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# The renewable energy research contribution of Tanzania: A review

Buruhan Haji Shame[a,b], Ubaidillah[a,c,*], Dominicus Danardono Dwi Prija Tjahjana[a], Zainal Arifin[a], Mohammad Aziz[d], Widyanita Harwijayanti[e], Mohammed M. Haji[f]

[a]*Graduate School of Mechanical Engineering, Universitas Sebelas Maret Surakarta, 57126 Surakarta, Indonesia*
[b]*The Ministry of Infrastructure, Communication and Transportation Zanzibar, 180 Zanzibar, Tanzania*
[c]*Mechanical Engineering Department, Islamic University of Madinah, 42351 Madinah City, Kingdom of Saudi Arabia*
[d]*Institute of Industrial Science, The University of Tokyo, 113-0044 Tokyo, Japan*
[e]*Aircraft Maintenance Technology, Universitas Tunas Pembangunan, 57139 Surakarta, Indonesia*
[f]*College of Engineering and Technology, University of Dar es Salaam, Dar es Salaam City, Tanzania*

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**Abstract**

The central objectives of this study are to locate existing research on renewable energy, examine the energy policy of Tanzania, assess bibliometric factors, determine the direction of the current research, and comprehend unexplored research topics. This exploration focuses on a bibliometric-based study using computer-assisted software tools known as VOS viewer and RStudio in analyzing the Scopus data retrieved package for the key phrase of "Renewable energy" in the article titles published from 2002 to 2022. A total of 661 publications (which is only 0.45% and 6.3% of the global and continental publications from Africa respectively) were analysed after refining using different bibliometric criteria like study site, type of document, publication stage, language used in the document, and publication time interval. The results shows that Energy fuels, engineering, technology, environmental sciences, ecology, and business economics are the most frequently studied fields. Also, from a total of 661 publications, only 32 documents were published from Tanzania for 20 years from 2022 which is less than 2 publication/year. This study concludes that there is a notable lack of research output from Tanzania in this critical field. This gap underscores the need for greater investment in renewable energy research and development within the country, as well as targeted efforts to build research capacity and foster collaboration among academia, government, and industry stakeholders.

*Keywords:* Renewable energy; energy policy; alternative energy; bibliometric analysis; Tanzania

## 1. Introduction

Renewable energy is defined as energy derived from natural or environmentally friendly renewable sources that are not harmful to the environment [1–3]. This incorporates energy sources such as solar radiation [4], wind [5], water currents [6], and geothermal heat [7]. Some renewable energy sources, which are in some cases both unattainable and unsustainable, contradict the existence of multiple resources [8–10]. An introductory assessment of the literature reveals that there are areas that could benefit from a multidisciplinary approach and that research on renewable energy challenges frequently concentrates on the energy factor [11]. Indeed, interdisciplinary contributions can broaden these themes to include social, economic, and environmental considerations in order to support more sustainable and officially recognized energy growth [12].

* Corresponding author.
Email: ubaidillah_ft@staff.uns.ac.id.
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The global contribution to renewable energy has witnessed remarkable growth and significance in recent years [13]. With increasing awareness of climate change and the need to transition towards sustainable energy sources, countries around the world have been actively investing in renewable energy technologies. This has led to a significant expansion of renewable energy capacity, with solar, wind, hydroelectric, geothermal, and biomass energy sources playing prominent roles [13]. In addition to addressing environmental concerns by reducing greenhouse gas emissions and mitigating air and water pollution, renewable energy offers numerous socio-economic benefits [14]. It creates jobs, stimulates economic growth, enhances energy security, and promotes innovation and technological advancement. Moreover, the decentralization of renewable energy production through distributed generation systems, such as rooftop solar panels and community-owned wind farms, has empowered communities and increased energy access, particularly in rural and underserved areas [15].

In comparing the renewable energy sectors of common east Africa countries Tanzania, Uganda, and Kenya reveals both similarities and differences in their development and challenges as all three countries possess abundant renewable energy resources, including solar, wind, hydroelectric, and biomass. However, differences exist among the countries regarding energy access, installed capacity, policy implementation, and technological innovation [16]. Kenya stands out with the largest installed capacity of renewable energy, with a strong focus on geothermal and wind power, and has made significant progress in improving energy access, particularly through off-grid solar solutions [17]. In contrast, Tanzania and Uganda still face challenges in providing electricity to rural and remote areas, although efforts are underway to address this issue. Furthermore, while all three countries have renewable energy policies in place, the effectiveness of policy implementation varies. Kenya has been relatively successful in implementing its renewable energy policies, while Tanzania and Uganda encounter challenges related to enforcement and coordination among stakeholders [17]. Also, Kenya has been a leader in technological innovation in the renewable energy sector, particularly in solar and wind power technologies, whereas Tanzania and Uganda are making progress but may benefit from increased collaboration and knowledge-sharing to adopt innovative renewable energy solutions.

Tanzania is one of the east Africa countries which plan to make an energy access revolution to boost economic development and social welfare. Due to these reasons, some studies have been assessing the energy sector and discussing energy outages during the dry season since hydroelectric power is a major energy source utilized for power generation. Tanzania has multiple compelling reasons to consider adopting renewable energy sources. Firstly, by diversifying its energy mix to include renewables, Tanzania can bolster its energy security [18]. Unlike fossil fuels, which are vulnerable to price fluctuations and geopolitical tensions, renewable resources like solar, wind, hydro, and geothermal energy are abundant domestically, reducing reliance on imported fuels. Transitioning to renewables can help Tanzania mitigate the environmental impacts associated with conventional energy sources such as coal, oil, and natural gas [19]. Renewable energy generation emits minimal greenhouse gases, aiding in the fight against climate change and reducing air and water pollution, thereby benefiting public health and preserving ecosystems.

The decrease in water levels within hydroelectric power river basins poses significant challenges to electricity generation [20]. As water serves as the primary fuel for hydropower plants, reduced water availability directly impacts their ability to generate electricity. This decline in water levels can lead to diminished power output, affecting the reliability and stability of electricity supply from hydroelectric facilities. In regions heavily reliant on hydropower for electricity generation, such as many developing countries, the decrease in water levels can exacerbate energy shortages and increase dependence on costly and environmentally damaging alternative energy sources like fossil fuels [21]. Moreover, fluctuations in river flow patterns and water availability can disrupt the operation and planning of hydroelectric power systems, necessitating adjustments in energy management strategies and infrastructure investments to mitigate the impacts of water scarcity on electricity generation. Therefore, addressing the factors contributing to declining water levels in hydroelectric power river basins is crucial for ensuring the resilience and sustainability of electricity generation from hydropower in the face of evolving environmental and socio-economic challenges [22].

There have been ongoing efforts to promote renewable energy development in Tanzania, including the negotiation and implementation of renewable energy deals. The country has abundant renewable energy resources, including solar irradiation and wind speeds, which present significant opportunities for investment and development in these sectors. In recent years, there have been initiatives to attract investment in renewable energy projects through policies, incentives, and partnerships with the private sector and international organizations [23]. These efforts aim to increase energy access, reduce reliance on fossil fuels, and promote sustainable development in Tanzania.

