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Enhancing spectrum management analysis to optimize economic value

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ABSTRACT

This study examines how improved spectrum management can enhance economic value in Somalia by focusing on spectrum band valuation, allocation strategies, and the alignment of licensing models with market conditions. Spectrum management involves administrative, scientific, and technical measures to regulate radio frequencies, aiming for efficient use and support of telecommunications growth. Using a cross-sectional descriptive design, the study gathers data from various stakeholders, including telecommunications companies, regulators, and consumers, through surveys, interviews, and document reviews. The findings show that aligning spectrum allocation with economic and social goals increases societal benefits. A clear regulatory framework supports competitive bidding, reduces uncertainty, and encourages fair access. Most participants viewed current allocation methods as moderately effective, while spectrum auctions were identified as key tools to reduce spectrum misuse and boost economic value. Somalia's primary hybrid licensing model, along with market-based pricing and secondary trading, plays a vital role in ensuring spectrum is used efficiently. The study recommends transparent, demand-driven pricing models and competitive auctions to ensure fair pricing and effective distribution. As technologies like 5G and IoT drive new usage demands, adaptable spectrum management is essential to foster innovation, meet future needs, and promote economic development.

1. Introduction

Spectrum management, which encompasses a combination of administrative, scientific, and technical procedures for effectively administering the radio frequency spectrum, is the process of regulating radio frequency use to maintain Effectiveness and overall social benefit (Matinmikko and Mustonen, 2019; Yun and Lee, 2021). The radio spectrum wirelessly transmits information for various services, including television, radio, mobile phones, Wi-Fi, baby monitors, GPS, and radar (GSMA, 2017). Spectrum management goals include rationalizing and optimizing spectrum use, avoiding and solving interference, designing short and long-range frequency allocations, advancing the introduction of new wireless technologies, and coordinating wireless communications with neighbors and other administrations (Brown and Rong, 2024).

The young physicist Heinrich Hertz is credited with creating the first radio transmitter in the world in the 1880s, which could transmit a signal a few meters in length. In 1897, Guglielmo Marconi achieved the first wireless signal transmission. In 1907, the first functional oscillator and transmitter for broadcasting was developed. The technology supporting mobile radio was initially employed in the 1890s to help ocean-going ships, which had previously relied on carrier pigeons and flags for communication. RF Matthews was the first ship to use a wireless device to solicit emergency assistance (Percy et al., 2012).

The concept of spectrum management began to take shape in 1927 when the International Radio Consultative Committee (CCIR) laid the groundwork for spectrum management, which evolved into the International Telecommunication Union Radiocommunication Sector (ITU-R) in 1992 (Rosenberg, 2022). In the 1930s, Spectrum was first assigned through administrative licensing, which was intended to prevent signal interference by issuing exclusive licenses to specified users. With the

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expansion of satellite communications and the introduction of mobile telephony in the 1960s and 1970s, spectrum management became more complex, establishing more advanced regulatory frameworks.

By 2000, the expansion of wireless broadband and the Internet of Things (IoT) prompted additional changes in spectrum management, with numerous countries moving toward shared spectrum regulations to accommodate the expanding number of wireless devices.

It is no longer considered a luxury to own a computer or any other information and communication technology (ICT) device in the home today. Questions about the spectrum management framework are also raised by the new opportunities brought forth by the evolving communication landscape (Ciupac-Ulici et al., 2022). Following the development of broadcast or "wireless" communication, numerous private properties were distributed under common law based on the "first-in-time" principle, as were rights to use a certain electromagnetic Spectrum frequency. This approach gave exclusive usage rights to the first person to claim a frequency. Through temporary licensing agreements, broadcasters were given access to specific channels in the Spectrum (Brotman, 2017).

1.1. International spectrum management

The International Telecommunication Union (ITU) is the United Nations specialized agency for information and communication technologies that oversees the usage of both the RF Spectrum and space satellites by nations. The ITU coordinates global spectrum management operations, ensuring that radio frequencies are used efficiently and without detrimental interference (ITU, 2023). Harmonized Spectrum utilization among nations is crucial for international roaming, interconnection, and cost-effective radio communication services.

The ITU is divided into three sectors: the International Telecommunication Union Telecommunication Standardization Sector (ITU-T), which creates globally recognized technical and operational standards; The International Telecommunication Union Development Sector (ITU-D), which supports the development of telecommunications infrastructure in developing countries worldwide, which account for two-thirds of the ITU's 194 Member States; and the Radiocommunication Sector (ITU-R), which establishes the technical features and operational procedures for wireless services and is essential to the management of the radio frequency spectrum. Notably, national regulatory agencies oversee Spectrum use within their own countries while balancing the needs of various consumers and services. "The sovereign right of each State to regulate its telecommunications" is fully acknowledged in the ITU constitution. National, regional, and international regulations are necessary for effective spectrum management (ITU, 2023). Every three or four years, the ITU-R hosts the World Radio Communication Conference (WRC), which updates the Radio Regulations in response to changes in spectrum needs and demands (Brotman, 2017).

1.2. Spectrum management in Africa

Spectrum management in Africa is an important part of the telecommunications industry, supporting the continent's growth and innovation. Even though Africa's telecommunications industry has undergone remarkable expansion and innovation, according to Pedros et al. (2020), Africa has licensed less Spectrum than the rest of the globe, having licensed only 70-80 percent of the given Spectrum compared to the other growing economies. Africa accounts for only 8% of total worldwide connections; the number of connections in Sub-Saharan Africa has expanded at a 30% Compound Annual Growth Rate (CAGR) since 2000, a rate that is expected to rise to 44% in the coming years. Despite significant advances in the growth of mobile services and mobile internet connectivity, 50% of people in Africa (680 million people) did not use mobile phones, and nearly 75% (950 million people) did not have access to mobile internet services in 2019 (Pedros et al., 2020). Efficient management of mobile infrastructures is essential, given the significant role that telecommunications play on the continent, which should include the management of Spectrum and its availability to telecommunications operators.

1.3. Spectrum management in Somalia

Somalia is making progress in managing its radio frequencies to support the growth of its telecoms network. The National Communications Authority (NCA) is spearheading this endeavor, including establishing a Spectrum Monitoring Operations Center (SMOC). This center will improve the monitoring and assessment of spectrum usage nationwide. The SMOC's primary function will be to detect activities that could compromise the integrity of the Spectrum. By enhancing airwaves monitoring, the NCA intends to swiftly tackle interference issues that may disrupt communication services (NCA, 2023).

