Climate finance across sub-Saharan Africa: Decision trees and network flows

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DATES:
Received: 24 Mar. 2023
Revised: 16 Oct. 2023
Accepted: 02 Jan. 2024
Published: 27 Mar. 2024

HOW TO CITE:
Chukwudum QC. Climate finance across sub-Saharan Africa: Decision trees and network flows. S Afr J Sci. 2024;120(3/4), Art. #15837. https://doi.org/10.17159/sajs.2024/15837

ARTICLE INCLUDES:
☒ Peer review
☒ Supplementary material

DATA AVAILABILITY:
☐ Open data set
☒ All data included
☐ On request from author(s)
☐ Not available
☐ Not applicable

EDITOR:
Jennifer Fitchett

KEYWORDS:
mitigation, adaptation, climate finance architecture, multilateral climate funds, IPCC

FUNDING:
None

The structure of climate finance flows from donors (multilateral sources) to recipients (sub-Saharan African countries) was studied. This is the first study to provide a comprehensive network structure of the climate finance flows into Africa, based on the global public climate finance governance system. Network theory and decision tree techniques were employed. The results obtained generally fit the multilateral funding units (MFUs) into two categories: central funding units (CFUs), which simultaneously attend to the climate-related projects of many African countries, and the boundary funding units (BFUs), which cater to only a few countries at once. An isolated region with no BFUs was identified. African countries within this group could be more exposed to climate financial risk as they rely on only the CFUs. In general, with the exception of mitigation REDD (reducing emissions from deforestation and forest degradation) climate finance, a disproportionate distribution of climate themes, with particular reference to adaptation finance, was observed across sub-Saharan Africa. This has real implications for equitable resource allocation of climate funds. The need for African-bred region-wide MFUs is recommended.

Significance:

Insights from this analysis expose the presence of contagion effects within the sub-Saharan African climate finance network structure and, consequently, the flow of climate finance-related risks. This knowledge is critical for future planning as it can provide African governments and interested stakeholders with informed evidence upon which they can make reliable and justifiable decisions, such as shaping of sectoral strategies and improving of climate finance flow coordination.

Introduction

The United Nations Framework Convention on Climate Change (UNFCCC)[1,2] defines climate finance as the local, national or transnational financing that seeks to support both mitigation and adaptation actions, with the underlying aim of addressing climate change. A similar definition given by Watson and Schalatek[3] refers to climate finance as the financial resources mobilised to fund actions that mitigate and adapt to the impacts of climate change, including public climate finance commitments by developed countries under the UNFCCC. According to the Intergovernmental Panel on Climate Change (IPCC)[4], the core objectives of climate funds are low carbon transition-related transformations; establishing a platform upon which developing countries can be assured of an unflinching support from developed nations; and an environment for nurturing technological innovation. This implies that climate finance is necessary for achieving sustainable development, most especially for developing countries, given the adverse impact of climate-related risks on the economy, society and governance. Moreover, climate finance is also owed to developing countries because developed countries are responsible for most emissions. Hence, African governments and policymakers, including climate stakeholders, need to fully understand the dynamics of climate finance distribution in order to develop better climate finance negotiations in regard to the scale of the finance required and the need for additional finance where gaps exist, and the type of finance needed. This solid grasp of climate finance dynamics also plays a major role in the aspect of accountability and planning of sustainable policies.

One core aspect that has received very little attention is climate finance flows across sub-Saharan Africa. According to the IPCC[5], one of their key themes is the need for insights into scenarios of and needs for investment, and financial flows that are connected to mitigation tracks and climate change actions both at the global and regional levels. However, although millions of dollars are disbursed periodically to different African countries to cater for climate change mitigation and adaptation projects, the quantitative studies needed to aid African governments and stakeholders in understanding how the flow of these financial resources is structured are virtually non-existent. This study aims to fill this gap. The scarcity of academic literature on climate finance has been further stressed by Working Group III (WGIII) of the IPCC, which is working on integrating climate finance research undertaken by different researchers and other actors, as highlighted by Thomson et al.[6]

The funds involved are drawn from different sectors – public, private and alternative sources. Noting that climate finance flows, from financially buoyant sources (mainly from developed countries that are responsible for the majority of emissions) to less endowed and vulnerable target groups (mainly in developing countries), are central to accomplishing the Paris Agreement[5] and in actualising climate-resilient development, it is necessary for investors, lenders, insurers, policymakers and other stakeholders across sub-Saharan Africa to possess a sound knowledge of climate finance because it affects every one of them. Such insights can be made possible through research.

The perspectives of the few existing studies on climate finance vary and are mostly qualitative. Banga[7] investigated the relationship between climate finance and structural transformation in developing countries. With the aid of the DEPSAE (driver - exposure - pressure - state - action - effect) model, Banga argued that climate finance has the potential to hasten the drive towards achieving sustainable structural transformation only if it is allocated to sectors within the environmental sphere. Bird et al.[8] examined international climate funds in terms of their governance, while Steckel et al.[9] and Bowen[10] delved into the strategies for raising climate funds. A few studies have explored the distribution, supervision and tracing of climate finance.[11-14] Additionally, others[15,16] have focused on the ethical aspects of climate finance. A total of 160 reports (consisting of 188 parties) from the Intended Nationally Determined

Contribution (INDC) climate action communications were aggregated by Zhang and Pan[17]. Of these, 28 parties concluded that the overall mitigation and adaptation demand ratio is 1: 4. With respect to quantitative studies, Bowen et al.[18] employed a number of integrated assessment models to determine the financial transfers required to equalise climate mitigation efforts across regions. They indicated a threshold of at least USD400 billion as the required amount of climate financial transfer needed to attain equality across the distributed regions. Halimajaya[19] assessed the relationship between the characteristics of 180 developing countries and the allocations they received with regard to climate mitigation from 1998 to 2010. The attributes used to characterise the nations were CO_2 intensity, volume of carbon sinks, gross domestic product (GDP) and governance. The conclusions drawn indicate that those countries that receive more climate mitigation finance have the following attributes: higher levels of CO_2 and carbon sinks, lower per capita gross domestic product, and good governance.

