Received: 11 September 2025 | Revised: 19 November 2025 | Accepted: 2 December 2025 | Published online: 23 December 2025

RESEARCH ARTICLE

Journal of Computational Law and Legal Technology
2025, Vol. 00(00) 1–16
DOI: 10.47852/bonviewJCLLT52027639

BON VIEW PUBLISHING

Competition, Market Power, and Artificial Intelligence Ecosystems in Africa

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Abstract: The expansion of artificial intelligence (AI) use across global and African markets presents exciting opportunities but poses risks to economic policymaking, especially competition policies. Because of the integrated nature of an AI ecosystem, a simple exercise of market power, where a market player can exert power in an immediate level of the market, yields significantly different competition outcomes in an integrated ecosystem. To show the integrated nature of the AI markets, we construct a network structure of an AI ecosystem and use centrality measures based on a network analysis methodology from the field of computer science to assess ecosystem power and concentration in different AI input markets. Our findings are significant because the network structure reflects the current limited participation of African firms in the design, fabrication, and assembly of AI chips or in the semiconductor manufacturing field. Coupled with backward and forward integration that can occur in this ecosystem where firms move into adjacent markets potentially enhancing their ecosystem power in African AI ecosystems. African competition authorities and policymakers should be cognizant of the future implications of consolidation in nascent AI markets in Africa and should be proactive in adopting a competition lens in viewing AI ecosystems.

Keywords: concentration, power, network analysis, competition, AI ecosystem, AI policy, economic justice

1. Introduction

The premise of this research is that the already high levels of concentration in African markets should prompt a proactive stance on the desirability of artificial intelligence (AI) policy adoption within a competitive framework because of the integrated nature of the AI ecosystem and the complementarities and dependencies within it. These dependencies can accord significant market power to a few firms that already have control over AI and AI-related resources and that already enjoy first mover advantages in the AI domain [1, 2]. AI adoption in Africa should be within a competitive framework. Otherwise, the increased risk is that the AI ecosystem in Africa becomes overconcentrated and uncompetitive like other sectors in the continent.

To show the integrated nature of the AI ecosystem, we develop a network structure of an AI ecosystem system, and using centrality measures proposed by Bonacich [3] and Freeman [4], methodological considerations by Opsahl et al. [5], and elements of power relating to resource dependence, processes, and positionality examined by Lianos and Carballa-Smichowski [6], we assess ecosystem power and concentration in different AI input markets. We find that Taiwan Semiconductor Manufacturing Company Limited (TSMC) is the most central node in the AI ecosystem network covering AI chip fabrication and assembly (0.8235). NVIDIA, Intel, Microsoft, Google, AWS, and Oracle also have high degree centrality scores in related AI input markets. This finding is particularly significant because the network structure reflects the current limited participation of African firms in the design, fabrication, and assembly of AI chips or in the semiconductor manufacturing field. In addition, the backward and forward integration ability of these firms allows them to easily move into adjacent markets, thus enhancing their ecosystem power in African AI ecosystems. On the basis of these findings, we motivate that AI policies should be adopted within a competition framework to ensure that African AI markets remain open, fair, and competitive. Because the AI ecosystem and its related input markets are prone to increasing concentration coupled with increasing merger and acquisition activity, there is a need to better understand how the continued expansion of significant market players may affect smaller African AI ecosystem participants. We conclude with recommendations on appropriate regulatory responses that ensure that AI policies are designed and implemented based on a competitive framework, which adopt a whole-of-government approach to promoting competition in the African AI ecosystem.

2. Background

In 2016, the World Bank and African Competition Forum (ACF) published a report on competition policy in Africa. The report highlights how increased competition in African markets would increase growth and lift a million Africans out of poverty. The pro-competitive gains for Africa would be most beneficial in the cement, telecommunications,

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and fertilizer markets, which are prone to cartel behavior.[1] A McKinsey report in June 2023 states that only very few and extremely profitable firms dominate African markets [7]. Buthelezi et al. [8] discovered that the abnormal concentration in African markets, such as in South Africa, is due to scale factors, which incumbent powerful firms enjoy to reduce competitive restraints.[2] This is further bolstered by increased merger and acquisition activities. While these reports highlight the state of competition affairs in Africa, a new threat to the already low levels of competition in African markets is imminent with the adoption of AI. Although the use of AI has not yet gained as much ground in Africa as it has in other parts of the world, its use is rapidly increasing, and it is becoming increasingly significant [9, 10].[3]

South Africa, Nigeria, Kenya, and Egypt currently dominate the African market in their use of AI technologies, and other segments of Africa are witnessing a rapid uptake of AI.[4] AI encourages the development and deployment of life-saving AI technologies such as in healthcare. 7keema is an AI platform developed in Egypt for nursing triage and an Uber-style app to match licensed and registered nurses with patients.[5] In the agricultural sector, Nuru in Tanzania uses local Swahili language on an AI-assisted app to help farmers detect an aggressive cassava disease before it spreads.[6] Nigeria's Zenvus uses electronic sensors and a built-in Global Positioning System (GPS) to analyze soil composition.[7] Kenya's Eska is a smartphone application that allows farmers to send automated AI-enabled analysis on plant diseases using their phone cameras.[8]

While AI technologies applied to pricing algorithms, natural language processing, and machine learning create opportunities for businesses to leverage on improved business decision-making and for broad societal impact, experts have raised concerns over the potential for AI ecosystems to become concentrated with significant barriers to entry in the AI value chain and in related AI input markets.[9] This concentration may also be used to shut out competitors and designate "gatekeeper" roles to powerful market players [2, 11].[10] This is particularly problematic because of the integrated nature of the AI value chain that functions as an ecosystem. Anticompetitive conduct engaged in by any ecosystem participant is more egregious and is magnified by network effects, economies of scale, and scopes that result in the accumulation of infrastructure or critical data or significant consumer channels [12, 13].

In broadening the scope of possibilities for competition analysis of ecosystems such as the AI ecosystem, the key objectives of this paper are to:

1) Provide an understanding of the ecosystem concept and its applicability to AI.
2) Provide a visual representation of the AI ecosystem structure (upstream and downstream) using network analysis to identify nodes and vertices, the defining characteristics of the AI ecosystem network, and the complementarities and co-dependency in product and service delivery from producers to end-users.
3) Define centrality and/or ecosystem power in an AI infrastructure network.
4) Measure or assess AI infrastructure ecosystem power and centrality of nodes in the ecosystem.
5) Discuss the increase in merger and acquisition activity observed in the African AI ecosystem.
6) Discuss how the network effects observed within the AI ecosystem can produce significant barriers to entry and expansion in the African AI ecosystem.
7) Show that network analysis can be operationalized by competition authorities in Africa and is valuable in estimating complex patterns of dominance and market power in integrated business ecosystems and models.
8) Provide recommendations for adopting AI policies within a competition framework utilizing a whole-of-government approach to AI policy development and implementation.