The NCA has rolled out detailed Spectrum Licensing Regulations designed to enhance spectrum resource planning, utilization, and management. With the establishment of guidelines and standards, the NCA seeks to foster the use of the radio frequency spectrum crucial for developing and sustaining communication services in Somalia. These regulations are anticipated to spur innovation in the telecommunications industry. By introducing a spectrum allocation and usage framework, the NCA is potentially paving the way for market entrants to boost competition. Such competition reduces costs and enhances the quality of services offered to a consumer. These initiatives closely align with Somalia's broader vision of creating a digitally connected nation. By improving the management of spectrum resources, the NCA plays a role in enhancing telecommunications services nationwide. This supports the growth of a strong digital economy where reliable communication services are essential for progress and advancement. Somalia's spectrum management efforts, led by the NCA, include establishing the SMOC and introducing comprehensive licensing regulations, which are vital for improving telecommunications service quality. These initiatives focus on optimizing spectrum usage and encourage innovation and competition within the industry, ultimately contributing to the country's goal of becoming a digitally connected society.

1.4. Spectrum economic value

The direct Economic Value of spectrum licenses refers to the monetary value obtained through auctions, fees, or other sources, including revenue received by governments or regulatory organizations. An assortment of variables determines the economic value of the Spectrum; nevertheless, certain fundamental valuation assumptions can be employed (ITU, 2023). The economic value of the spectrum license considers factors such as market demand, technological advancements, and regulatory environments, which can be expressed as the net present value of the future stream of profits that a license holder expects to receive from the Spectrum.

There is no easy formula for calculating the absolute economic worth of Spectrum, which is determined from the economic and social values it provides as an input into the provision of wireless services. Users will value a specific band differently at different times because spectrum administrators frequently guarantee that each band is put to the best possible societal and economic use. The direct economic value of the service providers creates a consumer surplus for the service providers. Essentially, the total social benefits from the license of the Spectrum are 10 to 20 times the direct economic value of the Spectrum, as depicted in Fig. 1.

A spectrum license's economic worth is the net present value of the future stream of income expected by the license holder from the Spectrum. However, the mobile Spectrum has enormous physical and intangible benefits for a country's economy. The mobile sector generates enormous economic activity and has a large impact on the whole national economy.

To support affordable, high-quality mobile broadband services, fair access to an adequate radio spectrum is essential. Governments and regulators play a vital role in managing this limited resource to foster a dynamic digital economy. As mobile traffic is expected to grow exponentially over the next decade, driven by billions of connected devices, the demand for efficient spectrum management becomes increasingly urgent. This demand is further fueled by the rapid expansion of essential digital services such as electronic banking, education, health, and commerce, which require high reliability and low latency. In Somalia, effective spectrum management aims not only to reduce spectrum pollution but also to maximize economic value, contributing to the country's digital transformation.

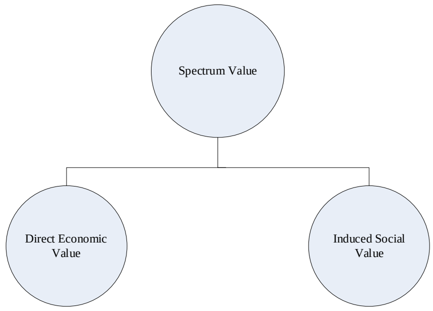

Fig. 1: Economic worth of spectrum

Spectrum management is fundamental to national economic growth, especially in the telecommunications sector, which drives economic activity and technological advancement. Beyond supporting communications, Spectrum plays a critical role in public safety, air traffic control, and weather forecasting (Rosenberg, 2022). The global reliance on effective spectrum management to facilitate seamless cross-border device usage highlights the need to continuously enhance these management processes. Accurate valuation of Spectrum mitigates commercial risks and depends on setting appropriate restrictions, obligations, and network coverage requirements. Moreover, a clear spectrum roadmap from regulators, outlining future spectrum plans, assists operators in long-term planning and investment, guiding them on whether the licenses are unique or will be recurrently auctioned. This study aims to analyze how enhanced spectrum management can optimize economic value in Somalia, supporting sustainable economic growth and digital advancement. Specifically, it seeks to:

1. Determine the economic value of various spectrum bands based on their potential use and demand.
2. Compare spectrum allocation approaches that maximize revenue while ensuring fair access and competitiveness.
3. Assess the economic and societal impacts of spectrum allocation decisions within the community.
4. Evaluate if current spectrum licensing pricing models are aligned with market value and promote efficient usage.

By addressing these questions, the study intends to provide insights into the economic potential of optimized spectrum management in Somalia, highlighting strategies that can contribute to national growth and digital innovation.

2. Literature review

Spectrum management has become essential in maximizing economic and social value within the telecommunications sector. This review examines studies related to the economic valuation of spectrum bands, allocation methods that promote efficient usage and revenue optimization, the economic impact of spectrum allocation on communities, and spectrum licensing pricing models. By addressing these areas, this review seeks to provide a comprehensive understanding of how spectrum allocation decisions can balance financial goals with broader social benefits, supporting digital inclusion and competitiveness.

2.1. Economic value of spectrum bands

The economic value of spectrum bands is largely determined by their demand and utility in specific applications. Spectrum bands in Africa are classified into licensed and unlicensed bands. Licensed spectrum bands are reserved for specific users, typically through a regulated process, and offer dedicated, reliable communication channels essential for applications requiring consistent service quality. Such bands are prioritized during spectrum scarcity, making them valuable assets for telecom operators and other organizations requiring uninterrupted connectivity. Unlicensed spectrum bands, on the other hand, allow flexible usage without regulatory costs, making them attractive for low-cost communication solutions. However, this flexibility comes with increased risk of interference, impacting service quality in congested areas.

With the rise of 5G technology, there has been an increasing demand for high-frequency bands, particularly millimeter wave spectrum, which supports high data rates and low latency. However, the growing need for millimeter wave spectrum challenges traditional spectrum allocation methods. Regulators are now facing pressure to balance the need for high-frequency bands for advanced 5G services with the continued demand for lower-frequency bands used in conventional wireless communication (Feng et al., 2016). Estimating the economic value of spectrum bands requires considering factors such as market demand, technical characteristics, geographic coverage, and competitive landscape, which collectively determine the value of these bands in economic and societal terms (Randolph, 2017).