Empirical research focused solely on sub-Saharan Africa is limited, if at all available. This presents numerous gaps that deny African players who are actively or passively participating in climate-related issues the opportunity of completely grasping the concept of climate finance, what it entails, and how they can fully take advantage of the opportunities it presents moving forward. Quantitative mapping of adaptation finance into individual African countries and regions was undertaken by Savividou et al.[20] They found that finance targeting adaptation in Africa is a far cry from what is required to cater to the scale of the problem. Doku et al.[21] employed regression techniques to characterise recipient countries and concluded that sub-Saharan African countries with a high poverty rate, high population growth rate, and a weak corruption control system, amongst others, are more likely to attract climate finance. This result, however, seems to be at variance with that of Halimajaya[19]. From an insurance modelling point of view, Chukwudum et al.[22] examined the frequency and severity of approved climate public funds flowing into sub-Saharan Africa with the aid of various probability distribution models, highlighting the need for a risk-adjusted distribution modelling process. Bird et al.[23] give reasons why spotlighting sub-Saharan Africa is vital. The region is the most vulnerable to the adverse effects of climate change, even though it is the least responsible. Several actors are involved in channelling funds to the region, which are employed to accomplish mostly mitigation and adaptation projects in agriculture, energy and environmental policy, to mention a few. For example, Watson and Schalatek[24] note that about 42% of the global adaptation finance goes to sub-Saharan Africa. Furthermore, grants play a major role in the overall climate finance sector as donors seek to balance the gender narrative, which involves taking into account the gender perspective when developing resource mobilisation strategies and climate finance instruments. These reasons underline the urgency for more (particularly, quantitative) studies on sub-Saharan Africa climate funding, undertaken in this study.

Thus, the contribution of this paper is its analysis of the network system of donors and recipients using network theory techniques in order to characterise the static and dynamic structures of the climate finance network in sub-Saharan Africa. Further, an assessment of the balance between the different themes/objectives of climate change finance cash inflows was carried out. The fund themes are: Mitigation general, Adaptation, Mitigation REDD, and Multiple foci.

Data

The data set used in this study was obtained from the Climate Funds Update website (climatefundsupdate.org), maintained by Heinrich-Böll-Stiftung Washington DC and ODI. It provides information and data from 2003 to 2020 on the different multilateral climate finance initiatives designed to help developing countries address the challenges of climate change. The data are not time series data. The variables within the project data subset which were used in this study were: Fund, Fund Type, Country, World Bank Region, Income Classification, Name of Project, Theme/Objective, Sector (OECD), Sub-Sector, Approved Year, End Year, Amount of Funding Approved (USD millions) and Disbursed (USD millions).

All data relating to sub-Saharan Africa were extracted, giving 693 observations of country recipients only (no multi-country and regional recipients). Country entries without any stated year for their approved funds were omitted. The final data used comprised a sample size of 667 made up of 48 African countries and 20 multilateral funds (Table 1). Each fund was assigned an identity serial number. A similar identification process was done for African countries, which started from number 21 (not displayed here).

Scaling the data region-wise, the region of each country was included. These regions are southern Africa, western Africa, eastern Africa (EA) and central Africa (CA). For funding units, 'multilateral' is assigned under the 'region' column. Table 2 displays an extract.

Table 1: Multilateral funding units with their associated numeric codes

Fund	Fund's numeric code
Adaptation for Smallholder Agriculture Programme (ASAP)	1
Adaptation Fund (AF)	2
BioCarbon Fund Initiative for Sustainable Forest Landscapes (BioCarbon Fund ISFL)	3
Forest Carbon Partnership Facility – Readiness Fund (FCPF-RF)	6
Forest Investment Program (FIP)	7
Global Climate Change Alliance (GCCA)	8
Global Environment Facility (GEF4)	9
Global Environment Facility (GEF5)	10
Global Environment Facility (GEF6)	11
Global Environment Facility (GEF7)	12
Green Climate Fund IRM (GCF IRM)	13
Least Developed Countries Fund (LDCF)	14
MDG Achievement Fund (MDG AF)	15
Partnership for Market Readiness (PMR)	16
Pilot Program for Climate Resilience (PPCR)	17
Scaling Up Renewable Energy Program (SREP)	18
Special Climate Change Fund (SCCF)	19
UN-REDD Programme	20

Table 2: Region-wise categorisation of funding units/countries

Fund code	Funding unit / Country	Region
18	SREP	Multilateral
19	SCCF	Multilateral
20	UN-REDD	Multilateral
21	Angola	Southern Africa
22	Benin	Western Africa
23	Botswana	Southern Africa
24	Burkina Faso	Western Africa
25	Burundi	Central Africa
26	Cabo Verde	Western Africa

Techniques used

Here, only a brief overview of the techniques used is provided, and the technically minded reader is referred to more appropriate sources.

Networks

Social networks can be thought of as a set of individuals in which the relationship between any of the two individuals is accounted for. Let $V = \{v_1, v_2, ..., v_n\}$ be a finite set of unspecified elements. We denote the set of all ordered pairs $[v_i, v_j]$ as $V \otimes V$. The subset $A \subseteq V \otimes V$ then defines a relation to the set A. The pair $G = (V, A)$ is called a simple graph, where V represents the set of finite nodes and A represents the edges. These edges have a symmetric and anti-reflexive relation to V. An anti-reflexive edge implies that the vertex does not have an edge to itself. Several network metrics exist, such as network centrality (which is used to estimate how important a given node is, based on its level of connectivity. Key players can therefore be identified. This further gives rise to the various types of centrality measures, namely, degree, closeness, betweenness and eigenvector. Additionally, different structures of network patterns exist, like the core-periphery structure, which is a network pattern with a dense core of tightly connected nodes and a sparse periphery of nodes that are loosely connected to the core. Others include the layered and the hub-and-spoke structures.

In this study, directed networks $G = (V, A)$ were used, where A is no longer symmetric. Here, V denotes the set of all individuals present (donors and recipients) and A represents the financial linkages, that is, the set of arcs (ordered pairs). Arc $(i, j) \in A$ implies that $i \in A$ can make direct contact with $j \in A$. The flow of climate finance pledges is then tracked from donors to recipients. The multilateral climate change funds are used as proxies for the donors, given that most of these funds are funded by several countries simultaneously. A few of these countries include the UK, Germany, the USA and Sweden. Other sources of funding, such as bilateral donors[3,25], were not considered. Hevey[26] can be consulted for a deeper understanding of network theory.

Decision trees

For easy visualisation and interpretation, tree-based techniques can be employed. They basically partition the predictor variable into different portions. This method adopts an iterative process of repeated splits that are then displayed as a tree. Both regression and classification analyses can be carried out using decision trees. For the former, quantitative data are required, while the latter uses qualitative responses. In this study, the classification tree approach was adopted as it works best when predicting discrete class labels. Kotsiantis[27] gives a more detailed review of decision trees.