Our regional focus on Africa is two-fold. First, in the African context, due to the low levels of household wealth and the inability of businesses to achieve scale, economic justice is vital in all sectors. The spillover effects of the current economic or competition landscape in Africa and its forecasting of an overly concentrated AI ecosystem would further reduce consumer welfare, increase prices, stall innovation and raise privacy concerns. This is especially important in the AI sector because of the degree to which AI is forecasted to affect elements of our lives through its broad applicability across most sectors and markets in an economy. The reality is that businesses operating in African markets already have high barriers to entry and expansion. This is especially the case for small- and medium-sized enterprises (SMEs). Aside from significant infrastructure and resource limitations, competition concerns are a key reason for failed businesses and increased market exit. This is replicated in most African markets, and with the introduction of AI technologies, this would very well re-occur in this nascent market. Failure to address the foundations of AI policy adoption and facilitate a strong competition culture in the AI ecosystem would yield high prices, limit consumer choice, and foster continued anticompetitive conduct in the future. To reveal core features of the network, it is imperative to examine the link between AI, competition, and economic justice and to consider the adoption of strategies that address the competition risks posed by the increased adoption of AI and competition [9].

Second, given the limited data on AI ecosystems in Africa and the novelty of this topic, we are adding to the potential pool of peer-reviewed academic references to spur more research around AI policy and its nexus with competition policy in Africa.

In view of this, Section 3 provides a literature review of the AI ecosystem concept and the relationship between AI and competition, Section 4 provides an overview of the network analysis methodology adopted, Section 5 provides a discussion of the findings and results, and Section 6 provides recommendations for AI policy adoption within a competition framework.

3. Literature Review

3.1. Introduction

Considering the expansion in the use of AI globally, it is important to explore the challenges and risks that AI poses to competition in

[1] World Bank Group. (2016). *Breaking down barriers: Unlocking Africa's potential through vigorous competition policy* (English). Washington, D.C. Retrieved from: http://documents.worldbank.org/curated/en/243171467232051787/Breaking-down-barriers-unlocking-Africas-potential-through-vigorous-competition-policy

[2] Concentration can be defined as the number of firms active in a market.

[3] Singla, A., Sukharevsky, A., Yee, L., Chui, M., & Hall, B. (2024). The state of AI in early 2024: Gen AI adoption spikes and starts to generate value. *QuantumBlack AI survey by McKinsey* May 30, 2024 | Survey.

[4] AI for Good. (2022). *Groundbreaking report highlights artificial intelligence in Africa*. Retrieved from: Groundbreaking Report Highlights Artificial Intelligence in Africa - AI for Good (itu.int)

[5] Jackson, T. (2019). *Egyptian e-health startup 7keema to expand across Africa via quasi-franchising model*. Retrieved from: Egyptian e-health startup 7keema to expand across Africa via quasi-franchising model – Old Disrupt Africa

[6] Tsanni, A. (2024). *Africa's push to regulate AI starts now*. Retrieved from: Africa's push to regulate AI starts now | MIT Technology Review

[7] United Nations Environment Programme. (2018). *In Africa, tech-savvy entrepreneurs sow seeds of a farming revolution*. Retrieved from: In Africa, tech-savvy entrepreneurs sow seeds of a farming revolution

[8] KDHI. (2023). *An overview of AI technologies in African agriculture*. Retrieved from: An Overview of AI Technologies in African Agriculture (kdhi-agriculture.com)

[9] Korinek, A. (2024). Presentation at the OECD-EU Online Workshop on Regulation of Artificial Intelligence: Ensuring competition in the AI value chain, April 16, 2024.

[10] Martin, M., & Karga, N. (2023). *Managing the competition law risks of AI*. Retrieved from: Dentons - Managing the competition law risks of AI

the African market and to consider strategies that may be employed to address these risks. This section discusses the literature on the concept of the ecosystem and the analysis of market concentration in that context. It also considers scholarship on how AI systems operate, with a focus on African markets. Finally, it examines literature on the relationship between AI and competition.

3.2. The ecosystem concept and AI

Assessments of market concentration have traditionally been conducted solely based on the substitutability of products or services. Goods or services are said to compete with one another when consumers consider them to be reasonably substitutable. Although this conventional approach is still prevalent, it has been argued that this approach to understanding competition and market power does not factor in situations where firms compete with one another without offering substitutable products or services for sale [14]. In this context, the term "ecosystem" has recently gained traction in competition discourse, especially in relation to the digital economy.

Like the biological ecosystem, the business ecosystem involves a group of several actors who operate independently of each other and contribute to the value creation of the ecosystem [15, 16]. The concept of "value capture" is highlighted by Gawer [17]. The business ecosystem has been described as "a highly connected network of organizations, stakeholders, and consumers involved in exchange, production, innovation, trade, cooperation, and competition that co-evolve with regard to a specific goal or central organization."[11] The actors in an ecosystem provide complementary services or products that are not necessarily perfect substitutes [18]. Firms participating in an ecosystem coordinate their contributions and adjust them to one another. They are connected on a common interface, whose overall performance has an impact on the firms. The actors do not necessarily produce directly substitutable products, but they compete with one another for participation in the ecosystem.[12] Therefore, interdependence and competition exist among the ecosystem participants. Thus, the ecosystem has an integrated nature. The benefit of a business ecosystem is that its structure enables different firms to work together to create complex products and encourages innovation by fostering competition. The boost of competition and innovation, in turn, benefits consumers by providing a wide range of product choices and the combined use of complementary products.[13]

Ecosystems take different forms. Digital ecosystems tend to have a single firm that carries out the function of an orchestrator, who controls access to the central platform on which the products and services operate. Orchestrators can do this because of the strong market power that they possess in the ecosystem. This upper hand gives orchestrators the ability to promote their own products in the ecosystem by creating unfavorable conditions for other players [11, 19]. The AI market is one example of a business ecosystem, and it is not exempted from these dynamics. This is why it is imperative to examine the link between AI and competition to ascertain ways of addressing the potential challenges posed by the dynamics of the AI ecosystem to competition [2].

3.3. AI and competition policy

There is no universally agreed definition of AI. Definitions vary from AI being the simulation of human intelligence in machines and the ability of machines to display traits associated with the human mind, such as learning and problem solving.[14] We adopt the definition provided by Sheikh et al. [20] that AI takes various forms as systems that display intelligent behavior achieved by environment analysis, take actions to achieve specific goals, and can be applied in many sectors and industries. This definition is of great significance to Africa's economy.

