25 billion devices will be connected and generate over 2 zettabytes of traffic annually. This implies an average of 3 devices1 per human being and each device generating 80 GB of data per year.

ii. Reliance on HPC by industry and Small and Medium Enterprises (SMEs) will increase in order to reduce costs and time for producing and marketing innovative solutions, products and services.

iii. Scientific and technical breakthroughs are increasingly relying on HPC due to demands for higher computing power and capabilities.

iv. A paradigm shift is expected from petascale to exascale HPC by 2022. These will perform one trillion (1018) operations per second. By 2020, pre-exascale computers will be in the market.

v. The development of a continental strategy for improved HPC infrastructure will result in benefits in industries, SME's and creation of new jobs.

Consequently, the main driver for HPC growth is the need to process and analyze big data in faster and innovative ways, to fuel major advances and innovation in the digital age, while providing an understanding of concerns of the citizenry in a modern world. In this regard, some of HPC's key applications have included:

i. Development of personalized medicines based on simulation and molecular sequencing, early detection and treatment of diseases, development of new drugs, and deciphering the function of the human brain using in medicine and pathology.

ii. Human brain mapping using deep learning on HPC platforms.

iii. Forecasting for climate simulations and early warnings including accurate weather forecasts and visualization of tornadoes.

iv. Future smart mobility in autonomous vehicles.

v. Increased agricultural production by enabling farmers to produce more with less input.

vi. Fraud analysis and prevention.

vii. Computational fluid dynamics.

In Africa, the scarcity of HPC resources and gaps in their accessibility over the years is not comprehensively documented (Thiga, 2017; Amolo et al., 2018; Amolo, 2018) nor is it clearly understood. Furthermore, issues that concern what HPC is, how scientists and especially business enterprises can sustainably collaborate with researchers and academia to make sense of their big data have not been clearly discussed and documented. This work thus attempts to map the existing HPC resources in Africa, with a key emphasis on a new concept referred to as hybridization.

Subsequently, this paper seeks to achieve the following objectives;

1. To map HPC cluster systems in sub-Saharan Africa (including South Africa).

2. To develop a potential HPC hybridization conceptual map to effect industry-academia collaboration in the continent.

To achieve the aforementioned objectives, two methodological approaches have been utilized. First is the systematic review of secondary literature on HPC clusters in Africa. Thereafter, mapping of HPC cluster systems has been done to enable development of an evolving hybridization map that provides a sustainable approach towards enhancing HPC infrastructure.

2. Research Methodology

The methodology that this paper adopts is essentially literature review of documentation from both academia and industry, identification of gaps that would be the starting point for the development of comprehensive design strategies and their subsequent implementation across the African continent. It investigates contemporary HPC platforms from a global scale and narrows down to a synopsis of their regional distribution in the African continent with a view towards enabling the reader identify the strengths and weaknesses in their designs.

An analysis of the status mapping activity culminates in the authors' proposition of a hybridization approach, a design and subsequent presentation of details regarding this viable proposition. The authors aver that their proposition is impactful and cost effective taking into consideration resource constraints in the African continent. This approach potentially provides adequate support for flexibility, maintainability and extensibility requirements of next generation HPC platform implementation in Africa to provide support for teaching and learning, innovation and research activities.

It should be noted that the scope of this paper does not cover cluster management, power and/or human resource requirements or investigation of specific load balancing algorithms; rather, its main focus is on providing a general design framework that can accommodate the co-existence and run-time configuration/re-configuration of multiple HPC platform implementations which suit a range of the continent's research and innovation requirements in a financially sustainable way.

2.1 Technology Description

In this paper, a HPC framework is considered as a multi-node and multi-CPU system with a minimum of teraflop or 1012 floating points operations per second. This HPC framework is essentially configured as illustrated in Figure 1 below.