The study “Barriers to large-scale solar power in Tanzania”, conducted by Aly et al. explains the existing situation, difficulties, and chances for renewable energy in Tanzania [18]. This study gives a summary of the nation's biomass-based energy sector, which also includes hydropower [24], natural gas [25], and a negligible amount of electrical power derived from oil [26].The authors claimed that Tanzania has a significant amount of renewable energy potential [27], including geothermal, solar, and breeze energy, which could be used to satiate the nation's expanding energy requirements [19,20]. Overall, the paper offers a thorough analysis of Tanzania's renewable energy prospects and challenges. The need for concerted action among stakeholders to promote renewable energy [28] and lessen the nation's reliance on conventional energy sources is also stressed [29]. The paper also emphasizes how crucial it is to provide a supportive political and regulatory atmosphere in order to draw investment and promote expansion in the renewable energy sector [23,24].

A review by Bishonge et al. has analyzed Tanzania's prospective energy resources and covered the tactics that could facilitate Tanzania's easy access to renewable energy [30]. Lack of human resources and training, high initial investment costs, low level of research and development, and poor and unfriendly institutional framework are among the energy difficulties highlighted by the author [26][27]. The author advised developing sound plans for domestic and foreign direct investment in the energy industry.

Recently, Sichilalu et al. [32] have evaluated the legislative and policy methodologies for promoting renewable energy [33], including the National Energy Policy (NEP), Rural Energy Agency (REA) Act [34], and National Renewable Energy Strategy [35]. The constraints and opportunities for renewable energy in Tanzania were thoroughly examined in their research [14]. The research emphasized the necessity of stakeholders working together to promote renewable energy and lessen the nation's reliance on traditional energy sources [32]. The author discovered several challenges faced in the implementation of renewable energy policies and frameworks in Tanzania [14,36,37], including limited access to financing [38], lack of technical expertise [39], and inadequate infrastructure [40]. However, the authors also highlighted the potential for growth and development in the sector, including increased investment and the use of innovative financing models [1,41].

According to a study conducted by Mrema et al. [42], Tanzania has abundant renewable energy resources [43] like sun, wind, hydropower, and biomass [44], but only approximately 40% of Tanzania's population has access to power [45], which is a significant portion considering the country's availability of renewable energy resources. The authors then evaluated the various institutional and policy frameworks established to close the energy access gap [46] and advance the development of renewable energy sources [47], including the electricity act, national energy policy, and renewable energy policy [48]. The authors thoroughly studied these regulations, looking at their goals, benefits, and drawbacks [49].

Tanzania has already been working to develop energy-producing plants to guarantee reliable and sustainable energy may be obtained in both rural and urban settings [34]. The key power sources in Tanzania include carbon fuels, petrochemicals, and hydroelectric power [19]. Tanzania has already been working to develop energy-producing plants to guarantee reliable and sustainable energy that may be obtained in both rural and urban settings [50]. There is a total of 1,264 MW installed power capacity, 568 MW are generated from hydropower plants, 685.4 MW are generated from thermal energy sources, and the remaining renewable energy subsidies are less than 82.4 MW. However, the real energy distribution shows that about 85% of the residents are using conventional fuels as domestic energy bases.

According to a survey conducted by REA and the Bureau of Statistics, only 32.8% of the total population of Tanzania has access to electricity, from which only 65.3% of the population in urban regions were found to have access to energy, while only about 16.9% of the population in a rural area have access to power. This indicates that 88.83% of the rural population and 34.7% of the urban population, respectively, do not have access to energy. In the residential sector, 74.9% and 24.7% of all-electrified households are powered by solar panels and the national grid, respectively. The remaining households of about 0.3% are connected by private power sources such as slight generators [30]. Because Tanzania is a member of the East African power pool (EAPP), Tanzania imports nearly 1% of its power from other East African countries like Kenya, Uganda, and Zambia [19].

The energy business is critical to a country's socioeconomic success [51]. The key factors for Tanzania's envisioned socioeconomic progress include the accessibility, affordability, reliability, and availability of modern energy services [52]. NEP was first developed in 1992 as a result of socioeconomic reforms implemented in the 1990s [53]. Following that, a revised version of the NEP was developed in 2000 and officially published in 2003, aiming to modernize the energy trade [53] and enhance private sector engagement in the energy domain [54].

## 2. Justification of the Current Policy

Given the rapid growth of the energy sector [55], many political measures are required to achieve national political goals in the framework of energy [56]. Issues in the current energy markets highlighted policy areas that need adjustment [57], leading to the development of the NEP 2015 [58]. The goals of the new NEP includes Advancing energy resources to fulfill internal needs and streamline energy interchange [59], accelerating the expansion and development of energy substructures to restore a modern energy service mix [60], promoting the adoption of clean energy, create an atmosphere conducive to private storage in the energy sector [61], expanding energy resources [62], decorating energy efficiency and management of all subsectors [63], maximizing the interests of the Tanzanian government and people, full strategic participation and fair sharing of benefits [64], ensuring responsible management of oil resources and revenues for long-term benefits to society [58], Promoting the utilization of regionally manufactured commodities and services in the oil and gas sector, fortify institutional, legal, and regulatory structures, allocate resources to human capital to foster the sustainable expansion of the energy domain [65], and ultimately encouraging the acceptance of environmental [66], well-being, protection and controlling standards in the energy segment [66,67]. The policy document covers diverse domains or segments, including power (production, transfer, distribution, linkage, power transaction, and countryside electrification), oil and gas (upriver, midway, and downriver operations), sustainable power, energy preservation, and comprehensive issues (subsidies, institutional, legal, regulatory, monitoring, and assessment frameworks) [68]

### *2.1. Consideration of the renewable energy*

The energy policy of Tanzania classifies renewable energy as a crucial component of the country's energy mix and outlines strategies for its promotion and development. Renewable energy sources, such as solar, wind, hydroelectric, geothermal, and biomass, are recognized for their potential to contribute to energy security, environmental sustainability, and socio-economic development. Tanzania's energy policy aims to diversify the energy mix by increasing the share of renewables and reducing dependence on fossil fuels. This includes setting renewable energy targets, providing incentives for investment in renewable energy projects, and promoting the adoption of renewable energy technologies. Additionally, the policy emphasizes the importance of enhancing energy access in rural and remote areas through decentralized renewable energy solutions, such as off-grid solar systems and mini-grids. Overall, the energy policy of Tanzania recognizes the significance of renewable energy in achieving the country's energy objectives and outlines measures to harness its potential for sustainable development.

Section 3.1.4 of the National Energy Policy strongly emphasizes the significance Tanzania boasts diverse renewable energy sources, gusty, radiant, organic, diminutive-scale aquatic subsurface heat, oceanic motion and sea temperature gradient. Presently, the nation is actively employing various renewable energy technologies, such as solar thermal, solar photovoltaic (PV), wind, and biomass (in solid, liquid, and gaseous forms). Table 1 lists a few laws that Tanzania's government has put in place to encourage the development of energy, including renewable energy [69][70]. Tanzania has also participated in the Scaling Up Renewable Energy Program (SREP), a global program that aids developing countries in the development of renewable energy projects. The project provides both financial and technical assistance to promote the usage of renewable energy technology.

To a considerable degree, the effective enactment of NEP 2003 has produced notable achievements, including the establishment of the Energy and Water Utilities Regulatory Authority (EWURA), the initiation of operations for the Rural Energy Agency (REA) and the Rural Energy Fund (REF), the introduction of a Standardized Power Purchase Agreement (SPPA), an increase in the number of participants in the petroleum industry, the creation of a reliable supply of petroleum products, the implementation of the Bulk Procurement System (BPS) for petroleum importation, the creation of a Model Power Purchase Agreement (MPPA), the formulation of the Electricity Act of 2008, and the development of the Power System Master Plan (PSMP 2009-2033).