Regarding the nexus between AI and competition policy, AI is likely to affect market concentration and the trajectory of competition law and policy in several ways. On one hand, AI has the effect of fostering innovation, lowering barriers to entry into markets, and improving efficiency.[15] Thus, AI can help in boosting competition. On the other hand, the AI capabilities of dominant firms could be used to facilitate anti-competitive conduct such as price-fixing and self-preferencing.[16] Korinek and Vipra [2] highlighted the risks of market tipping and vertical integration of dominant firms, which could lead to competition concerns in the future. This is particularly concerning due to the traits of the AI ecosystem that create fertile ground for the development of market concentration and power.

First, participation in the AI ecosystem relies largely on access to data and inputs. However, lack of access to proprietary data, which play a significant role at certain stages of the generation of some AI technologies, may create a barrier to the full participation of new entrants in the market, coupled with opportunities for ongoing data capture [13, 17].[17] Large firms, which may already have access to the proprietary data, would have a competitive advantage over the new entrants, thereby creating market concentration.

Second, individual AI markets within the AI ecosystem are concentrated or near monopolies [2].[18] In the market for compute, for example, NVIDIA, a chipmaker whose graphical processing units (GPUs) supply the "compute power" needed in many AI products such as data centers and super computers - as of February 2024, was estimated to control 98% of the market of the data center GPU market [2].

Firms may attain market power using AI for product differentiation or identification of customers that would be targets of price discrimination, thereby disrupting competition [21].[19] AI could also be used for exclusionary and predatory conduct aimed at pushing competitors out of the market, for example, by refusing to supply critical input necessary for the generation of AI technologies to a downstream firm [21].[20] In addition, firms may engage in collusive pricing by making use of AI through AI pricing algorithms to monitor and adjust their prices.[21] These practices potentially clear the pathway toward natural monopoly in the AI ecosystem [2].

In light of this strong link between AI and competition, calls have been made on the need to apply competition laws and policies to address the challenges posed by AI to competition [2, 13, 21]. Promoting competition and innovation must be central to AI policies. It is increasingly being recognized that the regulation of the digital economy needs to go beyond conventional modes of competition enforcement [11, 22]. For example, the Digital Markets Act was adopted by the European Union in 2023 to address regulatory challenges posed by digital advancement [22]. Although the act shuns the term ecosystem,

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[11] Moss, D., Gundlach, G., & Krotz, R. (2021). Market power and digital business ecosystems: Assessing the impact of economic and business complexity on competition analysis and remedies. *Available at SSRN 3864481*.

[12] Moss, D., Gundlach, G., & Krotz, R. (2021). Market power and digital business ecosystems: Assessing the impact of economic and business complexity on competition analysis and remedies. *Available at SSRN 3864481*.

[13] Moss, D., Gundlach, G., & Krotz, R. (2021). Market power and digital business ecosystems: Assessing the impact of economic and business complexity on competition analysis and remedies. *Available at SSRN 3864481*.

[14] African Union Development Agency (NEPAD). (2021). *AI for Africa: Artificial intelligence for Africa's socio-economic development*. Retrieved from: AI for Africa: Artificial Intelligence for Africa's Socio-Economic Development | AUDA-NEPAD

[15] Competition Bureau of Canada. (2024). *Artificial intelligence and competition*. Discussion paper. Retrieved from: Artificial intelligence and competition (canada.ca)

[16] Ibid

[17] Ibid

[18] Vipra, J., & West, S. (2023). *Computational power and AI. AI Now Institute*. Retrieved from: https://ainowinstitute.org/publication/policy/computational-power-and-ai

[19] Ibid

[20] Ibid

[21] Martin, M., & Karga, N. (2023). *Managing the competition law risks of AI*. Retrieved from: Dentons - Managing the competition law risks of AI

its approach to market analysis leans toward an ecosystem approach. Similar legislative responses have been made at the national level, such as Section 19a of the German Competition Act. The provision aims to control abusive behavior and is based on the ecosystem concept [22]. The United Kingdom is also working toward adopting a sector-specific piece of legislation for the digital economy that augments and transcends its current competition legislation [22].

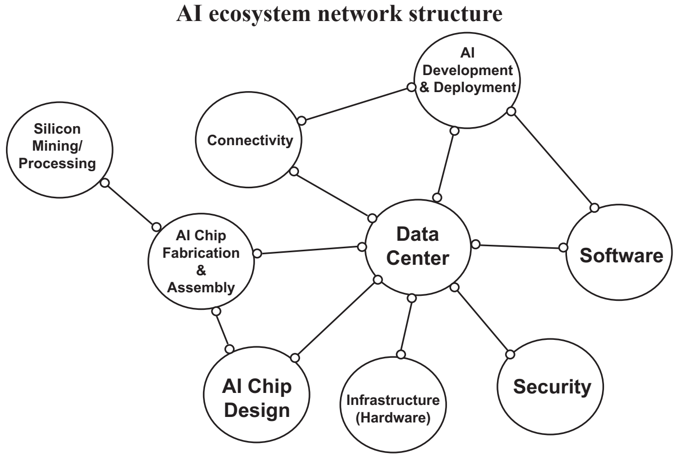
Appropriate responses are also necessary in the case of Africa because the developments in AI can potentially disrupt and transform socio-economic activities across industries [23]. AI poses challenges to governance and regulation in the African context, and the general lack of AI regulatory frameworks and institutional capacity across the continent could lead to adverse consequences [23]. Evidently, there is a need for African competition laws and competition policies to adjust to the complexities of the AI ecosystem, to address the challenges posed by advances in this area, and to fully reap the benefits of this digital advancement.

4. Network Analysis Application to AI Ecosystems

4.1. The AI ecosystem concept

The AI ecosystem encompasses horizontal and vertical relationships among market participants.[22] Figure 1 shows that the AI ecosystem is made up of an AI infrastructure market within the AI ecosystem, markets for AI development and deployment, and source markets for raw materials, e.g., silicon for manufacturing AI chips. The integrated nature of this ecosystem is one of complementarities and co-dependency in product and service delivery. For example, AI chips are a necessary component for "compute power" for many AI products such as data centers and super computers.[23] In addition, the AI development and deployment markets ("consumers of AI products and services") are dependent on data centers that require AI hardware such as AI chips, AI software such as data management software, software to enable the use of AI chips, security and data center infrastructure such as cables, cooling equipment, and racks.[24]

Figure 1
AI ecosystem network structure



Thus, because of the integrated nature of an ecosystem, contrary to simple market power assessments, where a market player can exert power in an immediate level of the market, the strategy employed by an ecosystem participant, when anticompetitive, can significantly affect competition, depending on the extent of asymmetry in the ecosystem [6, 11]. As explained by Lianos and Carballa-Smichowski [6] and as applied to the architecture of the AI ecosystem and interdependences within it by Jacobides and Gawer [24], the AI ecosystem can be thought of as being made up of communities of "collaborating" firms involved in value co-creation and made up of supermodular complementarities. This means that a firm with significant power in a core market of the AI ecosystem (such as AI chip fabrication) can harm competition in that core market or at the level of the ecosystem through the acquisition of a neighboring or linked product or service offered by another ecosystem participant (AI chip design).