The modelling process and application

This section seeks to unravel the structural relationships within the climate finance flows across sub-Saharan Africa.

Network analysis of climate finance flow

In designing the network model for the data, the nodes (or vertices) represent both the donors (funding units) and the recipients (African countries) of climate finance. The edges represent the flow of climate finance, and the network describes the total relationship structure of the actors who exhibit some attributes. The main assumption is that no self-edges exist. This means that the nodes do not form ties with themselves.

For the static network, the node attributes include the funding unit/country, the region, and the amount of funding approved, which indicates the numeric node level variable. The latter is chosen instead of the amount of funds disbursed because of the problem of missing values. The summary statistics indicating the number of countries in each region are 8, 15, 8, 17, and 20 for CA, EA, SA, WA and multilateral, respectively.

However, funds approved does not automatically imply that the target countries will receive the stated funds. For example, in Supplementary table 1, although the GCF IRM fund ranks the highest in approving funds, confirming Watson and Schalatek's[23] assertion of the GCF IRM multilateral unit's approval of the largest amount of adaptation projects (in 2019), it ranks about the lowest with respect to the proportion of total climate funds disbursed to the countries to which it caters. Conversely, funding units like SCCF, MDG AF and GEF4 have completely disbursed their approved funds. This result was computed based on the assumption that there are no disbursed funds (that is, zero value) for the few missing values observed.

In order to build the dynamic network, time points are incorporated to understand the temporal nature of how the climate finance flow system is evolving. The onset, which indicates the time at which the actor came into the climate finance network, represents the year that the first project was approved, while terminus, which indicates when it left the network, represents the very last year the last project (within the period of analysis) was approved for a given African country. With respect to the funding units, this refers to the total time it distributed climate funds to different countries in Africa. The duration represents the total time spent in the network. For example, the funding unit GEF4 approved/distributed funds from the year 2006 to 2010. Thus, the onset is 2006, the terminus is 2010 and the duration is 4 years. With respect to Angola, funding for different projects was approved by different funding units from the year 2008 (representing the onset) to the year 2018 (representing the terminus). This gives a duration of 10 years.

In constructing the attributes for the dynamic network edge, all the funding units sending climate funds to a given African country were extracted. Given that the number of years taken to complete a specific project was missing for many entries, a set of standard time periods was adopted – 3 years, 5 years and 10 years, to cater for short-term, medium-term and long-term projects, respectively. The entry (onset) period therefore represents the first time a project was approved by the specific funding unit, while the terminus period makes use of the standard time adopted. The duration is the total time spent. Other attributes include the tail and head, which respectively refer to the donor and the recipient. For instance, in Supplementary table 2 (the Angola case), for GEF5, number 10 represents the tail while number 21 represents the head. In total, there were 67 node and 667 edge observations.

The static network plot is shown in Figure 1. It incorporates the labels and colour codes the donors (light blue) and the recipient countries (maroon). The outlier (number 5) in both figures refers to the Congo Basin Forest Fund (CBFF). The R packages used were ndtv and tsna.

Different network runs consistently show that the funding units can be broadly categorised into two – those at the middle and those at the boundaries. These are respectively denoted as central funding units (CFUs) and boundary funding units (BFUs) (Table 3). Furthermore, the whole network displays portions that are more dense (or connected) and portions that are less dense (sparse) at the boundaries, that is, connected boundary zones and isolated boundary zones. The more dense portions are characterised by the presence of different BFUs and the isolated zones have no BFUs. This interesting observation indicates that, while the CFUs climate finance flows to many African countries, it is the only source of funding for countries in the less dense region of the network.

A closer look at the countries at the outermost parts of the isolated region reveals that western African countries constitute more than half. These countries include Benin (21), Burkina Faso (23), Gambia (37) and Senegal (55). Those from other regions are Ethiopia (35), Sudan (61) and South Africa (59).

The CTF multilateral fund falls under the BFUs. This finding directly confirms Watson and Schalatek's[28] statement which clearly states that the CTF benefits only a small number of emerging economies. They also point out that GEF 4, 5, 6 and 7 cover most developing countries. With the exception of GEF 7, this study's findings are also in agreement, as GEF 4–6 fall under the CFUs (Figure 1), which indicates that they fund a large proportion of African countries. From the foregoing, it is safe to generalise that BFUs cater to only a few African countries while CFUs cater to many African countries simultaneously.

When the finance approved is taken as the weights, it was observed that GEF7 (with numeric code 12) is the largest BFU and South Africa (59) is