Table 1. The Government initiatives toward development of energy sector [21]

| Policy/Initiative | Impact |
|---|---|
| Tanzania Development Vision 2025 | This long-term development blueprint aims to transmute Tanzania into a middle-income country by 2025. It underscores the need for consistent, affordable, and sustainable energy access for all citizens. |
| NEP 2001 | This policy sets out the government's objectives and strategies for the energy sector. It promotes the development of diverse energy sources, including renewable energy, and stimulates private sector involvement. |
| REA Act 2005 | This legislation established the REA, which is accountable for implementing rural energy projects. The REA focuses on expanding access to electricity in pastoral areas through off-grid and mini-grid schemes. |
| Feed-in Tariff (FiT) Policy: | The FiT policy was introduced in 2008 and revised in 2015. It guarantees long-term power purchase agreements and favourable tariffs for renewable energy producers, encouraging investment in small-scale renewable energy projects. |
| SE4ALL Action Agenda | Tanzania has committed to the SE4ALL initiative, which aims to ensure universal access to modern energy services, double the share of renewable energy, and double the rate of energy capability upgrading by 2030. |

## 3. Energy balance and current installed potential sources

In Tanzania, the main sources of power include natural gas, petroleum, and hydropower. Of the total installed capacity of 1,264 megawatts (MW), hydroelectric power accounts for 568 MW, thermal power for 685.4 MW, and other renewable energy sources for less than 82.4 MW. More than 85% of the population depends on traditional fuels for household energy. According to the Bureau of Statistics and the Rural Energy Agency, only 32.8% of Tanzanian communities have access to electricity, with urban areas having higher access (65.3%) than rural areas (16.9%). Among electrified households, 74.9% are connected to the national grid, 24.7% use solar power, and 0.3% use electricity from other sources such as small generators.

Tanzania's energy mix includes charcoal and firewood, petroleum products, coal, and renewable energy sources. Charcoal and firewood account for 85% of the nation's energy consumption, followed by petroleum products at 9.3%, electricity at 4.5%, and coal and renewables at 1.2% [21]. Reliable and affordable energy sources are essential for socio-economic development. By 2014, electricity access had risen to 36.4% in urban areas and 11% in rural areas. Excluding large hydropower plants, only 4.9% of electricity came from sisal and sugar factories, solar, and small hydropower plants. Over the past two decades, hydropower plants provided about 80% of electricity until natural gas commercialization in 2004 [21]. The total capacity of hydropower plants was 561.84 MW from six power stations, which is 12% of the identified 4.7 GW hydropower resources. However, the potential hydropower resource is estimated to exceed 38 GW [19].

Fig. 1 shows the status of electricity generation in Tanzania from hydropower, natural gas, oil, coal, peat, and oil shale between 1971 and 2015 [20]. Natural gas became a key electricity source after hydropower, with five gas power plants totaling 495.44 MW [20]. Additionally, two off-grid gas power plants have a combined capacity of 25.25 MW, and eleven off-grid diesel-fired engines have a combined capacity of 28.682 MW, resulting in a total electricity generation capacity of about 1.1 GW [71]. Despite this, hydropower and other renewable energy sources are increasingly favored for electricity generation in areas without grid access. However, major hydropower reservoirs faced severe drought from 2003 to 2005 [71]. The energy policies and power master plans for 2012 and 2016 prioritize four primary energy sources for electricity generation.

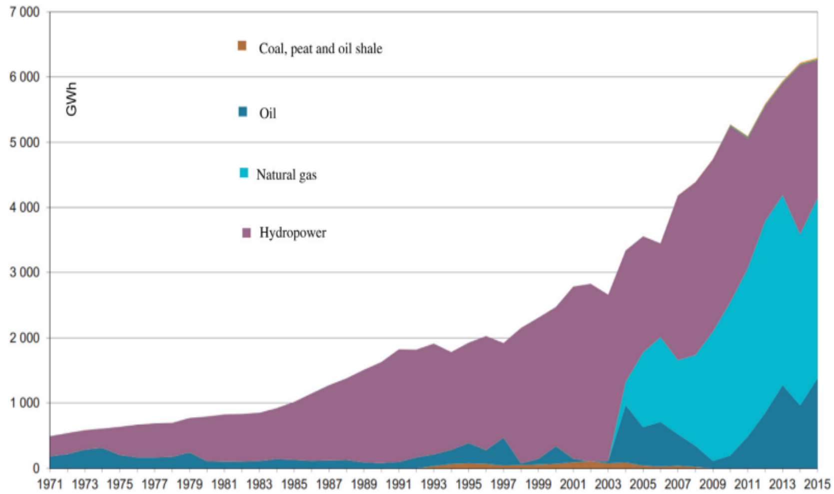


Fig. 1. Variation of the installed capacity from different energy resources [20]

### 3.1. Hydropower

Hydroelectric is the most widely utilized renewable energy source globally, contributing about 1000 GW and accounting for over 16% of the world's net electricity production and more than 65% of the power generated from renewable resources [13]. Hydropower plants are typically built in water reserves. Worldwide, China leads in hydroelectric generation capacity, followed by Brazil, the United States, Canada, and Russia. In Tanzania, hydropower currently makes up over 45% of total power generation. It has traditionally played a significant role with an installed capacity of 561 MW, representing roughly one-third of the total installed power capacity, which is expected to reach 2612 MW [13].

This information is summarized in Table 2 [13]. Tanzania has a potential hydropower capacity exceeding 3.173 GW, positioning the country for further development. However, challenges like weak transmission infrastructure have hindered progress in this sector. Hydropower used to dominate Tanzania's power industry before natural gas took precedence. Hydropower plants are plagued by unreliable rainfall, a problem worsened by agricultural activities upstream of rivers. Consequently, the government is seeking alternative solutions, such as integrating natural gas into the energy mix, to ensure the community has access to efficient, reliable, and affordable power.

Table 2. Current hydroelectric power potential installed capacity [13]

| Power station | Installed capacity (MW) | System | Region |
|---|---|---|---|
| Kidatu | 204 | Great Ruaha River | Morogoro |
| Kihansi | 180 | Kihansi River | Morogoro |
| Mtera | 80 | Great Ruaha River | Dodoma |
| New Pangani Fall | 68 | River Pangani | Tanga |
| Hale | 21 | River Pangani | Tanga |
| Number ya Mungu | 8 | River Pangani | Tanga |
| Stiegler's Gorge | 2,100 | Rufiji River | Morogoro |
| Kikonde | 300 | Ruhuhu River | Ruvuma |
| Songwe | 180 | Songwe River | Songwe |
| Rumakali | 22 | Rumakali River | Iringa |
| Small Hydropower | 10 | Various Rivers | Various Regions |
| Total | 3,173 | - | - |

The Stiegler Gorge Hydropower system is a planned hydroelectric dam in Tanzania with a capacity of 2,100 megawatts [13]. It is anticipated to generate 5,920 GWh of power annually. Proposed as an energy solution for Tanzania since the 1960s, it is seen as a key project to meet the country's energy needs [13]. The dam is included in the Tanzania Power System Master Plan (2016 update) and is slated for completion by 2035. Stiegler’s Gorge, the site for the dam, is located in the Selous Game Reserve, a UNESCO World Heritage Site known for promoting sustainable development through tourism. However, the World Wildlife Fund opposes the SGHPS project in protected areas due to potential negative impacts on the reserve's ecological integrity and its World Heritage status. In February 2017, the International Union for Conservation of Nature (IUCN) also acknowledged that constructing the dam would adversely affect the Selous Game Reserve's ecology and the life of organisms outside the protected areas.