4.2. Network analysis methodology

Because of the interconnectedness and co-dependencies inherent in AI ecosystems, the simple model employed for analyzing competition dynamics utilizes a network approach. Network analysis enables researchers to estimate and quantify multifaceted patterns of associations using a network's structure [6, 25, 26]. The starting point of the analysis involves constructing a network structure comprising graphically represented relationships called edges between variables, known as nodes [25]. The nodes include the variables to be analyzed, which are the supply points (the nodes can also represent individual firms or firm groupings) along the supply chain of an AI ecosystem. The edges constitute the relationship between the nodes.

Network analysis is a broad methodological area. However, to understand how ecosystem power along the AI ecosystem can be conceptualized (e.g., who can act as a gatekeeper? What are the choke points along the supply chain of the ecosystem? Who can profit excessively? Who controls access to compute resources? Who is the main conduit to AI customers?), this research introduces how "centrality" and power in a network can be understood. This is based on the supposition that centrality in a network structure is equivalent to power and is, in most instances, a vital structural property of a network [3, 4].

The centrality measures proposed by Bonacich [3] and Freeman [4] and the methodological considerations by Opsahl et al. [5] are applied. In addition, other elements of power relating to resource dependence, processes, and positionality examined by Lianos and Carballa-Smichowski [6] are briefly contemplated.

4.3. Analysis subsection: network analysis model

In characterizing a network based on graph theory, a few concepts are examined below:

A simple *network or graph*

$$\mathrm{M} = (\mathrm{V}, \mathrm{E}).$$

$$V = V(M) = set\ of\ nodes = \{1, 2, 3, 4, 5, 6, 7\}.$$

Edges represent connections between nodes. Thus, the set of edges for M is represented as

$$\mathrm{E} = \mathrm{E}(\mathrm{M}) = \{\ \}.$$

Edges are of the form {u,v} in the network graph.

Thus, network M consists of a node set *V(M)* and the edge set *E(M)*. The edge set *E(G)* induces a symmetric binary relation on *V(G)*, which means that nodes connected by an edge are *adjacent*, i.e., the node "AI chip design" and "AI chip assembly" are adjacent. "Security" and "AI chip assembly" are not. Nodes are *incident* when they share a common vertex, that is, *V E e*. Thus, nodes "AI chip fabrication" and "AI chip design" are incident to AI chip assembly.

Degree, *di*, of a node, means the number of edges incident to it. Thus, for *d* (*data center*) = 5, *d* (*AI chip fabrication*) = 3. The Degree concept will prove useful for our ecosystem power analysis.

[22] Competition Bureau of Canada (2024).
[23] Vipra, J., & West, S. (2023). *Computational power and AI*. AI Now Institute. Retrieved from: https://ainowinstitute. org/publication/policy/computational-power-and-ai
[24] Ibid

Edges can be *weighted* or *unweighted*. An *unweighted* edge represents the presence of a relationship, while a *weighted* edge represents how strong a relationship or connection is (represented by the thickness of the edge). To keep the model simple, we do not allocate edge weights but consider edges as supply or purchase relationships that a node has with other nodes it is *incident* to in the ecosystem.[25]

4.4. Results

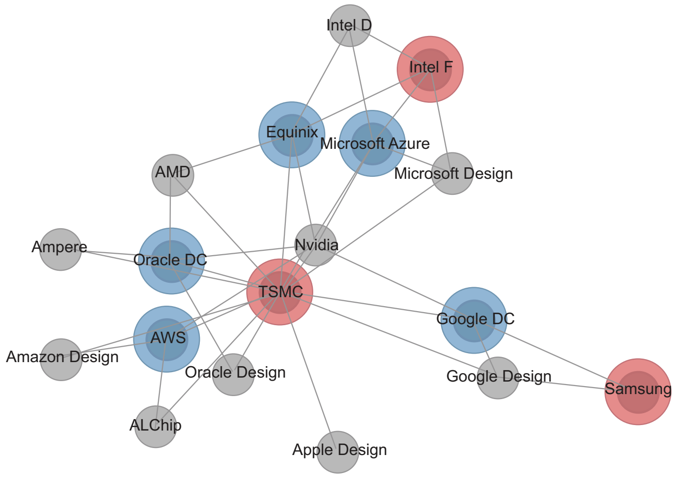
4.4.1. Data and network construction

For our simple network analysis model, we assume: *a simple static network* (no movement in the nodes for an extended period). The network structure was constructed based on available information from company websites, news media, and public announcements of the termination or renewal of partnerships or supply relationships that AI ecosystem participants have with each other (see *footnotes*).[26,27] The constructed network graph is based on the AI ecosystem concept that AI data centers are necessary for AI development and deployment and that these AI data centers require AI chips.[28] We refer to this as the upstream sector of the ecosystem.

The network represents only upstream AI markets, which is the combination of various AI markets from chip design to AI-enabled data centers. For example, AI chip design is a single market focused on corporations that participate in designing AI chips. We exclude the downstream of AI development in this ecosystem.

An AI market is defined as a role within the AI ecosystem. Each node in the ecosystem network represents a market player (corporation) in the AI ecosystem differentiated based on their roles (market). Finally, the edges connecting the nodes represent supply relationships that AI ecosystem participants have with each other. For example, Figure 2 shows that TSMC (red-colored node) provides AI chip fabrication and assembly services to many players in the data center node (blue-colored nodes) like Google, Oracle, and Amazon Web Services and also to players in the AI chip design market (gray-colored nodes). The edge in the network is non-directional connecting two nodes (market players), and we attach equal weights across all edges. Table 1 shows the markets and the market players considered in the construction of the ecosystem network. Although there are 234 DCs across Africa, only few of them have traceable connection to AI development as of 2023.