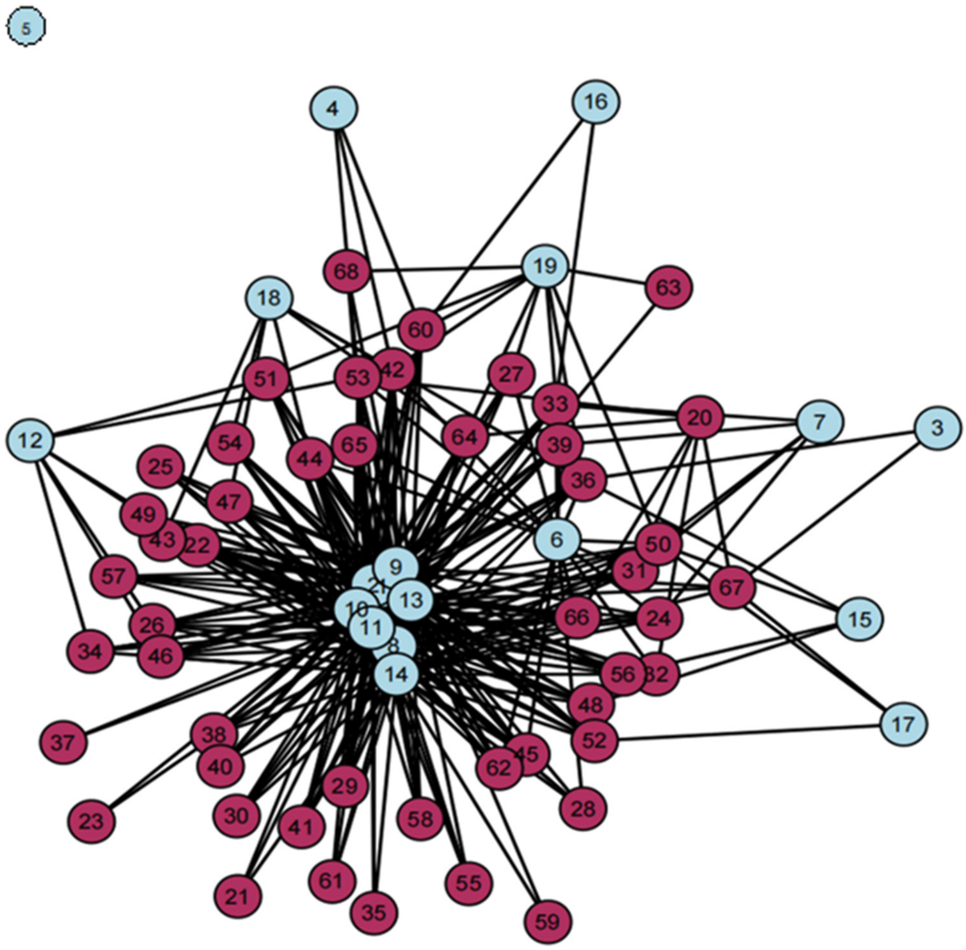

Figure 1: Static network based on climate fund transfer from multilateral funds (light blue) to different African countries (maroon).

Table 3: Boundary and central multilateral funding units

Boundary funding units	Numeric code (BFUs)	Central funding units	Numeric code (CFUs)
BCF-ISFL	3	ASAP	1
CTF	4	AF	2
FIP	7	GCCA	8
GEF7	12	GEF4	9
MDG AF	15	GEF5	10
PMR	16	GEF6	11
PPCR	17	GCF-IRM	13
SREP	18	LDCF	14
SCCF	19		

the country with the largest portion of climate finance, all coming from the CFUs (Figure 2).

To visualise the dynamic nature of the network, the filmstrip function in the ndtv R package was applied. It breaks the network up into successive temporal slices, giving us a view of the network as it develops over time (Figure 3). Hence, we get to see snapshots (that is, static plots) at a few key moments of the dynamic networks, over the lifetime of the projects.

It can be observed that longer-term project networks tend to 'mature' (or transform) faster than 5-year or 3-year duration projects. There is a persistent pattern of a sparse neighbourhood emerging around the year 2010 for the 3- and 5-year duration projects only. This pattern persists for a while up to the year 2014, for only short-term projects. In both the medium- and long-term projects, however, more dense subgroups can be observed in the latter years of formation where the transition behaviour from the year 2012 follows a similar pattern. Figure 4 denotes how centrality changes over time, year on year, based on the rolling aggregated betweenness centrality. This is an example of crucial node types which capture how much a specific node lies in between other nodes (serving as a key broker). It measures the fraction of the least paths that are passing through a given node. High values of betweenness centrality are generally used to identify vertices that preserve the whole network's connectivity. The climate finance flow network (Figure 4) experienced its lowest dip around 2007, and although it has risen since then, it has not approached its 2004 peak (or thereabout). This suggests that the connectivity of the financial flows across sub-Saharan Africa was at its lowest during the period of the global financial crisis which started in 2007 and lasted until 2009, most probably because the major key players (donors) temporarily stopped or drastically reduced funding. By 2010, after the crisis, it had stabilised a bit, but was not yet fully recovered.

Decision tree analysis of climate finance flow

The theme/objective of the data set entries was used as a guide. The four themes are Mitigation General (Mitigation G for short), Adaptation, Mitigation REDD and Multiple foci. The amount of funding approved for each country under each specific theme was then extracted as shown in Table 4 (for the first 15 countries).

Overall, across the 48 sub-Saharan African countries, a total of USD1437.95 million has been approved for projects under the Mitigation G theme, USD2038.27 million for Adaptation, USD565.58 million for

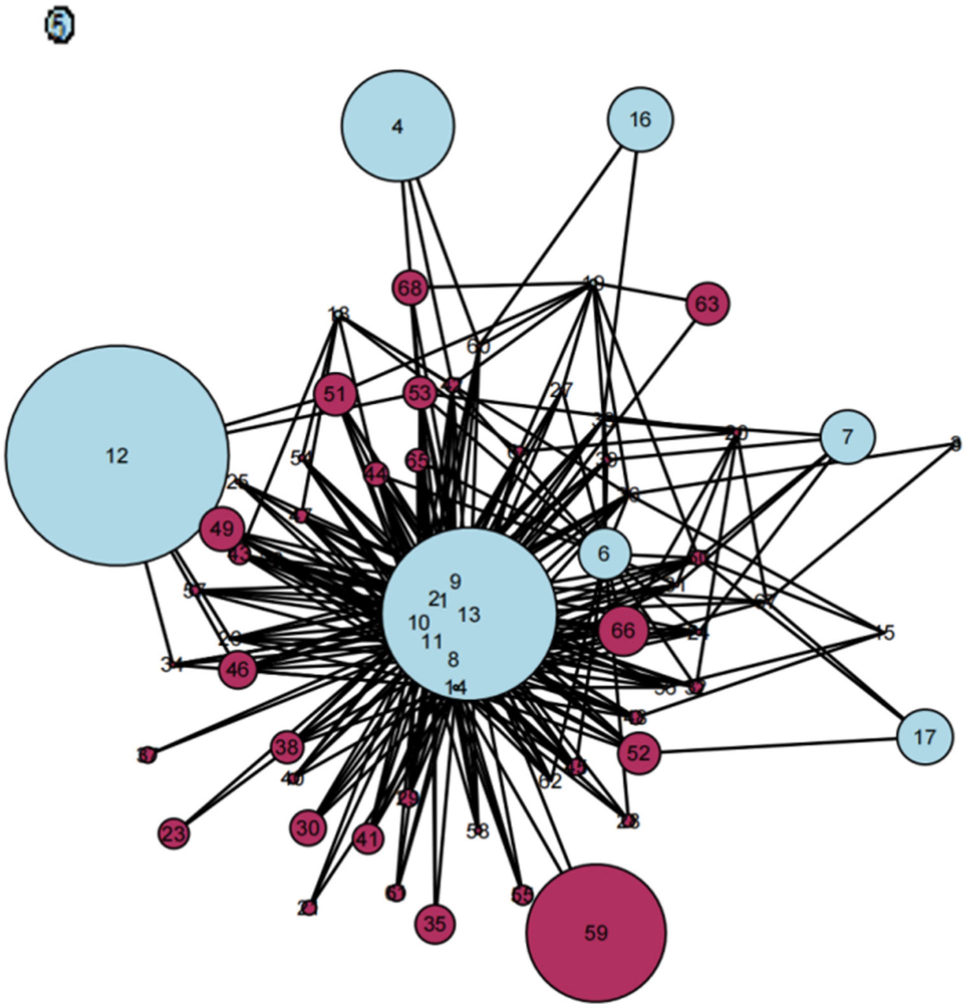

Figure 2: Weighted static network of climate finance flows from multilateral funds (light blue) to different African countries (maroon). The approved funds serve as the weights.