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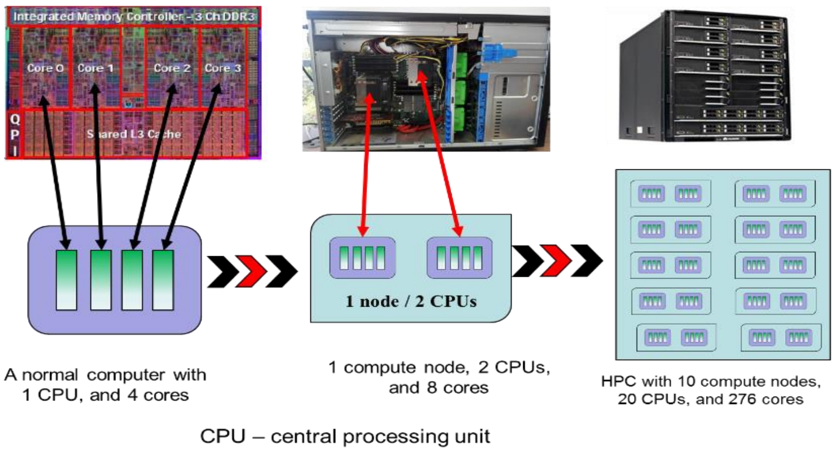

Figure 1. Configuration of an HPC's CPU

Further to the aforementioned, HPC essentially handles large volumes of Big data wherein big data is considered data that is from a wide variety of sources and gets to its destination in increasing volumes and at very high velocity.

The need for a hybridization model and what it means, is based on the current state of HPC infrastructure in Africa and the challenges experienced therein. The distribution and challenges are addressed first, followed by an appreciation of what hybridization is and the potential model it may have.

2.2 Distribution of HPC Infrastructure in Africa

The number of mini or fully-fledged HPC clusters in Africa is limited. An analysis of the top 500 HPC systems globally lists only two systems located in Africa which constitute 0.4% of all top-tier HPC systems in the world. As illustrated in **Table 1** below, Asia has the highest deployments of HPC infrastructure led by China, then followed by the United States of America (USA) in the Americas. In Africa, the two systems are in South Africa, one in Lengau which is publicly owned and another private one operated by Lenovo Software Company

Table 1. Continents Share of top 500 HPC Systems Globally (System, 2018)

Continents	Count	System Share (%)	Rmax (GFlops)	Rpeak (GFlops)	Cores
Asia	276	55.2	602,704,077	1,059,161,713	34,089,716
Americas	119	23.8	548,360,120	781,028,806	16,576,400
Europe	97	19.4	254,160,835	358,680,537	8,073,050
Oceania	6	1.2	7,578,080	11,658,371	275,896

Africa	2	0.4	2,152,470	2,779,930	71,256

The main HPC systems in the sub-Saharan subcontinent (SSA) are found in South Africa where there are four systems as shown in Table 2 below, one of which (the Tsessebe), was decommissioned, disaggregated and sent to a number of other African countries including Kenya under the Square Kilometre Array (SKA) programme.

System	Year	Cores	Rmax (GFlop/s)	Rpeak (GFlop/s)
Lengau - PowerEdge C6320, Xeon E5-2690v3 12C 2.6GHz, Infiniband FDR	2016	32,856	1,029,320	1,366,810
Tsessebe - Blade X6275/ PowerEdge C6100 Cluster, Xeon X5570/X5670/ 4C 2.93 GHz, Infiniband QDR	2009	6,336	61,330	74,257.9
Blue Gene/P Solution	2008	8,192	23,415	27,850
Lenovo C1040, Xeon E5-2673v4 20C 2.3GHz.	2018	38,400	1,123,15	1,413,12

Figrue 1. Technical Specifications of the South African HPC Systems

Considering publicly available data, about 20% (11 out of 55) of African countries may have some form of HPC. Table 3 below identifies some of these countries and their respective HPC systems. Nigeria, Morocco, Libya, Tanzania and Burundi have an HPC Inspur system from China (Dong, 2016). Data on the technical specifications of the system is however not readily available.

Table 2. Publicly Owned Available Mini and Fully Fledged HPC Clusters in Sub-Saharan Africa (Amolo, 2018; Adllan, 2014; KENET, 2018).

South Africa - Centre for High-performance computing (CHPC)	Lengau	Texas Advanced Computing Centre (TACC)
Sudan – HPC & Grid computing Centre at the Africa City of Technology	Inspur TS10000	Potentially was a collaboration between China and Sudan. The system from Inspur.
University of Zimbabwe's Zimbabwe Centre for High-Performance Computing (Zim-CHPC)	Inspur	A loan from the Chinese government The system from Inspur- a Chinese firm.