Figure 2
Network analysis



Legend for node colors: red – global AI fabrication and assembly companies; blue – data centers that are connected to leading AI development corporations and are present in Africa; gray – global AI chip designers

Table 1
Markets and the market players considered in the construction of the ecosystem network

Market	# of players	Market players
AI chip design	10	Alchip, Intel, Ampere, Apple, NVIDIA, Microsoft, AMD, Amazon, Oracle, Google
AI fabrication and assembly	3	Intel F, TSMC, Samsung
Data center	1	Equinix, Amazon, Google, Microsoft, Oracle

Figure 2 shows the network graph presenting global AI chip designers as gray-colored nodes, global AI fabrication and assembly companies as red nodes, and some data centers that are connected to leading AI development corporations and are present in Africa as blue nodes. An edge shows supply and purchase relationships between two nodes.[29]

4.4.2. Data and network construction

The network analysis was run using Python 3, Networkx package (see the functions used in the Appendix).

4.4.3. Centrality definitions

To know if a node is central, Freeman [4] suggested that the node should have the most ties, can reach other nodes quickly, and controls communications between other nodes. He introduced three centrality measures:

1) Degree centrality is a fundamental measurement in network analysis that quantifies the importance of a node based on the number of edges (or ties) that it shares with other nodes.
2) Betweenness centrality ascertains the frequency with which a node falls between nodes. Thus, if we counted every pair of nodes in a network structure, the node that falls within the shortest path to reach every other node has high betweenness centrality. Words like “broker” and “intermediate” would refer to nodes that have high betweenness centralities.
3) Eigenvector centrality calculates a node’s centrality as a sum of the influence of the immediate neighboring nodes.

The research sough to provide an understanding of the ecosystem concept and its applicability to AI ecosystems by identifying the AI ecosystem structure (upstream and downstream) using network analysis to categorize nodes and vertices, the defining characteristics of the AI ecosystem network, and the complementarities and co-dependency in product and service delivery from producers to end-users. The metrics for assessing centrality and/or ecosystem power in an AI infrastructure network were also applied.

Centrality in a network can be arrived at using different centrality measures. We utilize three measures for assessing power or centrality

[25] This is based on available information from company websites, news media, and public announcements of the termination or renewal of partnerships or supply relationships that AI ecosystem participants have with each other. For example, TSCM provides AI chip fabrication and assembly services to many players in the data center node like Google, Oracle, and Amazon Web Services. Correspondingly, large ecosystem players like Apple can design their own chips and rely on TSCM for chip fabrication and assembly.

[26] *Measuring The Scale Of AWS Data Center Locations Worldwide*

[27] Data center sites: *21st Century Technologies; Welcome to Paratus Africa; PAIX - Pan African Internet Exchange data centres; https://www.mainone.net/our-network/; About Us – Medallion Communications Limited; Teraco Data Environments; Vantage Data Centers Expands to Africa with US$1 Billion Flagship Johannesburg Campus in Continent's Largest Data Center Market - Vantage Data Centers*

[28] The network analysis was run using Python 3, Networkx package.

[29] The nodes for analysis from Figure 1 are “data center,” “AI chip design,” and “AI chip assembly and fabrication.”

in the AI ecosystem developed by Freeman [4] and Bonacich [3]. First, we apply the *Degree*, *di*, of a node, which means the number of edges *incident* to a node ($\sum d_i$) for each node n. Second, we calculate degree centrality following Freeman [4], where m_i is a given node that can be adjacent (at most) to n-1 other nodes.

$$C'_d(m_i) = \sum_{i=1}^{n} a(m_i, m_k)/n - 1.$$

This incorporates an (n-1) element, limiting the number of reference nodes to nodes that are the focus of the activity in the network. The third measure is an eigenvector centrality measure, which incorporates the centralities of other neighboring nodes. Essentially, the power or centrality of a node is a function of the importance of its own neighbors [3].

Table 2 and Figure 2 both show that the three measures of centrality present Taiwan Semiconductor Manufacturing Company Limited ((TSMC) as the most central node in the network covering AI chip fabrication and assembly (0.8235). NVIDIA, Equinix, Microsoft, Google, Oracle, Intel, and AWS also have high degree centrality scores (0.3529, 0.2941, 0.2941, 0.2941, 0.2941, 0.2353, and 0.2353, respectively).

This suggests that the upstream and downstream markets in the AI ecosystem have only a few key players. This could result in significant network effects within the AI ecosystem producing barriers to entry and expansion in the African AI ecosystem for smaller AI players. This is worsened by the reality that only a handful of start-ups in Africa are involved in the design, fabrication, and assembly of AI chips or are in the semiconductor manufacturing field,[30] evidenced by isolated research activity and some manufacturing efforts in adjacent markets, for example, microelectronics research in South Africa through the Microelectronics and Nanotechnology Centre at the Council for Scientific and Industrial Research (CSIR) and automotive electronics activity in Egypt and Morocco.[31]

In addition, the finding is that AI ecosystem participants like Google, Microsoft, and Amazon Web Services are now involved in chip design.[32] These same firms also provide cloud infrastructure services, a key operational component of a data center that covers the database, network, storage, and cloud compute resources.[33] The backward and forward integration ability of these firms both on the AI chip supply side and their data center centrality affords them process-based power. It also reveals that integrated business ecosystems like the AI ecosystem are fertile grounds for increased concentration that require a cautious approach to factors that hasten consolidation and abuse of market power in such systems.

5. Discussion

The simple network analysis model developed highlights how the integrated nature of an AI ecosystem works and how competition can be affected. This analysis shows possibilities with network analysis to potentially cover assessments of positional power, resource dependence, and process-based power. Once the first step of identifying the network structure of an ecosystem or market is done, elements of firm interactions would reveal power and competition dynamics. Positional power such as panopticon power (strategic position in a network structure) may show that data centers have a strategic position as a sole recipient of AI chips in the network structure (Figure 1) and as a key point of supply to AI development and deployment users. Another interesting dynamic from the network is that certain players play across large segments of the AI ecosystem in different nodes, i.e., data center owners may also design their own chips and move into AI chip fabrication and assembly while remaining dominant and active in the adjacent nodes that enable the functioning of data centers such as connectivity, software, and security.