2.2. Spectrum allocation approaches

Spectrum allocation approaches vary widely, with strategies aimed at maximizing revenue, ensuring fair access, and promoting efficient usage. Spectrum auctions are one of the most common methods, particularly for cellular telecommunications, where the government grants exclusive spectrum rights to the highest bidders. This approach ensures that Spectrum is allocated to parties that value it most highly, promoting efficient use and competition while generating significant public revenue (Kane et al., 2023). Auctions are often designed with specific objectives, such as encouraging widespread network deployment or preventing monopolistic control.

Dynamic spectrum allocation (DSA) is another approach that leverages real-time adjustments in response to availability and demand. DSA enables multiple users to share the same spectrum bands based on network conditions, spectrum quality, and user requirements. This approach is closely associated with cognitive radio technology, where devices can detect and adapt to their surroundings to use the Spectrum more efficiently (El Gamal and Kim, 2011). DSA enhances spectrum utilization by enabling dynamic reassignment, making it a flexible solution for managing scarce spectrum resources, especially in urban environments with high demand.

Spectrum sharing and leasing models provide an alternative to exclusive licensing by allowing multiple users to access the same Spectrum without causing harmful interference. This approach is particularly beneficial in rural or underserved regions where demand may be lower, enabling more efficient use of Spectrum through temporary or flexible access arrangements (Feng et al., 2016). Spectrum sharing and leasing have also been explored in high-demand areas to increase access, reduce idle bandwidth, and enhance overall utilization rates. These models are supported by regulatory frameworks that allow spectrum holders to lease their rights temporarily, thereby creating new revenue streams.

2.3. Economic impact of spectrum allocation decisions

Spectrum allocation decisions have far-reaching implications for economic growth, local businesses, job creation, and digital inclusion. By providing access to digital tools and services, spectrum allocation enables local businesses and entrepreneurs to leverage technology, driving competitiveness and innovation. The deployment of 5G and other high-speed networks through efficient spectrum allocation is essential for supporting digital infrastructure, which benefits sectors like healthcare, education, and finance (Kerrigan, 2023). Access to advanced technologies also helps bridge the digital divide by extending connectivity to underserved communities, promoting social inclusion and equity.

Financially, spectrum allocation methods such as auctions generate significant government revenue by awarding Spectrum to the highest bidders. Incentive-based allocation, where spectrum holders are encouraged to release or share unused Spectrum, maximizes utilization and can reduce the cost of network expansion for telecom operators (Lewis and Johnson, 2023).

Beyond direct financial benefits, spectrum allocation provides societal value by enhancing public services, supporting emergency communications, and facilitating technological innovation. For example, allocating Spectrum for public safety networks improves the reliability and responsiveness of emergency services, contributing to overall community resilience (GSMA, 2017).

In addition to direct financial benefits, spectrum allocation supports the broader economic ecosystem by fostering an environment conducive to innovation. By enabling connectivity for IoT, smart cities, and autonomous vehicles, spectrum allocation decisions drive economic activity and productivity, resulting in long-term socioeconomic gains (Suardi and Castells, 2022). Efficient spectrum management is also seen as an essential component of environmental sustainability, as it promotes innovative technologies that reduce energy consumption and emissions.

2.4. Spectrum licensing pricing models

Spectrum pricing models are critical in determining the accessibility and efficient use of spectrum resources. In many African countries, spectrum prices are significantly higher than in developed regions, which can deter investment and raise consumer costs (Pedros et al., 2020). Governments often set reserve prices to control minimum bidding levels, but excessively high reserve prices can discourage participation and reduce network investment, ultimately impacting service affordability. Auction design is an important factor in setting spectrum prices. Poorly designed auctions can inflate prices or create barriers for smaller operators, while well-structured auctions balance the need for revenue with the goal of promoting competition and accessibility (GSMA, 2017). Challenges in aligning spectrum pricing with market value include determining fair reserve prices, managing the timing and frequency of auctions, and balancing upfront fees with annual charges.

Efficient spectrum pricing models align with market demand and incentivize usage by offering flexible pricing arrangements. Governments may implement spectrum-sharing incentives, encourage the use of innovative technologies, and promote secondary markets where Spectrum can be leased temporarily. Such strategies help to align spectrum prices with market value, fostering efficient utilization without compromising accessibility. Financial incentives, such as subsidies for rural connectivity or tax breaks for technology upgrades, can further encourage spectrum-efficient practices and benefit underserved areas (Li et al., 2016).

Despite significant research on spectrum management, there are notable gaps in understanding how emerging technologies like artificial intelligence (AI) can optimize spectrum usage. AI-enabled spectrum management could enhance real-time frequency allocation, improve demand prediction, and minimize interference, but research on these applications remains limited. Furthermore, socioeconomic considerations—such as population density, income levels, and digital literacy—are often underexplored, though they influence both spectrum demand and access equity. Studies on inclusive spectrum policies that address the needs of marginalized or rural communities are particularly lacking. Future research could explore the integration of AI in spectrum management and develop frameworks for inclusive spectrum allocation that maximize both economic and social value.

2.5. Conceptual framework

The conceptual framework underlying this study was based on the concept of enhancing spectrum management analysis to optimize economic value in Somalia. The conceptual framework has presented the independent variables (Fig. 2), which include an economic value, spectrum allocation approaches that optimize revenue while guaranteeing fair access and competitiveness, economic impact of spectrum allocation decisions on the community, and Spectrum licensing pricing models. The dependent variable will be the optimized economic value. The moderating variables include the regulatory and supportive environment.

3. Methodology

This study investigated the relationship between spectrum management practices and economic optimization. A descriptive research design was adopted to observe and describe the characteristics of spectrum management without manipulating any variables. To enable efficient and cost-effective data collection, a cross-sectional survey design was employed. This approach was appropriate for gathering both quantitative and qualitative information within a limited timeframe.

The target population for the study comprised 7,800 individuals involved in spectrum management, including telecommunications companies, regulatory bodies, policymakers, technology developers, economic analysts, consumers, and academic researchers. These groups were selected because of their relevant roles and insights into the economic value and management of spectrum resources. Using Cochran's formula, a sample size of 262 respondents was determined to ensure adequate statistical representation. A multi-stage sampling technique was adopted, beginning with stratified random sampling to ensure proportional representation from the different sectors. This helped capture the diversity of viewpoints and reduced sampling bias.

Data collection was carried out using questionnaires and interviews. The questionnaire consisted of both open-ended and closed-ended questions. A 5-point Likert scale was used for most closed-ended items, adapted from relevant literature. To ensure wide reach and ease of access, questionnaires were distributed digitally via Google Forms using email, WhatsApp, and Telegram. In addition, interviews, including key informant interviews, were conducted to gain deeper qualitative insights. These interviews included both structured and semi-structured questions to allow for both consistency and depth in responses.