### 3.2. Solar and geothermal power

On a global scale, the total installed capacity of solar power reached approximately 405 GW by the end of 2017, with concentrated solar thermal power capacity reaching 5.1

GW, with Spain accounting for less than half of this capacity at approximately 2.3 GW, positioning it as the third largest renewable power source. Photovoltaic technology is the predominant source within the solar sector [72]. China, Germany, Italy, the US, and Japan possess the largest solar photovoltaic (PV) technology capacities worldwide [73].

In Tanzania, solar energy serves as a power source for 24.7% of households with electricity access [13]. The country boasts significant solar energy potential, particularly in its central regions, with high levels of solar irradiance ranging from 2800 to 3500 hours of sunshine per year and a global horizontal radiation of 4–7 kWh/m2/day [22]. According to the World Bank, Tanzania's solar energy potential surpasses that of Spain, and its wind energy potential exceeds that of California in the US.

Given its abundant solar resources, Tanzania is well-suited for harnessing solar energy as a viable alternative for modern energy supply and rural electrification. The solar energy market in Tanzania has witnessed considerable growth in recent years, with various applications such as solar thermal for heating and drying, and photovoltaic for lighting, water pumps, refrigeration, and telecommunication purposes. Solar energy usage is predominantly observed in rural areas, accounting for about 64.8%, with regions like Lindi, Njombe, Mtwara, Katavi, and Ruvuma leading in solar power electricity utilization [74]. Despite the growing market for solar energy applications, there are limited indications that the government plans to significantly integrate solar PV into the national electricity mix in the foreseeable future. However, the government aims to incorporate approximately 800 MW of solar power generation into the national grid by 2025.

Tanzania has significant geothermal power potential that has yet to be properly measured. Geothermal electricity potential analysis commenced in 1976, and Tanzania reportedly holds an estimated 5000 Megawatts of installed output that could be developed by geothermal power sources [30], and the most possibilities are in the East African Rift Delta [19].

Tanzania's geothermal incentives and investigation are divided into three main zones: the northeast boundary of Tanzania, which includes the Mara regions, Kilimanjaro region, and Arusha districts; the southwest zone, which includes Rukwa districts and Mbeya region; and the eastern seaboard grip zone of the Rufiji Watershed, which is affiliated to fissures and molten lava encroachments [9,19].

### *3.3. Biopower potential*

Biopower stands out as one of the most robust renewable energy sources, encompassing biomass in the forms of biofuels and biodiesel. Presently, biopower contributes to over 83 GW of global energy production [75]. Approximately 2.5 billion individuals worldwide rely on wood fuels for heating and cooking, with Sub-Saharan Africa (SSA) accounting for a significant portion. In SSA, around 85% of all wood harvested from forests is used as fuel or charcoal for heating and cooking [76]. While biomass derived from wood is renewable when trees are replanted, it can pose health risks due to indoor particulate air pollution. In Tanzania, biomass serves as the primary energy source, primarily in the domestic sector. The country boasts a substantial charcoal production and supply sector, engaging over 1 million individuals [77]. Demand for firewood and charcoal differs between rural and urban areas, with urban centers like Dar es Salaam being major consumers of charcoal [13].

A significant portion of biomass is sourced from forests, often harvested through traditional and unsustainable methods, attributed to factors such as weak law enforcement, limited awareness, and widespread poverty. In Tanzania, biomass energy is predominantly derived from forests, agricultural residue, animal dung, and solid industrial waste. According to the UN Food and Agriculture Organization's Global Forest Resources Assessment project, Tanzania boasts 33 million hectares of forests and woodland, but experiences an annual loss of over 400,000 hectares of forest cover [13]. Approximately 75% of the wood harvested remains unaccounted for in government budget systems, resulting in significant revenue loss. On average, households consume about 46.4 kg of charcoal per month, with urban residents consuming considerably higher amounts ranging from 93.6 to 180 kg per person annually. With the country's high population growth rate, charcoal production is expected to expand to 2.8 million hectares by 2030. Consequently, the government suffers an annual revenue loss of approximately US$100 million. Presently, biomass contributes about 18 MW of grid power generation, while the agro-industry is estimated to generate an additional 58 MW of electric power for its own use [13].

### *3.4. Wind energy potential*

Wind turbines are experiencing diverse growth across many countries in the world [78]. Wind power is the world's second most widely used renewable energy source [79], with a total installed capacity of 539.123 GW in 2017 and an annual growth rate of 12.6% [30]. China is the world's largest installed capacity of wind generators, with 188.392 GW installed capacity [80], followed by the United States (89.077 GW), Germany (56.132 GW), India (32.848 GW), and Spain (23.17 GW).

Africa and the Middle East account for just 4.528 GW of total installed d wind generating capacity [81], with South Africa leading the African continent with 2.085 GW [30]. Rising oil prices, a lengthy hydropower shortage, and increased demand for electricity due to fast population expansion will all drive up community engagement in wind power generation in Tanzania [41]. Regarding wind energy sources, various areas in mainland Tanzania are now being explored for wind energy capacity [82].

Tanzania has some established wind regime sites for producing commercial energy. The main obstacles to investment in wind power generation include insufficient wind regime data, high investment costs, integration and compliance with the grid system, and distance from grid and load centers [83]. The Department of Energy, in collaboration with the Tanzania National Petroleum Company, has conducted renewable power resource assessments in some regions of Tanzania's mainland [30]. Business organizations such as Geo-Wind Tanzania Ltd have shown a desire to invest in wind energy in Tanzania in order to construct wind farm complexes with capacities surpassing 50 MW in areas such as Dar es Salaam [19]. Wind Energy Tanzania Ltd. and Sino Tan Renewable Energy Ltd. are other private enterprises or private business companies having an investment in wind farms[9,30,50].

## 4. Bottleneck of the Policy and previous studies

The Tanzania Energy policy aims to diversify the energy mix by increasing renewables' share and reducing reliance on fossil fuels through setting targets, providing incentives for investment, and promoting adoption of renewable technologies. Despite notable achievements, the Energy Sector grapples with various challenges, including limited private sector involvement in large-scale power generation [84], overdependence on a narrow range of energy sources [85], an unreliable and costly energy supply, reliance on government subsidies [50], restricted access to modern energy services [54], a shortage of skilled human resources [52], minimal government and Tanzanian engagement in the petroleum value and supply chain, insufficient financial resources for sector development, and inadequate focus on research and development. The 2015 National Energy Policy (NEP) aims to address these obstacles, enhance sector performance [86] and promote efficient energy resource utilization [85,87].

Renewable energy technologies are constantly evolving and improving [88]. Research helps identify new materials, explore novel concepts, and develop innovative technologies that can enhance the efficiency, reliability, and affordability of renewable energy systems [15,89]. Through research, scientists and engineers can discover breakthroughs and push the boundaries of what is currently possible, leading to significant advancements in renewable energy[84].

Therefore, primary aims of this study are to identify previously conducted research on renewable energy, scrutinize Tanzania's energy policy, evaluate bibliometric factors, ascertain the current research trends, and explore undiscovered research areas. This investigation employs bibliometric analysis aided by computer-assisted tools such as VOS viewer and RStudio to analyze Scopus data encompassing articles published from 2002 to 2022. Specifically, the study focuses on examining articles containing the key phrase "Renewable energy" within their titles [90–93].