Square Kilometre Array (SKA) partner countries - Kenya and Ghana.	Tsessebe	South Africa - Centre for High-Performance Computing (CHPC). CHPC has used it for over 5 years and got it from Texas Advanced Computing Centre.
Kenya (USIU-Africa, Nazarene University & UoN)	2 core Mini HPC	Intel Corporation East Africa (EA)
Cheikh Anta Diop University (UCAD) in Dakar, Senegal	Grid computing	n/a
Kenya, ILRI	Access only to a supercomputer	Michigan State University (MSU)
KENET, Kenya.	Africa Grid science gateway	Provides a gateway to grid computing facilities.

2.3 Design and Current utilization of HPC Systems in Africa

The existing HPC clusters have the following historical and current utilization as depicted in **Table 3** below.

Table 4. Design and Current utilization of Africa's HPC Clusters

South Africa - Centre for High-performance computing (CHPC) Lengau	Modelling in Astrophysics, bioinformatics, chemistry, mechanics, computer sciences, Earth, Image processing, material sciences, Physics and space.	
Sudan – HPC & Grid computing Centre at the Africa City of Technology	Modelling in basic sciences	Not known
University of Zimbabwe's Zimbabwe Centre for High-Performance Computing (Zim-CHPC)	Part of Tsessebe work clusters	Undertake Astronomy studies
Square Kilometre Array (SKA) partner countries of Kenya and Ghana	Undertake Astronomy studies	Under implementation -

Kenya (USIU-Africa, Nazarene University & UoN) 2 core Mini HPC	Currently used for Big data analytical studies in Energy, environment and Internet of Things	Undertake Astronomy studies
Cheikh Anta Diop University (UCAD) in Dakar, Senegal Grid computing	make it easier for researchers at the university to collaborate with colleagues abroad, and give them access to considerable information technology resources.	Details unavailable
Kenya, ILRI	ILRI/BECA Bioinformatics Platform	Specialized software: Database searching Assembly software CGIAR Bioinformatics Grid https://www.slideserve.com/shani/ilri-beca-bioinformatics-platform-introduction
KENET, Kenya. Africa Grid science gateway	Provide training and materials for development and sustaining e-infrastructures in Africa.	Applications: http://www.sci-gaia.eu/applications/ Other services: http://www.sci-gaia.eu/service-catalogue/

Under the Square Kilometre Array (SKA) programme, there are plans to divide three main supercomputers, including the Tsessebe, into working nodes. These nodes will be shared among the SKA African partner countries. These countries include Namibia, Zambia, Botswana, Mauritius, Mozambique, Kenya, Madagascar and Ghana. The supercomputer nodes will include the Ranger come from Texas Advanced Computing Centre (TACC) in the USA, Stampede from the Cambridge supercomputer at the University of Cambridge in the United Kingdom (UK) and Tsessebe from the Scientific and Industrial Research (CSIR) in South Africa. It is however not clear if the utilisation of these mini-HPC systems will be confined to only SKA-related work or they will be used for other resource-intensive research purposes.

In addition to the physical HPC clusters, the potential for grid computing is noted in Kenya and Senegal. In Kenya, Kenya Education Network (KENET) offers Kenyan researchers the opportunity to link up with the Africa Grid Science Gateway, providing an opportunity for researchers and academicians to access HPC resources using a grid framework.

With the exception of the Sudan HPC (illustrated in Figure 2 earlier) which is as a result of a China-Sudan bilateral agreement, it is noticeable from Table 3 above, that the vast majority of the existing HPC systems in Africa are sourced from donations by other countries.

3. Africa's HPC Challenges and the Need for a Hybridization Model

The world is undergoing an economic revolution, and this revolution is largely digital. The catalyst for this revolution is the ability to process and analyze the unprecedented and current explosion of data (European Commission, 2017). It is estimated that for every $1 invested in HPC, the economic returns are in the region of $515 (Joseph, Conway, Sorensen, & Monroe, 2016). Unfortunately, and regrettably so, Africa has insignificant capability for high-performance computing that is essential for this revolution. This insignificant capability in Africa implies that despite having an increasingly huge proportion of the world population, the continent will miss out on major advances in research and innovation in the digital age. It is a well-known fact that there are huge disparities between Africa and other continents in social and economic development. Amongst the sectors in which challenges that lead to these disparities exist are Health, Agriculture, Climate Change, Energy, Education, Youth employment, Security and Innovation.