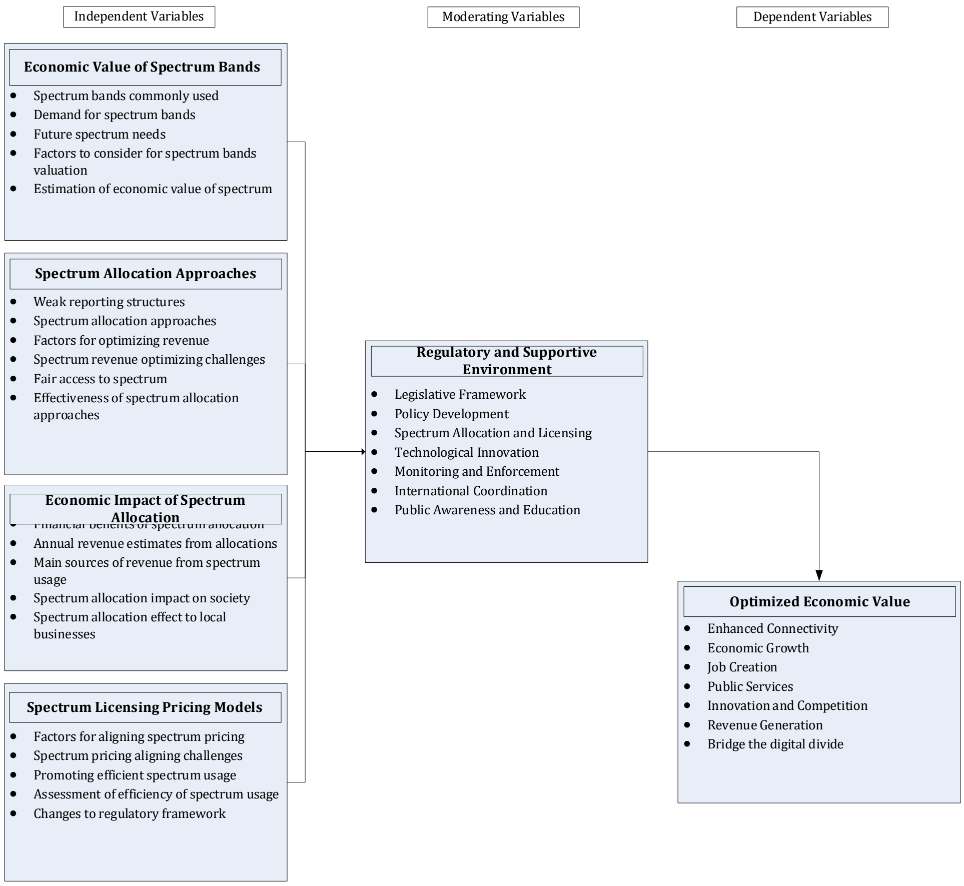

Fig. 2: Conceptual framework for enhancing spectrum management analysis to optimize economic value

Data analysis was performed using Microsoft Excel. Descriptive statistics such as frequencies, percentages, means, and standard deviations were computed to summarize the data. Relationships between key variables were explored through cross-tabulations and correlation analysis. For model testing, Partial Least Squares (PLS) path analysis was conducted manually in Excel, involving calculations of path coefficients, R^2 values, and other relevant indicators based on standard analytical procedures.

Despite the robustness of the methodology, certain limitations must be acknowledged. The use of online surveys may have introduced response bias, particularly among participants with limited digital access or varying levels of interest. Although stratified sampling helped ensure representation across sectors, non-responses from certain groups may have affected proportionality. Furthermore, the use of Excel for PLS analysis, while sufficient for this study's scope, lacked the advanced features and automation available in more specialized tools such as SPSS or SmartPLS. Nonetheless, the methods employed were suitable for addressing the study objectives and generating valuable insights into how spectrum management practices influence economic optimization.

4. Results and discussion

The study aimed to collect data from a sample size of 262 respondents, which was calculated using research scientific processes. However, data was collected from a total of 195 respondents, which was 74.4% of the proposed sample size.

As presented in Table 1, the demographic and professional characteristics of the 195 respondents provide a comprehensive snapshot of the study's sample, representing a 74.4% response rate from the target sample size of 262 individuals. This diverse group includes most male participants (70%), with the age groups 2534 and 35-44 making up a significant portion (37% each), highlighting the active involvement of mid-career professionals. The educational background spans diploma (41%), degree (37%), and postgraduate (22%) levels, reflecting the high qualification levels among respondents. The roles within this sample cover critical sectors utilizing Spectrum, with Telecom Operators comprising the largest segment (41%), followed by Researchers (22%), Policymakers (22%), and Regulators (15%).

Table 1: Demographic and professional characteristics of respondents

Variable	Category	Frequency	Percentage
Gender	Male	137	70%
	Female	58	30%
Age	25–34	73	37%
	35–44	73	37%
	45–54	43	22%
	55 and above	6	3%
Education	Diploma	79	41%
	Bachelor's	73	37%
	Postgraduate	43	22%
Role	Telecom operator	80	41%
	Researcher	43	22%
	Policy maker	43	22%
	Regulator	29	15%

4.1. Economic value of different spectrum bands

Different frequency bands are utilized in Somalia to offer a range of communication services. This wide-ranging use of spectrum bands ensures reliable connectivity across the country, which has faced significant challenges with its telecommunications infrastructure due to years of conflict and turmoil. Several of the spectrums are used for mobile and communication services. The National Communications Authority of Somalia allocates and manages the bands to guarantee optimal usage and support of the country's communication infrastructure. According to the NCA (2023), Table 2 shows the spectrum preferences in Somalia.

The increasing need for spectrum bands in Somalia is driven by the need for the expansion of mobile broadband services, the requirement for improved communication networks, and a growing number of users seeking dependable connectivity. The findings show the current demand for spectrum needs as indicated in Fig. 3.

The firm should assess its existing spectrum utilization and forecast future requirements based on expected growth, technical developments, and new services. This involves assessing the implications of upcoming technologies like 5G, IoT, and AI. The research findings demonstrate the organizations' future needs, as illustrated in the graph below. Organizations require more and more bandwidth to support their applications. Other requirements have been observed at varying levels, as shown in Fig. 4.