## 5. Data sources and methodology

### *5.1. Data sources and software tools*

In 2022, records from 2002 to 2022 was retrieved from the Online databases (by Elsevier) on 5th October 2022, counting from the preceding 20 successive seasons. The command used to retrieve data from Scopus database was "( title-abs-key ( "renewable energy" ) ) and ( ( Africa ) ) and ( Tanzania ) and ( limit-to ( pubyear , 2022 ) or limit-to ( pubyear , 2021 ) or limit-to ( pubyear , 2020 ) or limit-to ( pubyear , 2019 ) or limit-to ( pubyear , 2018 ) or limit-to ( pubyear , 2017 ) or limit-to ( pubyear , 2016 ) or limit-to ( pubyear , 2015 ) or limit-to ( pubyear , 2014 ) or limit-to ( pubyear , 2013 ) or limit-to ( pubyear , 2012 ) or limit-to ( pubyear , 2011 ) or limit-to ( pubyear , 2010 ) or limit-to ( pubyear , 2009 ) or limit-to ( pubyear , 2008 ) or limit-to ( pubyear , 2007 ) or limit-to ( pubyear , 2006 ) or limit-to ( pubyear , 2005 ) or limit-to ( pubyear , 2003 ) or limit-to ( pubyear , 2002 ) ) and ( limit-to ( pubstage , "final" ) ) and ( limit-to ( doctype , "ar" ) or limit to ( doctype , "re" ) ) and ( limit-to ( language , "English" ) )" .

To provide a comprehensive and informative view of the data [94], all documents released in Renewable Energy until October 2022 were analyzed. Notably, the science world generally accepts the examination of bibliometric indices such as total publications (TP)[95], total citation collected (TC)[96], citations per paper (CPP) [97], and h-index to estimate research findings and influence [98]. It should be noted that the citation counts and h-index analyses were limited to Renewable Energy articles. VOS viewer also has text analysis capabilities, which may be used to analyze, construct, and visualize co-occurrence networks of key terms extracted from research literature [99].

The researchers who interact with the Ruby programming language should be knowledgeable about RStudio[98]. RStudio is mainly used in research methodology to import, access, transform, examine, visualize, and model data and in all techniques to make it count [98]. RStudio is a research software application that provides a bibliometrics online interface[100]. Also, RStudio serves comparable functions in systematically examining bibliometric characteristics to increase research and innovation [95,97,98].

### *5.2. Methodology*

The employment of bibliometric analysis based on the Scopus database for the key term' "renewable energy" in the article titles until 2022 from 2002 [99]. The papers were evaluated using the term "Renewable Energy," by years, research fields, region, research organizations, and research sponsors, journals, journal citations, authors, publications, and keyword co-occurrence [100]. The VOS viewer was used to analyze the most cited publications and authors, as well as the co-occurrence of keywords. In addition, hierarchical cluster analysis was performed, and clusters were selected using a VOS viewer [94]. A total number of 178,295 publications on renewable energy were already published worldwide from the typed keyword "Renewable Energy" using command presented in sub-section 5.1.

After filtering the data using different Bibliometric criteria and study requirements using a specific keyword of the geographical location and period (2002 to 2022), the total of 661 publications on the Scopus database at the selected time interval of 20 consecutive years 2001 to 2022 inclusive which is only 0.45% and 6.3% of the total published in global and continental articles respectively. Mapping tools have been used to collect findings, explanations, and other information regarding advancements in science, engineering, and technology, as well as to assist in the conduct of research.

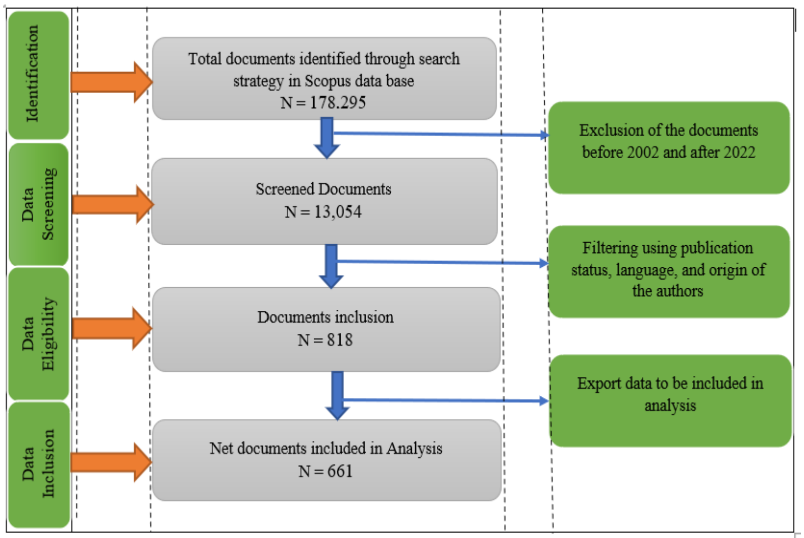


Fig. 2. Research data retrieval flow chart

Modeling is a tool that may be used to perform econometric literature data analysis; examples of mapping programs are VOS viewer and RStudio. Individuals, as well as organizations of writers, institutions, departments, or nations, can use the h-index, citations, and h-index without self-citations were also regarded as indicators of research quality [98]. Additionally, the foundation of this Bibliometric study was a systematic bibliographical examination of the literature pertinent to the main study issue that was conducted in accordance with a set of stages [101]. Referring to the summarized flow chart in Fig. 2, data retrieval was done by considering some processes. These processes were (1) specifying the search criteria, keywords, and time periods; (2) choosing a reputable data base (Scopus database); (3) tweaking and fine-tuning the research criteria; (4) fully exporting the results; and (5) analyzing the data and discuss the findings. To evaluate the papers from various angles and provide relevant results, MS Excel, VOS viewer, and RStudio User Interface [99] were used.

## 6. Study Outcomes and Debate

The outcomes of this bibliometric study showed that a total number of 178,295 publications on renewable energy were already published worldwide from the selected keyword "Renewable Energy" while for a specified continental location "Africa" a total of 13,054 publications (7.3% of the global published articles) were already published during the year 2001-2022. Furthermore, a specified keyword, "Tanzania" gave the results of 818 publications on the Scopus database at the selected time interval of 20 consecutive years between 2001 to 2022, which is only 0.45% and 6.3% of the total globally and continentally published articles, respectively. On further filtrations using some conditions like the language used by authors, type of documents, and state of the articles, the actual articles published were only 661 for a selected countryside.

The findings also revealed that engineering, science, technology, environmental sciences, ecology, and business economics were the most popular fields of study among these publications. American, Chinese, and Indian scientists published the vast bulk of the publications. Additionally, six distinct research clusters were identified, each of which has a special attachment to desalination, biomass, renewable energy, optimizers, and renewable energy sources.

The most efficient and cited sources, keyword and occurrence network analysis, and analysis of the most popular subjects were all done using a bibliography analysis tool like VOS viewer and Biblioshiny software applications in this part to characterize the scientific/technical outcomes of this study.

### *6.1. Annual documents publication and citation*

The annual publication was subcategorized into four main sub-time intervals of five years. The first range was between the years 2002 and 2006; only three documents with an average citation of 25 for each year were obtained in this time range. The leading citation was in 2002, with 109 citations, and in both 2003 and 2004, no document was published on the Scopus database.