The supply chain of the ecosystem is plagued with high costs and specialized technical knowledge that may bestow ecosystem power and the ability to flexibly enter new markets and leverage existing capabilities for dominant and well-funded, and in most cases, foreign players. For example, data centers require AI chips, connectivity, and cloud computing services to provide services to AI developers or to deploy AI products and services. These chips are mostly designed by firms such as NVIDIA, AMD, and Intel. However, the past few years have witnessed an increase in internal chip design by players like Google, Microsoft, and Amazon Web Services.[34] These same firms

Table 2
Centrality measure results

Node	Role (#market)	Degree	Centrality	Eigenvector
Equinix	Data center	10	0.2941	0.2690
NVIDIA	AI chip design	12	0.3529	0.3455
Intel D	AI chip design	6	0.1765	0.1337
AMD	AI chip design	6	0.1765	0.2094
TSMC	AI chip fabrication and assembly	28	0.8235	0.5511
Intel F	AI chip fabrication and assembly	8	0.2353	0.1639
AWS	Data center	8	0.2353	0.2291
Amazon Design	AI chip design	4	0.1176	0.1495
Alchip	AI chip design	4	0.1176	0.1495
Apple Design	AI chip design	2	0.0588	0.1056
Google DC	Data center	8	0.2353	0.2165
Google Design	AI chip design	6	0.1765	0.1610
Samsung	AI chip fabrication and assembly	4	0.1176	0.0723
Microsoft Azure	Data center	10	0.2941	0.2649
Microsoft Design	AI chip design	6	0.1765	0.1878
Oracle DC	Data center	10	0.2941	0.2725
Oracle Design	AI chip design	4	0.1176	0.1578
Ampere	AI chip design	4	0.1176	0.1578

[30] Semiconductor manufacturing Companies in South Africa | Sales leads list by Lusha

[31] Idiakhoa, O. (2023). *Leveraging AI and chip technologies for Africa's technological leap*. Retrieved from: Leveraging AI and Chip Technologies for Africa's Technological Leap | by Oluwafemidiakhoa | Medium

[32] Microsoft made an announcement in 2024 that it intends to release Athena, its own proprietary chip. Source: Microsoft reportedly working on its own AI chips that may rival Nvidia's - The Verge

[33] Zhang, M. (2024). *Data center architecture: An in-depth overview of design*. Retrieved from: Data Center Architecture: An In-Depth Overview of Design - Dgtl Infra

[34] Microsoft made an announcement in 2024 that it intends to release Athena, its own proprietary chip. Source: Microsoft reportedly working on its own AI chips that may rival Nvidia's - The Verge

also provide cloud infrastructure services, a key operational component of a data center that covers the database, network, storage, and cloud compute resources.[35] In addition, global brands like IBM, Google, and Microsoft, by reason of scale, have central positions in AI adoption and are mostly in charge of significant AI venture or projects in Africa.[36] The backward and forward integration ability of these firms both on the AI chip supply side and their data center centrality affords them process-based power.

Furthermore, foreign investment in data centers by dominant global partners is on the rise in Africa. This is majorly due to the high costs involved in establishing data centers. Approximately 50% of the 234 data centers active in Africa are in three African countries: **South Africa, Nigeria,** and **Tanzania (Data from Data Centre Map Africa Data Centers - 234 Facilities from Operators)**. It is important to note that some of these data centers are partly funded by the market players represented in the global AI ecosystem (Figure 2), extending further the ecosystem power of these global players in Africa's market. Table 3 shows some data centers owned by ecosystem participants with high centrality scores in the top three countries that constitute Africa's 50% of the data center market. It shows an AWS data center owned by Amazon in Johannesburg and Africa Data Centres owned by Cassava Technologies but with investments from Google, among others.

Table 3
Data center ownership of ecosystem participants in Africa

Data centers	Ecosystem participant	Country
AWS	**AWS**	South Africa
Africa Data Centres (Cassava Technologies)	**Google**	South Africa, Kenya, Nigeria
Microsoft Azure Data centers	**Microsoft**	South Africa, Kenya, Nigeria
Oracle Cloud	**Oracle**	South Africa; (planned Kenya and Morocco)
Equinix	**Equinix**	South Africa, Nigeria

5.1. Increasing concentration

Competition policy assessments involve reviewing mergers among competing firms or firms in vertical relationships that could substantially lessen or prevent competition. This starts with an assessment of the degree of concentration in a market (i.e., the number of firms active in a market) and whether merger activities among competing firms or those in vertical relationships would pose competition concerns in a defined market.

In the past few years, an increase in merger and acquisition activity in the African AI ecosystem has been observed. The biggest acquisition of an African AI company was the acquisition of Tunisia-born InstaDeep by BioNTech, a German biotech company for USD 682,000,000 in 2023.[37] From all indications, it seems that this is just the beginning of more to come. For example, Digital Realty, the world's largest provider of cloud and carrier-neutral data center, colocation, and interconnection solutions, acquired Nigeria's Medallion in 2021 and South Africa's carrier-neutral colocation data center operator Teraco in 2022, which now places them in ownership of over 10 of the largest data centers in Africa.[38,39] In addition, Equinix, an American multinational company acquired MainOne data center in 2022, making it in control of four data centers, and Convergence, a private equity firm acquired South Africa's Datacentrix in 2023, its sixth acquisition of a data center-related service in 2023.[40]

In 2020, Actis, a London-based private equity firm has acquired a controlling stake in Rack Centre, a leading Nigerian data center and service provider. The significance of this acquisition should be noted because Rack Centre was the first in the continent to be a "*Tier III Constructed Facility with the largest installed capacity in West Africa with a range of over 80 blue-chip international, multi-national and local clients. With over 35 carriers, Internet Service Providers, Mobile Network Operators present, and hosting the Internet Exchange Point of Nigeria; it is the most connected, carrier neutral, Tier III certified data centre in sub-Saharan Africa, with every country on the Atlantic coast of Africa directly connected….*"[41]

5.2. Ecosystem power

First, the simple network analysis model shows the integrated nature of the AI ecosystem, i.e., that African data center players like iXAfrica, Paix, 21st Century Technologies, and Rack Centre would likely require access to compute inputs (such as data center connectivity and cloud services) from a large cloud infrastructure provider (such as Amazon, Microsoft, Oracle, and Equinix), who also own data centers and are direct competitors in the AI ecosystem at the data center level. Second, the model shows that this integrated nature can produce economies of scope and scale for central players. Big players can very easily become more dominant. Third, network effects can put newer smaller entrants into the AI ecosystem at a disadvantage. Because larger participants have the infrastructure, expertise, and access to compute resources on a large scale, small players who do enter the market may find it very hard to compete. These can collectively produce significant barriers to entry and expansion in the African AI ecosystem.

Locating this within the African experience, while the premise of this research is that the already high levels of concentration in African markets should prompt a proactive stance on the desirability of AI policy adoption within a competitive framework, there is also the realization that Africa-specific constraints that can amplify ecosystem power exist (see Box 1).