Table 2: Common spectrum bands used in Somalia

Band	Application
450 MHz	Mobile and fixed communications
700 MHz	Mobile broadband services
800 MHz	Mobile broadband
900 MHz	GSM services
1800 MHz	GSM and LTE services
2100 MHz	3G services
2300 MHz	LTE services
2600 MHz	LTE services
3500 MHz	Fixed wireless access and emerging 5G

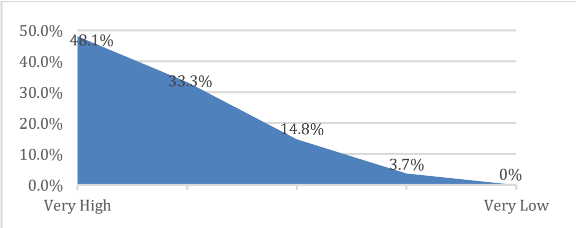

Fig. 3: Current demand for spectrum bands in Somalia

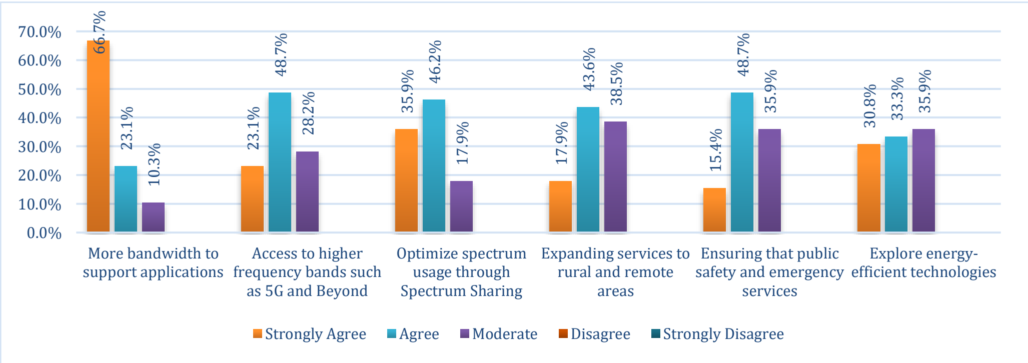

Fig. 4: Organizations' projected future spectrum needs

Estimating the economic value of spectrum bands involves assessing their potential contributions to various sectors. The study findings show various processes that are preferred for the estimation of the economic value of spectrum bands. Fig. 5 shows the preference used for the estimation.

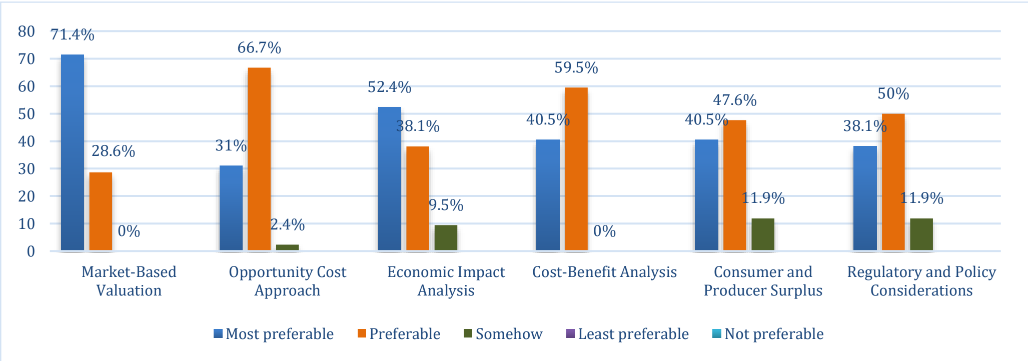

Fig. 5: Preferred methods for estimating the economic value of spectrum bands

Assessing the socioeconomic impact of spectrum usage is crucial for understanding its broader benefits and guiding policy decisions.

Fig. 6 shows the responses of various organizations on the most likely methods organizations use to assess the socioeconomic impact of spectrum usage. The findings show that most organizations are likely to use the methods provided to assess the socioeconomic impact of spectrum usage.

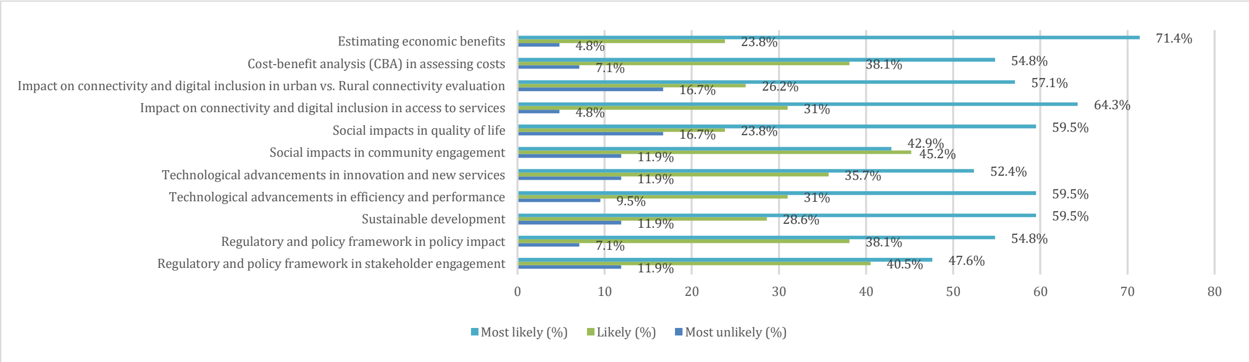

Fig. 6: Methods used to assess the socioeconomic impact of spectrum usage

4.2. Spectrum allocation approaches

The National Communications Authority in Somalia adopts a methodical and inclusive stance when it comes to distributing the radio spectrum. Additionally, the NCA has initiated a consultation process for its National 5G Strategy involving stakeholders and the wider public to develop a well-rounded and effective spectrum allocation plan, as indicated in Fig. 7.