For the years 2007 to 2011, there was an increment of up to 37 (5.6% of 661 documents), whereby the leading document year was 2008 (12 documents), followed by 2011 (11 documents) and 2009 with eight documents, the least number of documents was during 2007 with two documents followed by four documents in 2010. During the years 2012 to 2016, the number of articles produced increased to a total of 131 documents (19.8% of 661 articles published); in this sub-time frame, the least number of articles published was 15 articles during 2012 and the maximum was during 2016 (46 articles)

The average total citation during this time was 39.3; this means that the average citation decreased compared to 87.4 in the previous five consecutive years (2007 to 2011). The maximum peak was from 2017 to 2022, whereby according to the data extracted from the Scopus database, there were 490 articles (74.1% of 661 documents) with an average of 98 documents per year. During that time, the average total citation was about 29.3, one-third of the average citation from 2007 to 2011. In comparison between these four sub-time frames, it is seen that there are some years when the number of documents increases but have a small number of individual and average citations.

Also, according to the results of this study, the published articles during 2007/2011 were 12 times as compared to those of 2002/2006. There was an increment of nearly four times for 2012/2016 as compared to the previous period of five consecutive years, whereby the production ratio for the previous consecutive five years to the period of maximum peak (2017/2022) was nearly 1:4 as reference taken from Fig. 3 , which shows the of the article production and citation variation with time.

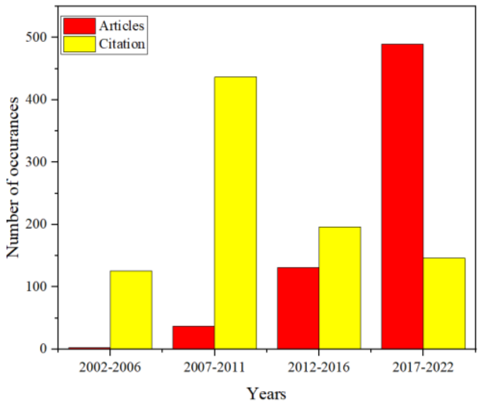


Fig. 3. Publication and citation in five years interval

### *6.2. Influential country and bibliographic coupling*

The most Influential country is the one with a large number of publications and can appear large in the network diagram of the VOS viewer [102]; for this reason, it means that the number of publications was taken as a primary reference that the United States takes the lead with 113 documents with a total citation of 4102 followed by the United Kingdom having 112 documents with 2429 citations, this is because these two countries are more technological and research-developed compare to other countries [103].

Also, using the VOS viewer application, the results show that the United States was the most productive country as the most expanded item/node in the network diagram, which is shown in Fig. 4. The Figure clearly shows the most productive countries and their collaboration network. According to this network diagram, the largest nodes indicate the most productive countries and the smallest nodes indicate that the countries have published a few articles in the respective database. The results show that most of the articles were published between the year 2017 to 2022.

Also reference the tabulated data in Table 5, which shows productive on the ranking of the top 6 countries whereby Germany takes a lead in bibliographic coupling with a total of 33,725 link strength, from extracted data from Scopus, up to October, Tanzania has published only 32 for 20 years which is average of only 1.6 official papers per year which is a small number of the documents compare to the other developing countries like South Africa and Rwanda.

Also, data in Table 3 shows productivity on the ranking of the top 10 countries, whereby Germany takes the lead in bibliographic coupling with a total of 33,725 link strength [30,101]. Tanzania did not appear in the network diagram as considering the data extracted from Scopus data for 20 years to 2022, Tanzania has had only 32 documents published for 20 years, an average of only 1.6 published papers per year [12].

Bibliographical coupling linkages are resemblance techniques utilized in scientific modeling structures discussed in the Bibliometric study, and they emerge when distinct papers exhibit the same references [100]. The bibliographical coupling of publications refers to their relatedness in relation to the number of citations they share [104]. In other words, bibliographic coupling happens when a third term is used as a reference within two papers [105]. Because the United States offers the strongest wind, solar, thermal, hydropower, and biofuel resources in the world, it has the opportunity to lead the globe's transition to renewable energy, also has a thriving culture of innovation, a plethora of financial options, and a talented workforce [90,106].

The country collaboration from 2002 to 2022 was ranked to have 1 to 3 repeated collaboration intervals between one country and another, 4 to 7, and above 7. Using the VOS viewer User Interface (VUI), the first leading country is Germany, with a total of 67 documents, 2167 citations, and 33,725 link strength, indicating the strong bibliographic coupling/collaboration with other countries.

However, for the Biblioshiny User Interface, the results show that the United Kingdom has collaborated with more than 46 countries, from which 23 countries have collaborated mono-frequently, and 13 countries have di-frequently collaborated. The minimum collaboration frequency made with countries like the Netherlands, Malaysia, Uganda, Tanzania, South Africa, and Japan was one time, five times with Uganda, six times with Ghana, and eight times only with Spain, which is the maximum collaboration. The more linkages in the network diagram indicate the more collaboration between the nodes. there are seven main clusters, and each cluster is represented by a specific color at their node, which means that the nodes of the same color are categorized in the same cluster and have strong collaboration between the nodes.

Table 3. Most influential countries, published documents, citations and strength

| Countries | Number of articles | Number of citations | Link strength |
|---|---|---|---|
| United States | 113 | 4102 | 29540 |
| United Kingdom | 112 | 2429 | 32713 |
| South Africa | 86 | 1087 | 14372 |
| China | 71 | 1658 | 18893 |
| Germany | 67 | 2167 | 33725 |

The strongest cluster is red, and it consists of more than 24 countries like China, Turkey, India, Saud Arabia, Indonesia, and Malaysia, while the second strongest cluster is the green color, and it consists of 20 countries, including the United States of America, Germany, Canada, Netherlands and Norway.

Other clusters include the one with a blue light node with the collaboration of the 14 countries whereby Spain is included, the yellow cluster with eight countries where Egypt and the United Arab Emirates are included, the purple cluster with four countries from which Saudi Arabia and Rwanda are included, also only Denmark and Chile were found to be in the same cluster, and Singapore was in the cluster alone as also referred to the Fig. 4 from which the arrow shows the node which indicates that Tanzania is among the countries that have an interest in renewable energy.

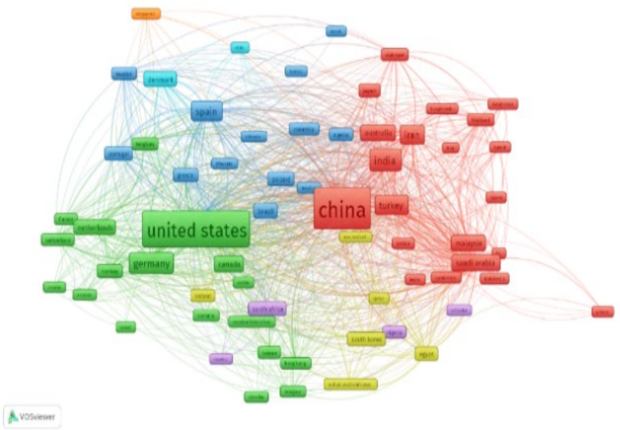


Fig. 4. Most influential countries and their bibliographic couplings

Also, using the Biblioshiny user's Interface, the results show that the United States of America also has 35 collaborations with different countries from different continental locations, whereby for the frequency of 1 to 3 collaboration frequency, the USA has collaborated with only 17 countries like Switzerland, Mali, Uganda, Costa Rica, and India, for the collaboration frequency of 4 to 7 publications, more than ten countries were engaged in the collaboration with the United States.