In an increasingly connected global village, Africa's problems certainly become world problems and it is therefore important that measures are taken which provide Africa with access to cutting-edge computing technologies that have become essential for research, innovation, growth and jobs (European Commission, 2017). This is justified because modern scientific discovery involves very high computing power and the capability to deal with massive volumes of data. Experts project that by the year 2020, 25 billion devices will be connected and will generate over two zettabytes of traffic data every year (European Commission, 2017). Moreover, the need for sophisticated computing platforms is further made acute by industry and SMEs that are also more and more dependent on the power of supercomputers to discover innovative solutions, cut cost and reduce time to market for products and services (European Commission, 2017).

Despite the above nature and demand for HPC infrastructure for Africa, challenges predominate, one of which is sustainable HPC infrastructure finance. The current value chain and financing model for HPC acquisition in SSA is shown in **Figure 2** below. It involves either a HPC donation from other nations or bilateral government agreements purposefully for the installation of new HPC systems.

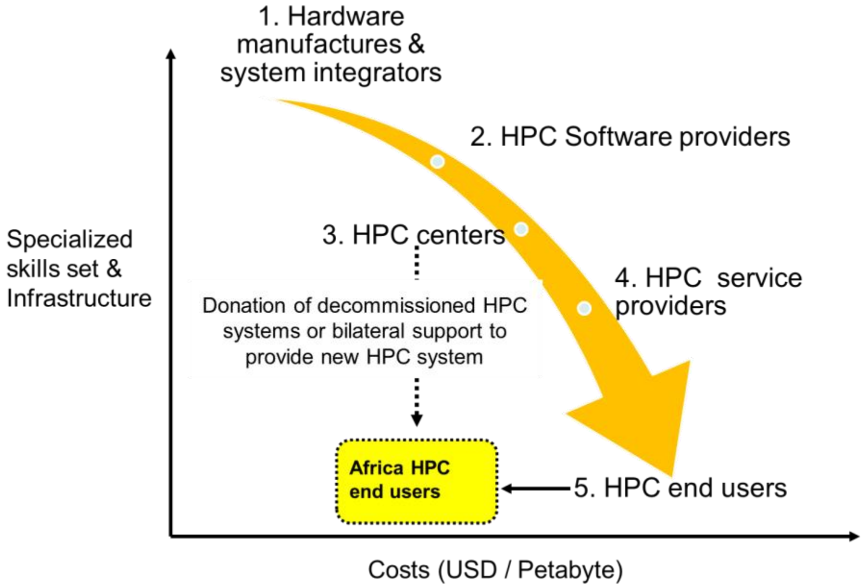

Figure 2. HPC Value Chain for Financing and Acquisition in SSA

While costs may be a key barrier in SSA, policy on promoting HPC infrastructure plays a much greater role. In 2001, China did not have a single HPC but is currently the world leader. The main reason for such exponential growth is the political will and recognition/awareness of the significance of HPC for development. Two HPC systems are worth comparing or analyzing due to the fact that they are much bigger (>30 Tflops) and may be of interest in hybridization as illustrated in **Table 5** below.

Table 5. Comparing key HPC configurations in Africa

Country	Sudan	South Africa
CalculationPerformance	38.92 Tflops	1 petaflop
CPU frequency	2.60 GHz	2.6 GHz
Cores/CPU	8	
CPU	8 * Intel Xeon E7-8830 (24MB Cache, 2.13 GHZ, 6.40 GT/s)	32832 cores arranged in 1,368 nodes of Intel ® Xeon ®
HDD	2 * 146 GB 2.5” hot swap SAS (10,000 RPM)	
RAM	16 * 8 GB registered ECC 1333 MHZ DDR3	
Total cores	2744	24,000
Processors	32 Itanium 2 processors	Xeon E5-2690v3 12C 2.6GHz
System memory	5,744 GB	148.5 TB
Memory frequency	1,600 MHz	