Box 1: Africa-specific constraints that amplify ecosystem power

- Limited capacity (skills and funding) in many African countries. *The State of AI in Africa Report* finds that outside entities such as IBM, Google, and Microsoft have led the charge in promoting AI adoption projects in Africa
- Limited national data localization regulations and digital sovereignty. Aside from a few African countries such as Senegal, Kenya, Nigeria, and South Africa, many African nations lack robust data protection legislation, which raises concerns regarding whether emerging data centers can be effectively regulated [27].
- Spectrum availability and harmonization. The African Union's Digital Transformation Strategy for Africa (2020–2030) identified the limited and divergent spectrum capacity in African countries [28].

[35] Zhang, M. (2024). *Data center architecture: An in-depth overview of design*. Retrieved from: Data Center Architecture: An In-Depth Overview of Design - Dgtl Infra

[36] Centre for Intellectual Property and Information Technology Law. (2023). *The State of AI in Africa Report 2023*.

[37] Kene-Okafor, T. (2023). *InstaDeep's acquisition is a classic case of an African startup gone global*. Retrieved from InstaDeep's acquisition is a classic case of an African startup gone global | TechCrunch

[38] Oluka, P. (2023). *It's official! Medallion Data Centre rebrands to Digital Realty*. Retrieved from: It's Official! Medallion Data Centre Rebrands to Digital Realty - Tech | Business | Economy (techeconomy.ng)

[39] Teraco. (2022). *Teraco announces completion of acquisition by Digital Realty*. Retrieved from: Teraco announces completion of acquisition by Digital Realty

[40] Equinix. (2022). *Equinix enters Africa, closing the US$320 million acquisition of MainOne*. Retrieved from: Equinix Enters Africa, Closing the US$320 Million Acquisition of MainOne

[41] Nigerian Investment Promotion Commission. (2020). *Actis acquires Rack Centre*. Retrieved from: Actis acquires Rack Centre – Nigerian Investment Promotion Commission (nipc.gov.ng)

Spectrum issues around emerging technologies: the development of a 5G and AI strategy; IoT devices prevent large-scale entry of small-scale players into the AI ecosystem, further enhancing the power of more established global players.

- Energy costs. The need for energy to power digital infrastructure such as data centers is known. However, the International Energy Agency's Africa Energy Outlook suggests that as many as 43% of Africans still lack electricity.[42] Local investors may be unable to bear the prohibitive cost of providing electricity to power AI projects, which more established players with deeper pockets may afford, further increasing barriers to AI market entry.[43]

6. Recommendations for Adopting AI Policies within a Competition Framework

While the AI ecosystem may make conventional business models redundant by shifting the competitive market landscape, issues of economic justice and its broad impact can easily get sidelined. Economic justice in the context of a competitive environment relates to markets remaining open, fair, and competitive. This means that the AI policy adopted should still provide leeway for SMEs and would-be competitors to participate freely in markets.

AI ecosystems have changed the market narrative from one that revolved around traditional business models to digital business ecosystems, which are driven by user data as a currency of exchange for goods and/or services. Digital business ecosystems are not only characterized by their integrated nature with existing co-dependencies between AI market players (i.e., platforms bringing together interdependent groups in a multi-sided market), but they also possess unique structural features, including data and data externalities, cloud computing technologies, algorithms, economies of scale, and network effects that are redefining the competitive landscape across all sectors of the economy.[44] Although AI enables businesses to innovate and enhance customer experiences, AI poses challenges and risks to market competition.[45]

Creeping mergers and acquisitions have been a key feature of the AI market globally through direct acquisitions and indirectly through partnerships that avoid the scrutiny of competition enforcers [29]. These acquisitions strategically target smaller players and new entrants for the big tech companies to reinforce their market positions in these platforms by expanding and diversifying their business models or ecosystems. Another competition issue lies in potential abuse of market power or dominance, where dominant firms can use AI capabilities to facilitate anti-competitive conduct including the following:

1) Self-preferencing by use of algorithms and data analytics to support consumer preferences and consumption patterns;
2) Engaging in exclusionary and predatory conducts to exclude competitors (e.g., by refusing to supply critical input necessary for the generation of AI technologies to a downstream firm); and
3) Imposing restrictions, which result in lack of access to user data, creating barriers to entry and participation by small players and/or new entrants in the market, particularly SMEs [13, 30].

In light of the above, there is an urgent need for a balanced competitive landscape that promotes entry and participation and fosters innovation while preventing market monopolization and increasing concentration levels. The strategies that we propose are two-fold: first, a broad call for joint coordination on AI policy adoption within a competition framework where opportunities for cross learnings between advanced competition enforcement jurisdictions such as the European and African national competition authorities and supranational competition authority especially in the explorations of methods for assessing power in digital ecosystems such as the AI ecosystem. Second, our call is for policymakers to be cognizant of the future implications of increased consolidation in nascent AI markets in Africa and to be proactive in adapting a competition lens in viewing AI ecosystems and in policymaking. Our recommendations are as follows:

To address increasing market concentration and potential abuse of power or dominance in the AI ecosystem:

Competition agencies should be better prepared to address competitive harm that emanates from AI technologies given the increasing concentration and market power arising from serial mergers and acquisitions: competition agencies have a role to play by proactively assessing mergers and acquisitions and understanding the theories of harm associated with AI ecosystems. For example, as a starting point, the South African competition authority published its guidelines on small merger notifications amid concerns of potential anti-competitive acquisitions in digital technology markets that are escaping regulation. The Competition Commission of South Africa found that many mergers in the digital tech space happened during the early stage in the life of the target firms before generating sufficient turnover or accumulated capital and physical assets that would trigger mandatory merger notifications as set by the turnover or asset thresholds in the merger assessment guidelines.[46]

The development of policies, regulations, and enforcement tools that prioritize AI ecosystem development and its application in Africa: AI ecosystems are currently displacing conventional approaches used to evaluate anti-competitive conducts in markets, including techniques such as how markets are defined and how competitive effects are evaluated. Such competition enforcement and/or investigation tools need to be revised and updated and better tailored for digital ecosystems. Policies and regulations should be developed to regulate the digital technology sector. In particular, measures should be adopted to address issues of compliance on data and algorithms because these are tools used to strengthen market power in various markets. For example, competition agencies such as the European Commission (EC) are revisiting their competition enforcement tools (i.e., The EU adopted a revised market definition notice for competition cases).[47]

Design and develop mechanisms and programs for the purposes of promoting entry and participation by small players and new entrants in AI ecosystems: policymakers can develop mechanisms and programs to ease structural restrictions in which small players and new entrants face. This can be through the development of small business programs and funding support to promote better inclusion of small businesses and new entrants in the AI ecosystem. In addition, policies that promote data access and data sharing can ensure equitable access to datasets for all market participants who may require training data for large language model development and other AI-related uses.