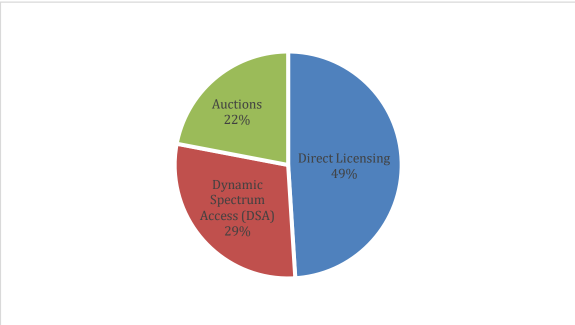

Fig. 7: Spectrum allocation approaches adopted by organizations

The research findings show that Somalia mainly relies on licensing for spectrum allocation. This approach entails issuing licenses to operators, granting them exclusive rights to utilize specific frequency bands for their telecom services. Direct licensing is preferred due to its simplicity and capacity to establish ownership and regulatory structures that promote efficient and effective spectrum usage. Although direct licensing continues to be the strategy for spectrum allocation in Somalia, the integration of dynamic spectrum access and auction methods demonstrates an ongoing initiative to enhance and improve the country's telecommunications sector. The Effectiveness of Somalia's current spectrum allocation approach in terms of revenue optimization has been assessed, and the findings are presented in Fig. 8.

Although the current strategy in Somalia seems organized and focused on maximizing revenue, reviewing and adjusting the plan regularly is crucial. This involves analyzing market needs, technological progress, and regulation shifts to ensure that the spectrum allocation method stays efficient. The findings show that the current spectrum allocation approaches in revenue optimization were effective, although several respondents were leaning towards the least effective, as shown in Fig. 9.

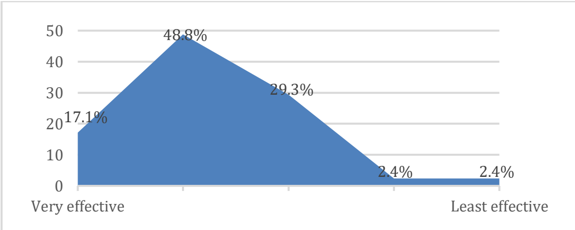

Fig. 8: Effectiveness of current spectrum allocation approaches in revenue optimization

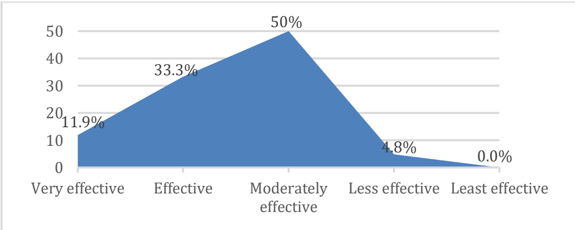

Fig. 9: Effectiveness of current spectrum allocation approaches in ensuring fair access

In terms of the Effectiveness of the current spectrum allocation approach in ensuring fair access, the findings show that for most of the respondents, the Effectiveness was at the average. This simply means access is not so fair, and neither is access unfair, as shown in Fig. 10.

On the Effectiveness of current spectrum allocation approaches, the findings show most of the respondents are at an average level of Effectiveness, with a large number between very effective and average.

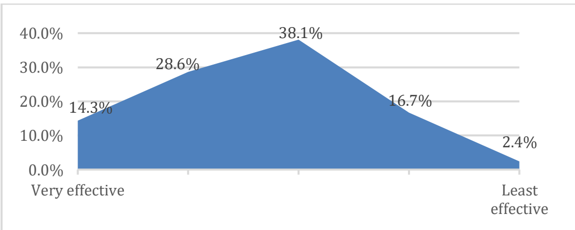

Fig. 10: Overall effectiveness of current spectrum allocation approaches

4.3. Economic impact of spectrum allocation

Given the significant economic impact of spectrum allocation on communities, policymakers must consider various factors to make informed decisions that promote economic development and social benefits. This includes analyzing the financial advantages of current allocation methods, projected annual revenues, primary revenue sources, societal impacts, comparisons of direct financial gains versus broader societal benefits, and effects on local businesses and entrepreneurs.

The financial benefits of the spectrum allocation approach can be significant for organizations. The findings show that it benefits various organizations. Spectrum auctions serve as a significant revenue stream for governments, enabling them to enhance public services and infrastructure projects. For companies, securing Spectrum through these auctions can give them a competitive edge, allowing them to introduce services that expand their market reach and strengthen their financial stability. By managing spectrum resources, organizations can reduce costs associated with interference and inefficient usage. Access to Spectrum is vital for the development and deployment of technologies like 5G, which can unlock new business opportunities, boost revenue, and lower expenses. This atmosphere of innovation fosters economic progress. Moreover, a synchronized strategy for spectrum distribution enables devices to operate smoothly in different areas, reducing production costs and aiding in worldwide market entry. This can lead to efficiencies benefiting consumers with lower prices. Better spectrum management allows companies to provide services like internet speed and more reliable connections, which can attract customers and increase revenue. The improvements in service quality can also result in cost savings for the business.

Information from secondary data sources shows that, in Somalia, revenue earned from spectrum allocations is included in the overall domestic revenue collection. According to FGOSMF (2022), telecommunication spectrum fees are a significant source of non-tax revenue. For instance, Somalia's total domestic income in 2021 is estimated to be $376.5 million. The 2023 budget estimates that domestic sources, including spectrum fees, will provide around $6 million.

The analysis of secondary data highlights the primary sources of revenue generated from spectrum usage, which are illustrated in Fig. 11.

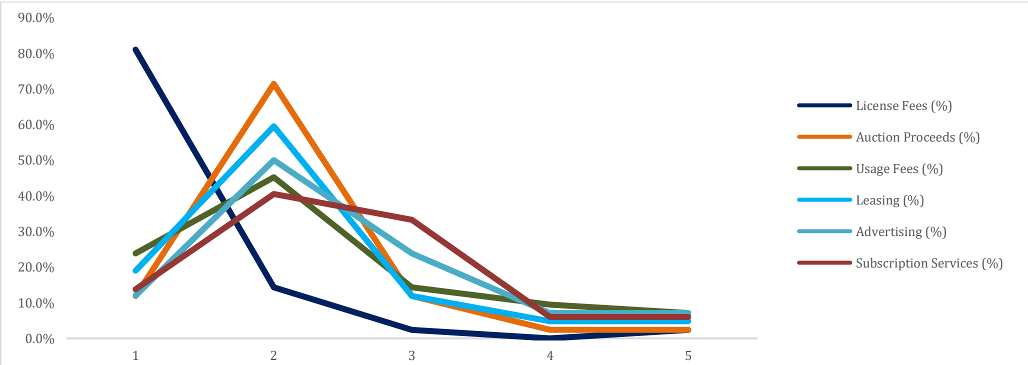

Fig. 11: Main sources of revenue from spectrum usage

As shown in Fig. 11, the source of revenue is from license fees. The rest are also major sources of revenue from spectrum usage.

The findings in Fig. 12 show that social aspects benefiting from the current spectrum allocation in Somalia are mostly economic growth and support to public services such as healthcare and education, among others. However, it must be noted that the benefits run across various sectors at the community level.