Storage	204 TB	4 PB Lustre Storage
Computing net (IO capabilities)	40 Gbps InfiniBand Fat Tree network	Mellanox EDR InfiniBand with a maximum interconnect speed of 56 GB/s.
System efficiency (Linpack)	92%	90%
OS	Linux 5.5_x64	Linux
Compiler	C/C++, Fortran 77/99/95, OpenMP and MPI, Intel C++, Intel Fortran, PGI	
Server monitor	Inspur TSMM 4.0	
Job manager	Inspur TSJM 2.0 grid	Bright Cluster Manager
Power	3 + 1 high conversion efficiency redundant power.	685 kW

A European study (Dong, 2016) demonstrates that 12 key areas exist for HPC applications as shown in **Figure 3** below. In Africa, the majority of applications for Sudan and South Africa HPC focus on chemistry, physics and medicine (KENET, 2018). However, it is noteworthy that very few software platforms have been parallelized in other fields that have a high socio-economic impact on the transformation of society such as medicine, security, youth employment, health, energy and sustainable environment.

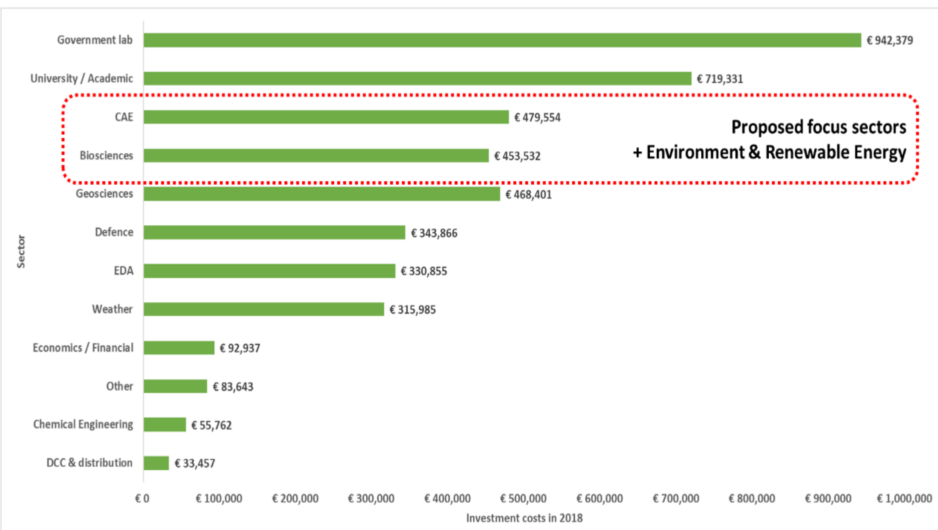

Figure 3. HPC Investments in Various Sectors

3.1 The Need for a Hybridization Model

Though it would be desirable to achieve a continent-wide HPC infrastructure, the main barriers for access and deployment of such HPC infrastructures are capacity gaps (skills sets and production infrastructure) and access to finance. In Africa like in Europe, the demand for HPC infrastructure far exceeds the supply currently offered by public HPC centers (Gigler et al., 2018). The HPC demand in Africa may be considered a suppressed demand and suppressed demand in this context refers to the fact that minimum service levels are unavailable or only available at an inadequate level. To address the gap between supply and demand, European researchers, industry and SME's rely on expensive cloud services offered by non-European HPC providers at a cost to carry out simulations and process their data.

The biggest challenge to availing more public HPC infrastructure in the African continent, like the European Union (EU), is financing considering the fact that operationalizing a system of minimal compute power would require a conservative budget of USD 50,000 capital expenditure (CAPEX). In addition, considerations should be given to recurrent operational expenditure (OPEX) as illustrated in **Table 6** below.

Hence the main challenge is not only the acquisition of CAPEX funds for initial infrastructure acquisition but also sustained financing of operating expenditure (OPEX) for the long-term. The next section introduces the concept of Hybridization as an evolving business model with a view towards resolving the affordability challenge that Africa currently faces.

4. Hybridization – Evolving an access-based Business Model

Table 6. Illustrative costing of HPC systems

8 – 12 cores, interconnects, disks, operating	10,000		
64 core Intel Xeon system, a reasonable amount of memory and disks.	50,000		
36-teraflop Inspur cluster 100 dual-socket x86 nodes plus four GPU/Xeon Phi accelerated nodes, encompassing 1,400 cores and nearly two terabytes of memory. The compute nodes are hooked together by QDR InfiniBand, with an 8 Gbps Fibre Channel network for storage.	5.4 million	(loan from the Chinese government)	University of Zimbabwe's Zimbabwe Centre for High- Performance Computing (Zim-CHPC).