Mitigation REDD and USD383.85 million for projects leaning towards Multiple foci objective. This finding underlines the fact that mitigation finance dominates the total climate finance flowing into sub-Saharan Africa, as previously noted by Savividou et al.[20] This is not a healthy path for the region. The summary statistics for each objective are denoted in Supplementary table 3.

Setting region as the target variable, each variable's univariate and bivariate distribution was examined with respect to the target variable using simple histogram representations. The R packages used in this analysis were plyr, dplyr, ggplot2, caret, rpart, rpart.plot, e1071 and stringi. The univariate distributions are displayed in Figure 5.

All the themes display right-skewed distributions and possess extreme outliers. Adaptation, however, is less skewed and there are fewer very high and low values in comparison with the other objectives. Most of the Mitigation G funds fall between 0 to USD100 million (Figure 5a). The bivariate distribution is created by converting the variable region to a factor variable where the region's numeric code features are used to represent the factor levels. Region 1 refers to western Africa, region 2 southern Africa while central and eastern Africa are represented by regions 3 and 4, respectively. Each of the continuous variables (the themes) was then examined in relation to the target variable (Figure 6).

From Figure 6a, countries in region 3 (central Africa) are more likely to receive a higher proportion of Mitigation G finance if the projects fall within the range of USD100 million. However, the countries in region 2 (southern Africa) get a disproportionately high amount of Mitigation G funds as indicated by the extreme outlier. With Adaptation finance (Figure 6b), a much more evenly distributed mechanism is at play (specifically when the funds are less than USD50 million). The histogram takes the form of a bimodal distribution, where the first mode is approximately normal. In the case of Mitigation REDD, an even distribution is also observed in general, with the exception that funds greater than USD100 million are more likely to go to countries in region 3 (Figure 6c). Finally, countries that fall under region 4 (eastern Africa) are more likely to receive higher Multiple foci climate finance if it is above USD25 million (Figure 6d). These patterns also speak loudly about the kinds of climate-related projects that are more dominant in a given sub-Saharan African region.

To further classify the themes of climate finance region-wise, decision trees were built. The plots are shown in Figure 7.

Train/test split approaches were implemented in the cases of Figure 7(b–d). One node remained unused in all cases, with the exception of Figure 7d where the leaf size was lowered. Although the test accuracy for the latter is lower than that in plot c, it will be adopted because it makes use of all the nodes (regions); however, Mitigation G is not used. It should be noted that these results may not be reliable enough, given the small sample size of 48 that was used. Figure 7d indicates that region 4 (eastern Africa) fully dominates when Adaptation finance is greater than USD55 million. This aligns with the bivariate plot in Figure 6b where we see region 4 showing up 4 out of 7 times when funds are greater than USD50 million and 1 out of 7 times when less than USD50 million. This finding was observed by Atteridge et al.[29] as well. They expressed concerns over the concentration of Adaptation finance in only a small number of sectors, noting that this could hinder the broader impact of the objective.