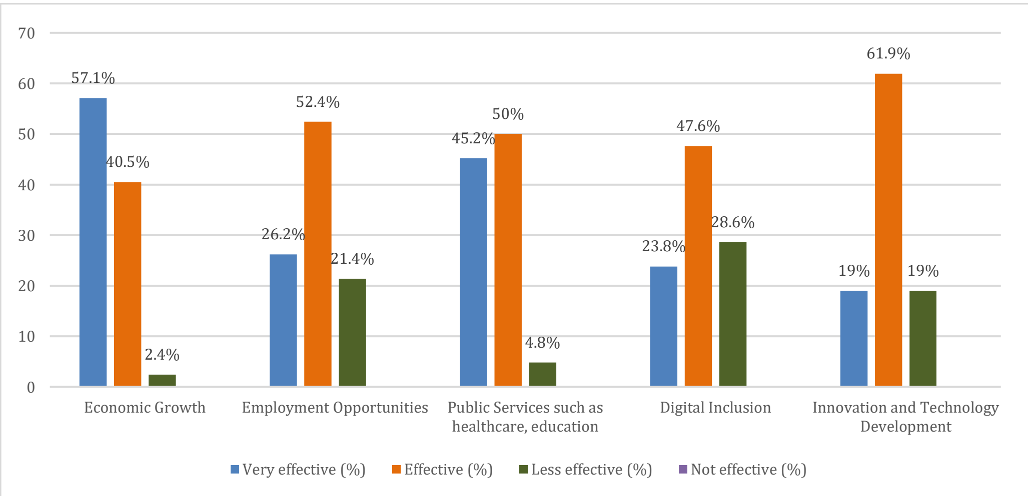

Fig. 12: Effectiveness of the current spectrum allocation

4.4. Spectrum licensing pricing models

Fig. 13 shows the assessment of the efficiency of spectrum usage. The findings show that most respondents were between very effective and average in efficiency of spectrum usage. This study investigated the economic impact of spectrum management in Somalia, analyzing current allocation methods, pricing models, and regulatory frameworks. The findings reveal both progress and persistent challenges in optimizing spectrum value for national development. The research highlights how improved spectrum management can drive economic growth, enhance connectivity, and foster innovation in Somalia's telecommunications sector. The study identified several key findings regarding spectrum usage and demand in Somalia. The most used frequency bands range from 450 MHz to 3500 MHz, supporting essential services including mobile broadband, GSM, LTE, and emerging 5G technologies. Demand for Spectrum was rated as "very high" by 48.1% of respondents, reflecting the growing need for digital connectivity. Future Spectrum needs focus on expanded bandwidth (66.7% agreement among respondents) and improved rural coverage (48.7%), indicating priorities for national development.

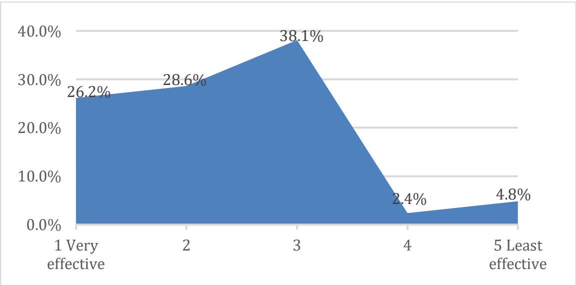

Fig. 13: Efficiency of spectrum usage

Regarding allocation methods, the research found that direct licensing remains the dominant approach (49%), though dynamic spectrum access (29%) and auctions (22%) are gaining traction. While current allocation methods were rated moderately effective for revenue optimization (48.8%), they scored lower in ensuring fair access (50% neutral rating). This suggests room for improvement in making spectrum allocation more equitable and competitive.

The economic and social impact of spectrum allocation was another critical finding. Spectrum management contributes significantly to economic growth and public services like healthcare and education. However, government revenue from Spectrum remains limited, with only $6 million generated in 2023. Respondents preferred market-based valuation (71.4%) and cost-benefit analysis (59.5%) as the most effective methods for assessing spectrum value.

Pricing and efficiency emerged as significant challenges. High licensing fees and rigid pricing models were identified as barriers to investment, with only 26.2% of respondents rating current spectrum usage as "very efficient." Strong consensus was on the need for more dynamic pricing approaches and greater auction transparency to better align with market realities.

When contextualized with global trends, Somalia's challenges reflect broader patterns in spectrum management. While advanced economies like the U.S. and Germany generate billions through spectrum auctions, Somalia's revenue potential remains underdeveloped due to its nascent regulatory framework. The study found parallels with other developing nations, where high spectrum fees and allocation inefficiencies similarly hinder digital growth.

Several international case studies offer valuable lessons for Somalia. Rwanda's successful implementation of coverage mandates boosted its 4G penetration to 95%, providing a potential model for addressing Somalia's rural connectivity gaps. India's secondary spectrum trading system improved utilization rates, suggesting that regulatory reforms Somalia might consider. Brazil's public-private partnership approach to infrastructure development offers insights into reducing deployment costs, a significant challenge in Somalia's market.

The study's broader implications highlight several policy recommendations. Modernizing allocation methods through competitive auctions with coverage obligations could significantly improve outcomes. Enhancing flexibility through spectrum sharing and leasing arrangements, as successfully implemented in the U.S. and U.K., could optimize scarce resources. Regional collaboration with neighboring countries could reduce interference and lower costs through harmonized policies.

5. Conclusion and recommendations

This study highlights the vital role of effective spectrum management in driving economic growth, enhancing public service delivery, and supporting technological innovation in Somalia. Drawing on the views of 195 respondents from various sectors, including telecommunications, broadcasting, aviation, and regulatory institutions, the research explored core aspects of spectrum governance such as allocation methods, licensing models, pricing strategies, and socioeconomic implications. The findings clearly show that spectrum management significantly influences national development by facilitating connectivity, enabling innovation, and improving access to essential services like education, healthcare, and e-government.

The study revealed that commonly used spectrum bands in Somalia, ranging from 450 MHz to 3500 MHz, are essential for mobile broadband services, GSM, LTE, and the upcoming 5G technologies. However, demand for Spectrum is rapidly increasing due to technological advancements and growing reliance on digital services. This requires forward-looking policies that address bandwidth shortages, promote energy-efficient technologies, and ensure equitable access, particularly in rural and underserved regions.