The results concluded that since Germany has more link strength using VOS viewer, Germany is the first-ranked country with strong collaboration and bibliographic couplings. Both VOS viewer and Biblioshiny User Interfaces show a strong collaboration from 2002 to 2022, ranked 1 to 3, repeated collaboration between countries, 4 to 7, and above 7.

Using VUI, the results show that the first leading country is Germany, with a total of 67 documents, 2167 citations, and 33,725 link strength, indicating the strong bibliographic coupling/collaboration with other countries.

However, for the Biblioshiny user interface, the results show that the United Kingdom has collaborated with more than 46 countries, from which 23 countries have collaborated in 1 to 3 research papers, and 13 countries have collaborated two times. The minimum collaboration frequency made with countries like the Netherlands, Malaysia, Uganda, Tanzania, South Africa, and Japan was one time, five times with Uganda, six times with Ghana, and eight times only with Spain, which is the maximum collaboration. Fig. 5 shows collaboration map whereby, African developing nations including Tanzania have been collaborating with other countries outside Africa.


Fig. 5. World collaboration map (Source: RStudio for retrieved data)

### 6.3. Affiliated institutions and their dynamicity

About institutions and author affiliations contributing to renewable energy, the study examined the publication performance of 15 major institutions. As a result, the University of Malaya takes the lead with its 25 documents, preceded by the "The University of California" and the "University of Cape Town" each with 20 documents, and "Universiti Teknologi Malaysia" and "The Polytechnic University of Milan" with a total of 18 and 15 documents respectively, "The University of Arizona" besides the "Kwame Nkrumah University of Science and Technology" each take a total of 14 public documents. Other remaining Institutions count a total of 13 documents each; a large number of documents issued by a particular agency indicates a high interest of that particular agency in a concern [93]. Apart from the documents published by the institution, which show to which extent the certain study topics. The results of this research obtained from software analysis tools showed that the top 10 institutions have been seen as the most dynamic affiliated institutions, as shown in Table 4. These institutions have been frequently publishing articles based on renewable energy for 20 years consecutively.

Also, corporate partnerships, also known as inter-organizational collaborations in this investigation [105], merely represent collaborations between various organizations, i.e., universities, academies, or companies, other than those between different departments of the same universities. As far as institutional collaboration is concerned, this study showed that top institutions from different countries have strong institutional collaborations. The results show that there is an inter-organizational collaboration because there is a linkage that exists between one node or organization to another, as shown in the network diagram in Figure 6 extracted from Biblioshiny mapping software, color codes specify eight different clusters; this means that the node means an affiliated institution and the nodes of the same color are found in the same cluster [105].

The results show that there is an inter-organizational collaboration because there is a linkage that exists between one node or organization to another, as shown in the network diagram extracted from Biblioshiny mapping software, color codes specify eight different clusters; this means that the node means an affiliated institution and the nodes of the same color are found in the same cluster [105].

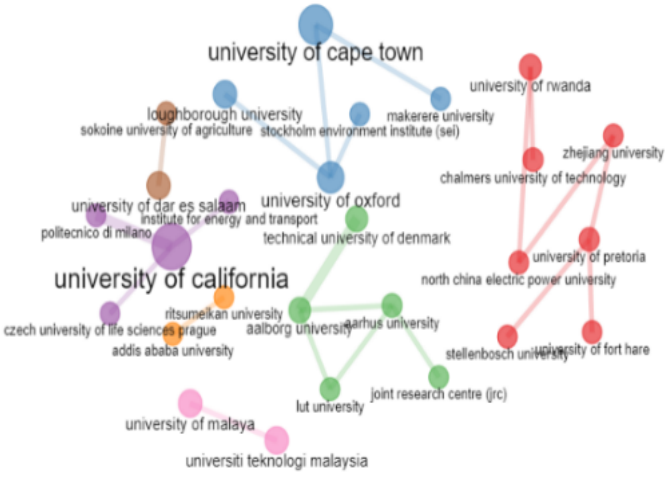


Fig. 6. Collaboration network between Affiliated institutions

All clusters seem to have interconnected nodes, and the most strongly connected cluster is made by the University of Rwanda, Chalmers University, University of Pretoria, Stellenbosch University, North China Electric Power University, and Zhejiang University, while the second strongly collaborated cluster is that made whereby there is the University of Cape Town, and the third most is the cluster which includes the University of California.

### *6.4. Co-Authorship and collaboration network*

The study explored the social structural component of the Bibliometric parameter [105] presented in the Biblioshiny user interface based on co-authorship and social collaboration assessment [12]. As per researchers, the social web of participants in a domain outlines the collaborative linkage among two or more individuals, organizations, or countries [92,105,107]. These relationships are shown in the form of networks, with nodes representing actors and links linking the nodes representing relationships. The most productive authors with their respective number of documents and citations are shown in the Table 5. As shown in Fig. 7, this study depicts the consortium blockchain among writers. The findings demonstrate that the famous names already cited as productive field academics, such as Moner-Girona [108], Mandell [109], Troller [109], Lin , Rich, and Bishonge, there is a strong and well-established collaboration network, as seen in that there are intersected lines between nodes of the Network. Also, there are 11 different clusters that were obtained and differentiated by different colors, the strongest cluster is the cluster with the many linkages between its nodes and even a linkage to the node outside the respective cluster.

There is a strong collaboration in the cluster, indicated by a light green color with the most productive authors. Also, this cluster is seen to have interconnection to the adjacent cluster through coupling between Szabo s of the strong node to Pedersen ab and Jensen ss, also Moner-Girona m with Aly a, Jensen ss, and Pedersen ab.

The collaboration of the other clusters also has been weakly established in all clusters, as shown in the author's collaboration network below, since each color indicates the specific cluster, the interconnection between the nodes in the same clusters or to the different clusters indicated a collaboration or research collaboration indicators whereby one author has cited the document of the other author or they have some identical thought in their research works [110].

For the case of article production, Moner-Girona takes the first rank with eight articles followed by Szabo with seven articles. But for the citation criteria, Bashir leads the citation ranks with a total of 288 citations, followed by Mustafa with 276 citations.