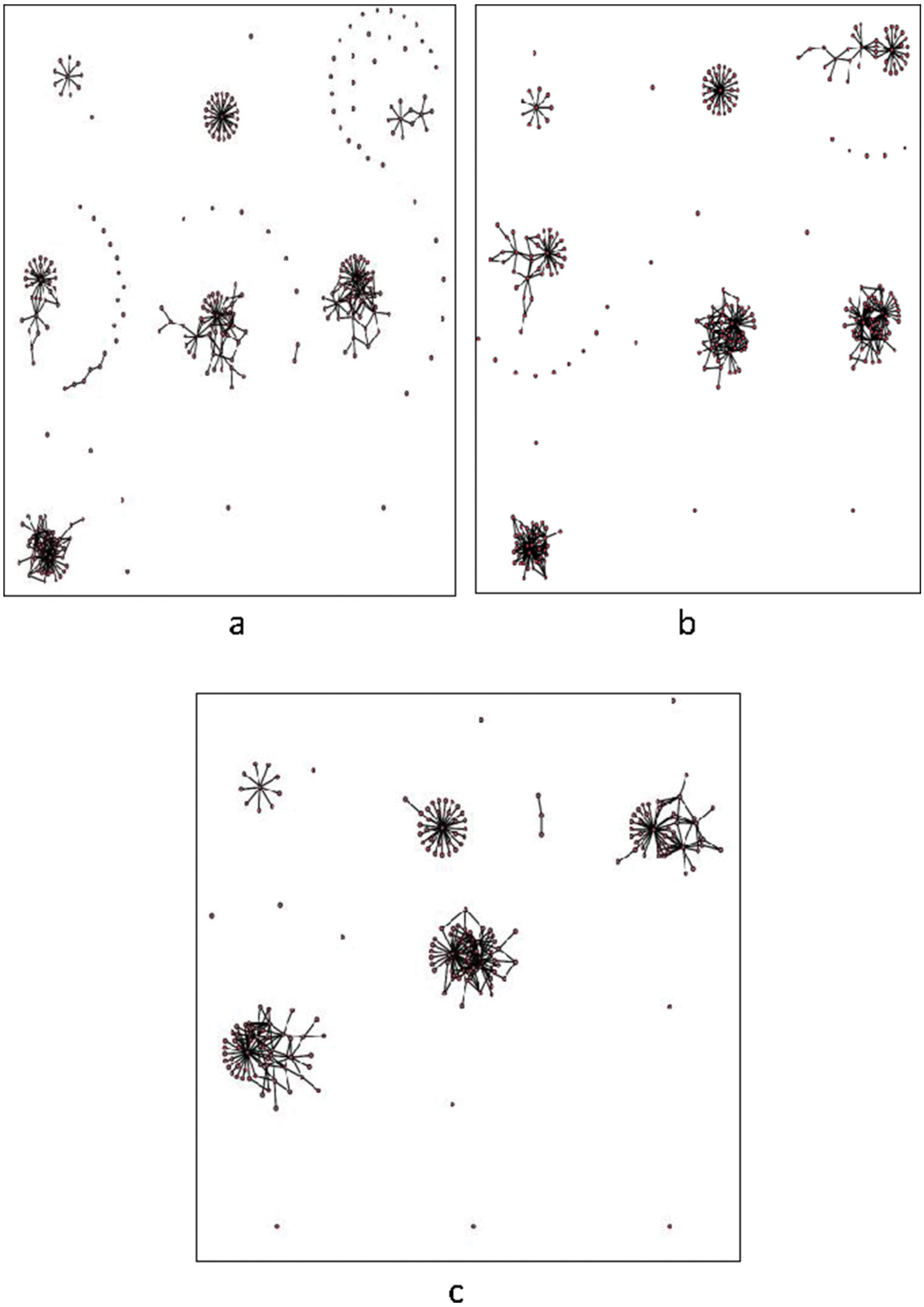

Figure 3: The (a) 3-year, (b) 5-year and (c) 10-year duration of the temporal snapshots for the dynamic network. Moving across the rows (three in each case) from left to right, the times of occurrence of the static projections of the temporal networks are t= 2003, 2005.375, 2007.75, 2010.125, 2012.5, 2014.875, 2017.25, 2019.625, 2022 for (a); t=2003, 2005.625, 2008.25, 2010.875, 2013.5, 2016.125, 2018.75, 2021.375, 2024 for (b); and t=2003, 2006.25, 2009.5, 2012.75, 2016, 2019.25, 2022.5, 2025.75, 2029 for (c).

Region 2 (southern Africa) is characterised by lower (less than USD55 million) levels of Adaptation finance with projects under Mitigation REDD costing less than USD0.98 million, and for Multiple foci, less than USD5.1 million. Region 3 (central Africa), however, gets more than USD0.98 million with regard to Mitigation REDD, even though it receives less than USD55 million in Adaptation funds. Their Multiple foci quota share is much less (less than USD1.8 million).

Implications for practitioners, policymakers, donors and regulators

About 63% of the multilateral climate funding units (studied in this paper) are yet to disburse up to 50% of their approved funds for climate-related projects in sub-Saharan Africa. This generally signifies the very slow pace at which the low-carbon, climate-resilient goal is being achieved. This is also a wake-up call to the African regions. More African regional-based multilateral funding units are needed. Both the private and public sectors should be fully involved in coordinating such climate finance pools with the associated required regulations.

Implications from network analysis: The less dense region of the network reveals some sort of vulnerable position for the countries (up to 16 of them) located therein. With the exception of South Africa, which gulps in the largest share of climate funds, the others in the sparse region have to share what is left with the countries in the denser region. Secondly, this brings to the fore the issues surrounding equitable

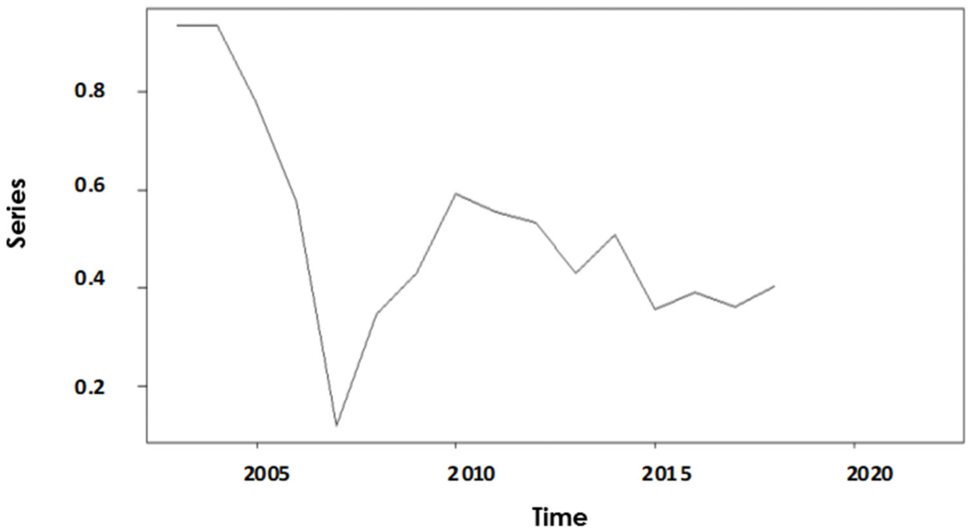

Figure 4: Year-on-year aggregated betweenness centrality changes for the temporal network.

Table 4: Approved funds for sub-Saharan African countries based on the themes

Country	Region	Region's numeric code	Mitigation G (USD millions)	Adaptation (USD millions)	Mitigation REDD (USD millions)	Multiple foci (USD millions)
Angola	Southern Africa	2	8.16	25.67	0	0
Benin	Western Africa	1	7.52	51.1	2.63	1.89
Botswana	Southern Africa	2	2.63	0	0	0.95
Burkina Faso	Western Africa	1	29.65	49.3	53.07	5.92
Burundi	Central Africa	3	3.4	22.86	0	0
Cabo Verde	Western Africa	1	4.53	7.28	0	8.12
Cameroon	Central Africa	3	3.73	4.03	13.99	0.34
Central African Republic	Central Africa	3	2.65	10.12	7.6	0.63
Chad	Central Africa	3	4.99	35.84	0	14.64
Comoros	Eastern Africa	4	5.91	69.93	0	3.76
Congo, Democratic Replubic of	Central Africa	3	28.15	26.86	120.91	0.96
Congo, Republic of	Central Africa	3	5.07	10	22.78	0.66
Cote d'Ivoire	Western Africa	1	8.35	6.34	49.31	4.24
Equatorial Guinea	Central Africa	3	4.36	0.2	5.93	0.9
Eritrea	Eastern Africa	4	0	15.77	0	8.26

resource allocation of climate funds, given the scarcity of BFUs allocating funds to a number of African countries. A situation in which the CFUs are overburdened might ensue, leading to the unexpected accumulation of approved funds if this type of setup tarries for a long time. An example of such a situation might be during a financial crisis. In the absence of alternative (boundary) multilateral funding units, the isolated regions are bound to suffer the most.