Allocation strategies must balance economic and technical considerations. While higher frequency bands are suitable for high-capacity applications, lower bands offer broader coverage. Transparent and well-regulated mechanisms such as competitive auctions, dynamic spectrum access, and direct licensing are necessary to ensure fairness and efficiency.

Spectrum pricing also emerged as a critical issue. High licensing fees can deter investment, reduce competition, and slow the deployment of new services. There is a clear need to adopt cost-reflective pricing models that support affordability while covering spectrum management costs. Incentivizing innovation through fee reductions for pilot projects, startups, and rural initiatives can further stimulate the efficient use of spectrum resources. At the same time, coordinated spectrum policies will help reduce production costs, increase access to international markets, and deliver better quality services to consumers.

Despite these opportunities, Somalia still faces challenges, including spectrum scarcity, outdated regulatory frameworks, limited historical data, and high infrastructure costs. Addressing these issues requires adaptive policy frameworks, improved regulatory capacity, and collaboration among stakeholders. Policymakers should prioritize transparent and competitive spectrum auctions that promote fair access and avoid inefficiencies. Spectrum sharing and leasing should be actively encouraged through flexible regulations, particularly in congested or high-demand areas. A shift towards pricing models aligned with market conditions and national development goals is essential to promote innovation and attract investment.

Moreover, regulators should enhance their technical capacity by investing in spectrum monitoring systems, maintaining up-to-date usage databases, and adopting international best practices. Allowing spectrum licensees to deploy a range of technologies, including 5G and IoT, within their bands will promote flexibility, innovation, and rapid adaptation to emerging needs. Regional cooperation with neighboring countries and international bodies can help harmonize policies, reduce interference, and ensure efficient use of resources. Expanding connectivity in underserved areas should also be a national priority, supported by spectrum allocation policies that incentivize rural deployment and promote inclusive digital development.

List of abbreviations

AI	Artificial intelligence
CAGR	Compound annual growth rate
CCIR	International radio consultative committee
DSA	Dynamic spectrum allocation
FGOSMF	Federal Government of Somalia, Ministry of Finance
GSM	Global system for mobile communications
GSMA	Global system for mobile communications association
ICT	Information and communication technology
IoT	Internet of things
ITU	International telecommunication union
ITU-D	International telecommunication union development sector
ITU-R	International telecommunication union radiocommunication sector
ITU-T	International telecommunication union telecommunication standardization sector
LTE	Long-term evolution
NCA	National communications authority
PLS	Partial least squares
RF	Radio frequency
SMOC	Spectrum monitoring operations center
WRC	World radio communication conference

Compliance with ethical standards

Ethical considerations

This study was conducted in accordance with ethical research standards. Participation was voluntary, and informed consent was obtained from all respondents. Data were collected anonymously and used solely for academic purposes. No personally identifiable information was recorded, and participants could withdraw at any time.

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

References

Brotman SN (2017). Revisiting the broadcast public interest standard in communications law and regulation. Governance Studies, Brookings Institution, Washington, D.C., USA.

Brown C and Rong B (2024). Enhanced IoT spectrum utilization: Integrating geospatial and environmental data for advanced mid-band spectrum sharing. Sensors, 24(18): 5885. https://doi.org/10.3390/s24185885 **PMid:39338630 PMCid:PMC11436128**

Ciupac-Ulici M, Beju DG, Bresfelean VP, and Zanellato G (2022). Which factors contribute to the global expansion of m-commerce? Electronics, 12(1): 197. https://doi.org/10.3390/electronics12010197

El Gamal A and Kim Y-H (2011). Network information theory. Cambridge University Press, Cambridge, UK. https://doi.org/10.1017/CBO9781139030687

Feng W, Li Y, Jin D, Su L, and Chen S (2016). Millimetre-wave backhaul for 5G networks: Challenges and solutions. Sensors, 16(6): 892. https://doi.org/10.3390/s16060892 **PMid:27322265 PMCid:PMC4934318**

FGOSMF (2022). End-year budget fiscal performance report for fiscal year 2021. Federal Government of Somalia, Ministry of Finance, Mogadishu, Somalia.

GSMA (2017). Introducing spectrum management. Global System for Mobile Communications, London, UK.

ITU (2023). Constitution of the international telecommunication union. International Telecommunication Union, Geneva, Switzerland.

Kane J, Shrode G, Dine J, and Puentes R (2023). Filling gaps in U.S. spectrum allocation: Reforms for collaborative management.

Information Technology and Innovation Foundation, Washington, D.C., USA.

Kerrigan K (2023). U.S. spectrum modernization is critical for entrepreneurs and competing with China. Small Business and Entrepreneurship Council, Vienna, USA.

Lewis JA and Johnson C (2023). Modernizing spectrum allocation to ensure U.S. security in the twenty-first century. Center for Strategic and International Studies, Washington, D.C., USA.

Li F, Sheng Z, Hua J, and Wang L (2016). Preference-based spectrum pricing in dynamic spectrum access networks. IEEE Transactions on Services Computing, 11(6): 922-935. https://doi.org/10.1109/TSC.2016.2589249

Matinmikko M and Mustonen M (2019). Spectrum sharing policy at global level. In: Zhang W (Ed.), Handbook of cognitive radio. Springer, Singapore, Singapore. https://doi.org/10.1007/978-981-10-1394-2_47

NCA (2023). NCA officially launches spectrum monitoring operations center. National Communications Authority, Federal Republic of Somalia, Mogadishu, Somalia.

Pedros X, Bahia K, Castells P, and Nichiforov-Chuang D (2020). Effective spectrum pricing in Africa: How successful awards can help drive mobile connectivity. GSMA Intelligence, London, UK.

Percy S, Knight C, Cooray F, and Smart K (2012). Supplying the power requirements to a sensor network using radio frequency power transfer. Sensors, 12(7): 8571-8585. https://doi.org/10.3390/s120708571 **PMid:23012506 PMCid:PMC3444064**

Randolph K (2017). Turning to spectrum valuation. Stout, Chicago, USA.

Rosenberg E (2022). An overview of spectrum management: What, why, and how. National Telecommunications and Information Administration, U.S. Department of Commerce, Washington, D.C., USA.

Suardi S and Castells P (2022). The socioeconomic benefits of mid-band 5G services. GSMA Intelligence, London, UK.

Yun DW and Lee WC (2021). Intelligent dynamic spectrum resource management based on sensing data in space-time and frequency domain. Sensors, 21(16): 5261. https://doi.org/10.3390/s21165261 **PMid:34450703 PMCid:PMC8401905**