Collaboration among competition agencies and regulators: competition policymakers and regulators should consider collaborative approaches on competition enforcement and regulation with other agencies to address issues of market power and concentration arising from these AI ecosystems. This can be done through participation in platforms such as the ICN and the ACF that foster information sharing

[42] IEA. (2022). *Africa Energy Outlook 2022*. Retrieved from: https://www.iea.org/reports/africa-energy-outlook-2022

[43] IEA. (2022). *Africa Energy Outlook 2022*. Retrieved from: https://www.iea.org/reports/africa-energy-outlook-2022

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[46] The Competition Commission of South Africa. (2022). *Guidelines on small merger notification*. Retrieved from www.compcom.co.za

[47] The European Commission. (2024). *Commission adopts revised Market Definition Notice for competition cases*. Retrieved from: Market Definition Notice for competition cases (europa.eu)

and country experiences on enforcement cases that have emerged as part of digital ecosystems. Platforms such as the ACF can also be used to address the implications arising from emerging digital technologies, including AI, because they intersect with the respective mandates of different agencies in Africa. Another method is through stakeholder engagement and advocacy by establishing cross-governmental collaborations, which can be made up of government institutions such as data and information regulators and department of telecommunication infrastructure. Furthermore, competition agencies can proactively engage private sector partners through stakeholder engagements and advocacy, including big tech companies, AI and software developers, and AI deployers, on the implication of AI technologies on competition as a proactive approach. These require a whole-of-government approach to AI policy design and implementation.

Promote an understanding of AI policy, competition, and economic justice: better understanding of AI ecosystems and how they affect competition can aid in the development of effective competition policy frameworks for better enforcement and regulation [9]. The International Competition Network (ICN) is a discussion forum that can be utilized to understand AI technologies and how they can be strategically integrated into the work of competition agencies to augment staff capabilities and for greater efficiency.

All in all, a whole-of-government approach in the application of competition policy and AI policy would aid in mitigating the risks and challenges posed using AI technologies. A robust regulatory framework is indispensable for the African market to reap the benefits of AI technologies in the continent.

7. Conclusion

This paper provided an understanding of the ecosystem concept and its applicability to AI markets. We provided a visual representation of the AI ecosystem structure (upstream and downstream) using network analysis to identify nodes and vertices, the defining characteristics of the AI ecosystem network, and the complementarities and co-dependency in product and service delivery from producers to end-users. We applied network analysis in understanding the AI ecosystem in Africa and the concept of ecosystem power using classic centrality measures such as degree centrality and eigenvector centrality measures.

Our results first show the possibilities with network analysis for African competition authorities to cover assessments of ecosystem power. Network analysis shows the number of players in the upstream and downstream markets of the AI ecosystem. The network structure highlights that only a few key players operate in this space, providing opportunities for significant network effects within the AI ecosystem, producing barriers to entry and expansion for smaller AI players especially in the design, fabrication, and assembly of AI chips. The backward and forward integration ability of these firms both on the AI chip supply side and their data center centrality affords firms like Google, Microsoft, and Amazon Web Services the ability to easily go into adjacent markets such as chip design. These same firms also provide cloud infrastructure services, a key operational component of a data center that covers the database, network, storage, and cloud compute resources.[48] This is worsened by the reality that only a handful of start-ups in Africa are involved in the design, fabrication, and assembly of AI chips or are in the semiconductor manufacturing field.

Second, aside from the fact that competition analysis can benefit from empirically measuring power or centrality with insights borrowed from the network economics literature, our finding suggests that competition enforcement design for integrated business ecosystems should be cognizant of factors that hasten consolidation and abuse of market power in such systems. With digitization and sprawling ecosystems, the high potential for winner takes all outcomes necessitates an understanding of firm-to-firm and firm-market pairings and how connections inherent in network structures can be beneficial to competition enforcement.

While we do not go into merger details in this research, we suggest that future competition-related research of integrated business ecosystems in Africa consider innovative approaches to defining a network's structure such as dynamic panel of networks, the potential for applying merger screening indicators using centrality thresholds per market identified, and integrating cost/price outcomes in ecosystem assessments of power and centrality.

Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

The data that support the findings of this study are openly available in Data Centre Map at https://www.datacentermap.com/africa/.

Author Contribution Statement

Oluwatobi Ogundele: Conceptualization, Methodology, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration. **Lozindaba Mbvundula:** Conceptualization, Writing – original draft. **Balisa Mhambi:** Conceptualization, Writing – original draft. **Olukunle Ogundele:** Methodology, Formal analysis, Data curation, Writing – review & editing, Visualization.

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How to Cite: Ogundele, O., Mbvundula, L., Mhambi, B., & Ogundele, O. (2025). Competition, Market Power, and Artificial Intelligence Ecosystems in Africa. *Journal of Computational Law and Legal Technology*. https://doi.org/10.47852/bonviewJCLLT52027639

Appendix

```
import networkx as nx
import matplotlib.pyplot as plt
import pandas as pd

#Read in the data from a csv:
df = pd.read_csv('ai_network.csv')

#Construct the graph from the dataframe
g = nx.Graph()
g= nx.from_pandas_edgelist(df, source='entity_a', target='entity_b', edge_attr='weight')
g.nodes()

#Draw the Graph
pos = nx.spring_layout(g, seed=7)  # positions for all nodes - seed for reproducibility

# nodes
nx.draw_networkx_nodes(g, pos, node_size=600, node_color="grey", alpha=0.5)
nx.draw_networkx_nodes(g, pos, node_size=1500, nodelist=['TSMC', 'Intel F','Samsung'], node_color="tab:red", alpha=0.5)
nx.draw_networkx_nodes(g, pos, node_size=1500, nodelist=['AWS','Microsoft Azure','Oracle DC','Google DC','Equinix'], node_color="tab:blue", alpha=0.5)
# edges
nx.draw_networkx_edges(g, pos, width=1, edge_color='grey')

# node labels
nx.draw_networkx_labels(g, pos, font_size=8, font_family="sans-serif")

ax = plt.gca()
ax.margins(0.08)
plt.axis("off")
plt.tight_layout()
plt.show()
#plt.savefig("Graph.png", format="PNG")


#Calculate Centrality
centrality= nx.degree_centrality(g)
eigen = nx.eigenvector_centrality(g, weight='weight')
degreeview = g.degree(weight='weight')

#Store the result in a dataframe
degree = pd.DataFrame(degreeview, columns=['node', 'degree'])

for i,j in centrality.items():
    for index, rows in degree.iterrows():
        if i == rows['node']:
            degree.loc[degree.index==index,'centrality']=j

for i,j in eigen.items():
    for index, rows in degree.iterrows():
        if i == rows['node']:
            degree.loc[degree.index==index,'eigen']=j
```