It must also be noted that while South Africa is the largest emitter of carbon in Africa, hence requiring more climate funds (particularly mitigation finance), the climate change issue remains a global problem. The attainment of low carbon across African countries will as well impact South Africa positively, judging from the extremal dependence of climatic variables that may be present in African regions, eastern Africa for example.[30] This therefore implies that a fair balance for climate fund allocation needs to be struck by the donors. Thirdly, the presence of this gap presents opportunities for practitioners seeking to engage in the global/continental climate fund negotiation processes, as the entry of more multilateral funding units can help limit the monopolisation of African countries' access to international funds. Fourthly, the structure of the network seems to suggest a greater coordination between CFUs than BFUs, although this may not be reflective of the real situation. Nevertheless, there is need for greater coordination between the funding units at the boundaries and at the centre to enable every African country to benefit from both sources.

Implications from decision tree analysis: Although eastern Africa is arguably the hardest hit region in terms of the adverse effects of climate

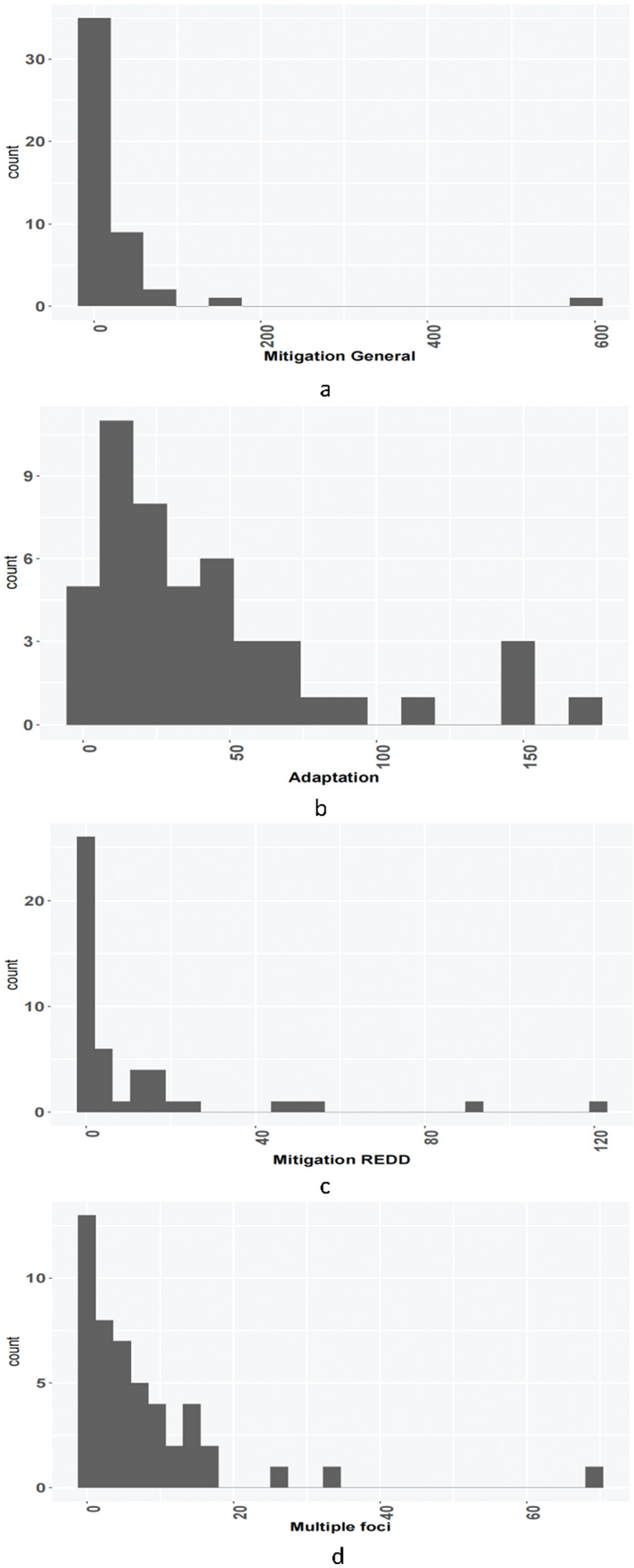

Figure 5: Univariate distributions of themes (a) Mitigation G, (b) Adaptation, (c) Mitigation REDD and (d) Multiple foci, with respect to the different African regions.

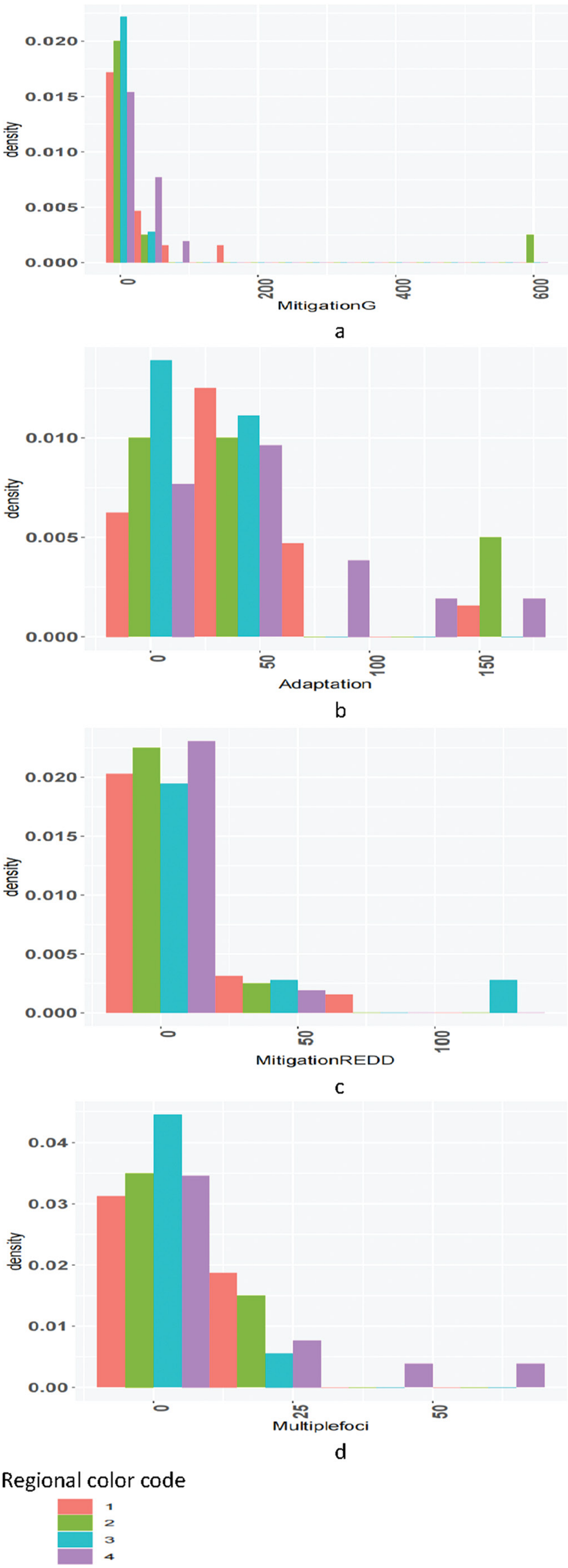

Figure 6: Bivariate distributions of themes with respect to the countries' regions: western Africa = 1, southern Africa = 2, central Africa = 3, and eastern Africa = 4 in the colour-coded key.