1.4-petaflop Dell EMC PowerEdge C6320, Xeon E5-2690v3 12C 2.6GHz, Infiniband FDR. It has 32,856 cores	Donated from Texas University	South Africa's Centre of High-Performance Computing (CHPC)

4.1 Defining a Hybridization Model

Orbital Hybridization is a chemical term that refers to the concept of mixing atomic orbitals into new orbitals to enable the formation of new shapes with different energies. Contextualizing this definition to Africa's HPCs, this would refer to two key issues; i) the identification and ii) re-mapping of existing HPC resources. The identification involves documentation of existing resources, while remapping is the formation and leveraging of these resources among different continental players. This process is what we refer to as HPC hybridization. Its relevance is to increase access to HPC facilities by overcoming barriers in infrastructure finance, capacity skills and operational costs.

Africa with its limitation in HPC resources can greatly benefit from some form of HPC hybridization that would enable the formation of HPC clusters. These HPC clusters would subsequently enable specific clusters to become specialized in a particular subject(s) or areas that would, by their very existence, be geographically dispersed across the continent. Such an approach also would enable the improved access as well as the development of a better business and funding model as shown in **Figure 4** below. Essentially, what is required for such an approach is the political will among nations to pool resources and an awareness creation among potential and current HPC users.

4.1 How HPC Hybridization Works

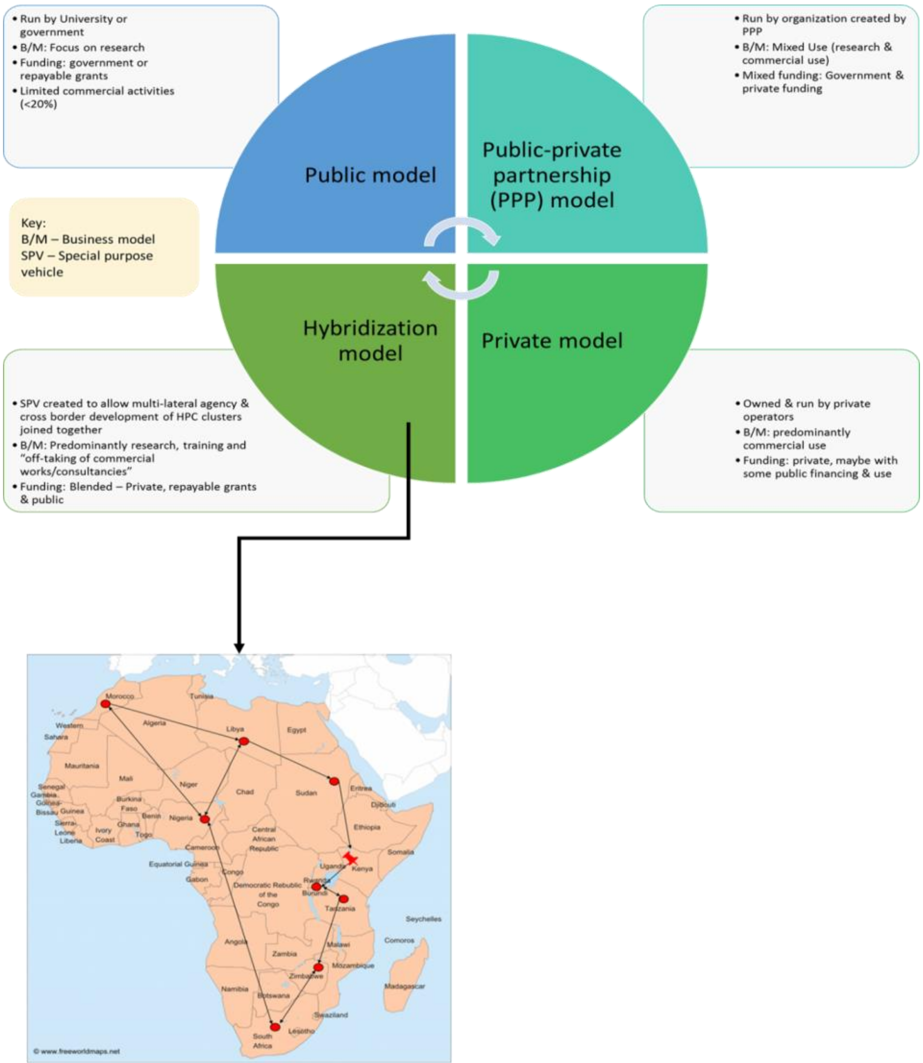

Figure 4. A Hybridization Model for HPC Infrastructure in Africa

In the HPC global arena, 3 main models (as illustrated in **Figure 4**) of establishing, operating and providing access to HPC infrastructure are commonly available. These include; i) a public model, that is funded and operated by public entities, ii) a public-private partnership model that is operated through partnerships between the public and private sector and finally, iii) a private model that is fully operated by private entities. The utilization of such HPC clusters varies depending on the business model employed and sector targeted.

In the three aforementioned HPC models, geographical curtailment of the HPC is its greatest limitation in such a way that the cluster is limited to either the institution or the country or at times a region. Further, the clusters are not joined 'hetero-homogenously' to enable one specialist cluster for instance in business to access facilities in another completely different cluster, like biology. The term 'hetero-homogenously' is used in this context to indicate two different yet symbiotic concepts; Hetero - from many, indicating many external and internal connections joining the HPC specialist cluster, and homogenous - implying working as one. Thus, the hybridization model appeals to continent-wide connections of different yet evolving specialist HPC clusters that work as a homogenous whole.

4.2 Benefits of HPC Hybridization in Africa

The hybridization model thus works by allowing nations across Africa to utilize a multi-agency to help support the establishment, operationalization and access capabilities of different specialist HPC clusters, including their interconnectivity. This implies a conjoining of the aforementioned three HPC models with their varying benefits.