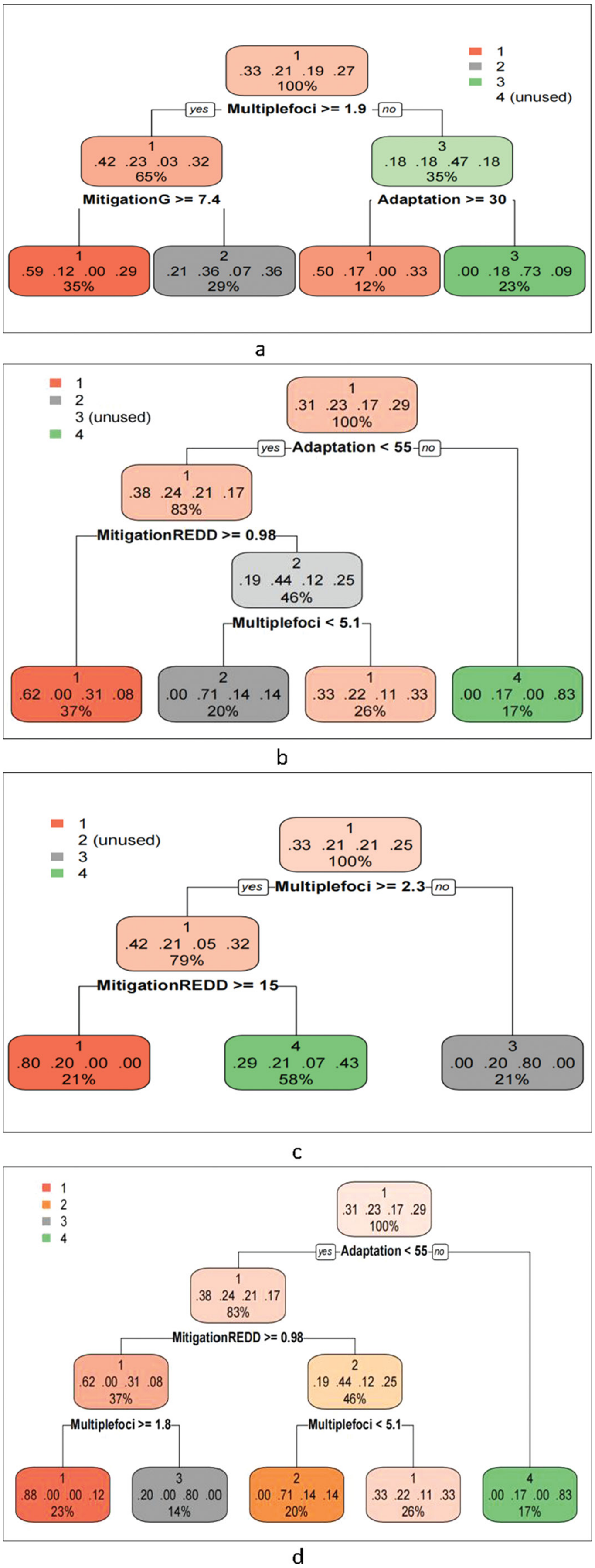

Figure 7: Decision trees classifying the climate finance themes region-wise. (a) No partition, (b) 70/30 partition with test data accuracy=7%, (c) 50/50 partition with test data accuracy=33%, (d) 70/30 partition with a lowered leaf size and test data accuracy=23%.

change in Africa, the highly unequal distribution of Adaptation finance for funds greater than USD50 million may be a matter of concern. This is due to the critical assistance other African countries currently need (particularly in the area of agriculture) in order to adapt to the rapid increase in the impacts of climate change already being experienced as a result of droughts and floods. Rapid desertification, for instance, lies at the base of the farmer–herder violence in northern Nigeria, which has since reached crisis levels, leading to the loss of thousands of lives and property, massive internal displacements, and heightened food insecurity.[31-33] Adequate adaptation funds will definitely go a long way in resolving this problem (all else being equal).

Conclusion

Climate finance holds the key to obtaining the goals set for achieving a low-carbon world. However, the complexities involved in monitoring its flow across sub-Saharan Africa have not been thoroughly dealt with. This study was an in-depth critical look at how the flow is structured. The results obtained generally fit the multilateral funding units into two categories: the central and boundary funding units. Although more African countries have the opportunity of a boundary funding source which supplements the central source, a substantial number of countries remain in the isolated region at the boundary as they rely only on the central funding units, thus increasing their vulnerability. This vulnerability can become even more evident when shocks such as pandemics and financial crises are introduced into the system, as the flow of money declines significantly during such periods. Hence, there is a need for the major stakeholders in the concerned countries to highlight these issues when negotiating for climate finance. Plus, other alternatives can be prepared ahead of time because mitigation and adaptation strategies for climate change demand huge amounts of finance.

Nevertheless, further studies are required to understand the evolution of this vulnerable group when other climate funding sources are accounted for, such as multilateral, bilateral, grant-type, national and local government sources. Additionally, the diverse nature of the countries in Africa implies that each has their own special climate-related problems, risks, and solutions. The complexities of how climate money is distributed within individual countries and each country's unique needs and efforts may be overlooked if countries are grouped into broad regional groupings. Other variables such as political links, past obligations, and the success of national climate policy also affect how climate financing is allocated. Hence, country-specific analyses of climate finance flows and their effects might offer a more perceptive viewpoint on the matter. To this end, African governments are encouraged to give keen attention to data collection and data storage. There is also a need to understand if there are any patterns emerging that differentiate projects into fully disbursed finance versus those that have partially disbursed finance, the regions affected and the reasons for failure to disburse funds.

Competing interests

I have no competing interests to declare.

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