It is important to note that hybridization overcomes the twin challenges, of the three previously mentioned HPC models of institutional or national boundaries and access rights. It supports a sustainable and cost-effective leveraging of resources and inter-disciplinary dialogue and research. More importantly, it allows private entities and businesses to collaborate with public entities in utilizing HPC clusters to address real-life challenges and model future scenarios across different sectors like health, climate, agriculture, energy, and infrastructure among others.

5. Conclusion and Recommendations

At its simplest level, hybridization aims at interconnecting of HPC installations across Africa. It, however, goes further by catalyzing such interconnection based on market/client’s needs, resources and political will, thus forming specialist HPC clusters – akin to call centers or clusters of excellence. Each cluster would specialize in a particular aspect but would still be connected to other specialist clusters within the continent. Subsequently, as more and more researchers from Special Interest Groups (SIGs), faculty and students in Higher Education Institutions (HEIs) utilize the existing HPC infrastructure, it is envisaged that demand for more HPC resources will organically increase, hence leading to “an increased evolution of installed HPC infrastructure”. Thus, the very basis of the latter statement is better and increased access to existing infrastructure, which a hybridization model will aim to bring. Why the hybridization model? Because no single HPC cluster can run all existing programmes (or applications) required by its clients as shown earlier in the limited utilization of the existing HPC infrastructure.

Thus, different clusters can specialize in different areas – becoming in essence, centers of excellence in those areas. By hybridization, different clusters can join up, and hence one cluster will have access to resources and applications of a different cluster specialized in a different area.

The paper has provided some background on HPC, its global distribution in Africa and hybridization as a cost-effective measure that could make a significant contribution towards catalyzing technological innovation and research on the continent. More importantly, it would allow increased access to HPC infrastructure by different actors and players.

From the foregoing, two recommendations are suggested here; First, with Hybridization the development of specialist HPC centres or clusters of excellence is feasible. However, potential capacity gaps (skills and specialist applications and software) loom. Thus, it is recommended that hybridization should be done under a South-South and North-South nexus. Such a nexus would, for instance, have Europe and Africa collaborating to develop these specialist HPC clusters. Secondly, the authors suggest that future studies ought to focus on the exact technical and costs details of the existing HPC infrastructure and subsequently, create a database that could form the basis for collaboration among African HPC practitioners.

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