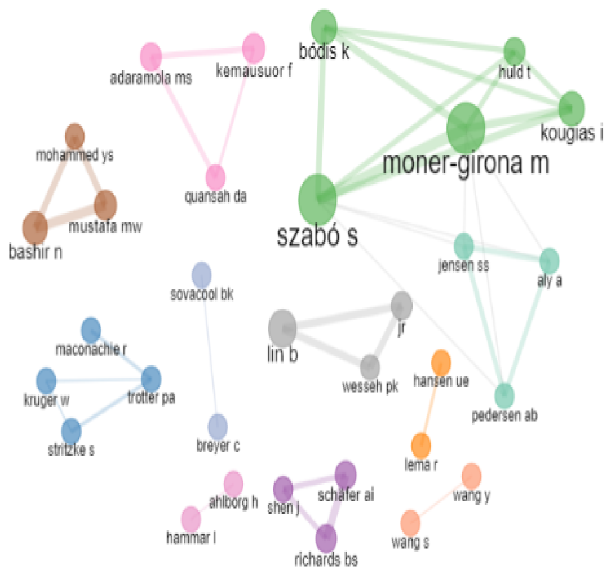


Fig. 7. Author collaboration network

Table 4. Most affiliated Academic institutions

| Rank | Affiliated Institution | Articles |
|---|---|---|
| 1 | University of Malaya | 25 |
| 2 | University of California | 20 |
| 3 | University of Cape Town | 20 |
| 4 | Universiti Teknologi Malysia | 18 |
| 5 | Politecnico di Malano | 15 |
| 6 | Kwame Nkrumah University | 14 |
| 7 | University of Arizona | 14 |
| 8 | Intergovernmental Panel on Climate | 13 |
| 9 | Loughborough Unversity | 13 |
| 10 | Oxford University | 13 |

### *6.5. Most productive and cited sources*

In this analysis, 40 different sources were taken as a sample with a minimum of 1 citation of the sources from which the top 15 sources were the most productive sources, whereby the leading source was Renewable and Sustainable Energy (RSE), which produced more than 90 documents with the total of nearly 5,000 citations while the second leading sources were dealing with Energy Policy (EP) having a total of 32 documents with 1597 citations. The common or most productive sources are elaborated in Table 6 below.

Also, the Renewable Energy source took the third position of the top 15 leading sources with a total of 34 documents and 1027 citations. In the case of production, Energy policy has to take a third leading position since it has fewer documents compared with Renewable Energy sources, while in citation ranking, it is vice versa, as shown in Table 8 below. In other words, the results show that "Renewable and Sustainable Energy" has more than 91 documents with 4761 total citations, meaning that the average citation for each document was cited nearly 53 times and an Average citation of 238 times. The source with the lowest number of citations is "Sustainable Practice concept" having only three documents with four citations.

Also, from the numerical results, through the result of this study, the larger the number of published articles of the source, the more productive the source is, while the larger the citation frequency, the more the source is coupled to its keywords as indicated by the frequency of citation [111]. The VOS viewer software shows the sources that are the most productive, and most of the cited/collaborated sources have strong networks with the other sources.

Table 5. Most productive cited authors

| Ranks | Authors | Articles | Citations |
|---|---|---|---|
| 1 | Bashir N. | 6 | 288 |
| 2 | Mustafa m.w. | 5 | 276 |
| 3 | Mohammed y. s | 4 | 253 |
| 4 | Magda Moner-girona | 8 | 192 |
| 5 | Szabo Sandor. | 7 | 192 |
| 6 | Jensen Steen Solvang | 3 | 186 |
| 7 | Pedersen Anders Branth | 3 | 186 |
| 8 | Richard b.s. | 5 | 163 |
| 9 | Kougias i. | 4 | 144 |
| 10 | Bodis k. | 4 | 135 |

Table 6. Most productive sources and their citations

| Productive Sources | Articles | Citations |
|---|---|---|
| Renewable and Sustainable Energy | 91 | 4761 |
| Energy Policy | 32 | 1597 |
| Renewable Energy | 34 | 1027 |
| Energy | 38 | 630 |
| Renewable Energy and Social Science | 35 | 882 |
| Energy for Sustainable Development | 21 | 402 |
| Biomass and Bioenergy | 7 | 389 |
| Energy | 20 | 656 |
| Applied Energy | 12 | 382 |
| Tech. Forecasting | 4 | 295 |
| Environmental Science and Pollution | 14 | 316 |
| Science of Total Environment | 7 | 650 |
| Journal of Sc. and Env. Management | 8 | 248 |
| Environmental Research Letters | 3 | 106 |

### *6.6. Most globally cited documents*

The most cited documents dictate the most frequently cited document in another research in this study; the results from Bibliometrix showed that Luquw R, 2008, published the most global cited document, it has a total of 480 citations, followed by *Joergensen RG, 2008* with the total of 425 and *Coedera M, 2009* with 336. The table below shows the most 20 globally cited documents for 20 years consecutively. The last three ranks were taken by *Kshirsagar MP,2014*, *Ozatac N, 2017* and *Yaqoot M, 2016* with 164, 149, and 148, respectively, as shown in Table 9. Luquw R (2008) examined environmental matters, the increasing energy demand, political considerations, and the mid-term exhaustion of petroleum have generated a requirement for the advancement of sustainable technologies relying on renewable resources. The topics of concern for the global most influential, such as Joergensen RG (2008), and Conedera M (2009), are shown in Table 7.

The absence of Tanzanian published documents from the top 20 most globally cited works underscores a notable gap in the international acknowledgment and influence of Tanzanian research. This could be due to various factors, including limited access to international research networks, insufficient funding for research initiatives, or challenges in publishing in high-impact journals. As a result, the unique challenges and opportunities faced by Tanzania may not be adequately addressed or prioritized in global research agendas. Additionally, the underrepresentation of Tanzanian research diminishes the potential for international collaborations, which are the keys for enhancing research quality and increasing access to advanced methodologies and technologies. To improve this situation, there is a need for targeted efforts to increase the visibility and citation of Tanzanian research, such as encouraging local researchers to publish in reputable international journals, increasing funding for research activities, and fostering collaborations with global research institutions.

### *6.7. Most locally cited documents*

Also, for the most locally cited documents, as taken from the 20 most locally cited documents in Table 10 , the document for the “Solar Power Potential of Tanzania” written by Aly A, 2017 is leading the ranks with 38 citations per year followed by “Renewable energy in Rwanda, Tanzania, and Malawi” written by *Marie-Louise 2011* and “Rural electrification in Tanzania and Mozambique” written by *Ahlborg H, 2014* having 35 and 23 citations respectively while “Independent power project in Sub-Sahara Africa” by *Eberhard A, 2017*, “Renewable Energy development in Uganda” by *Okello C, 2013* and “Biogas technology in Sub-Sahara Africa” by *Parawira W, 2009* have the smallest number of citations each with nine citation frequency as shown in the Table 8.

In the research context, the 20 most locally cited documents, with annual citations ranging from 9 to 38 over 20 years, demonstrate significant influence within the local academic community. Even the least cited document has accrued 180 citations, while the most cited has 760, indicating their foundational roles in local research. These high citation rates reflect

Table 7. The 20 Most globally cited documents for consecutive 2020 consecutive years from 2002 to 2022

| The main discussed topic | Author | Year | Citations | Citation/Year | Ref. |
|---|---|---|---|---|---|
| Biofuels | Luque R | 2008 | 600 | 30.00 | [112] |
| Fungal contribution to microbial tissue | Joergensen RG | 2008 | 531 | 26.56 | [113] |
| Reconstructing postfire regimes | Conedera M | 2009 | 448 | 22.40 | [114] |
| Biogas as a sustainable source | Surendra KC | 2014 | 666 | 33.30 | [7] |
| Mitigation of Greenhouse gas emission | Bogner J | 2008 | 340 | 17.00 | [115] |
| Decentralized energy planning | Hiremath RB | 2007 | 299 | 14.94 | [116] |
| The global energy, food and water | D'odorico P | 2018 | 787 | 39.33 | [117] |
| Energy and carbon emissions | Mirza FM | 2017 | 651 | 32.57 | [118] |
| Environmental degradation in Africa | Wang J | 2019 | 788 | 39.40 | [119] |
| Renewable Energy and biodiversity | Gasparatos A | 2017 | 520 | 26.00 | [120] |
| Prospects of biodiesel from Jatropha | Mofijur M | 2012 | 302 | 15.08 | [6] |
| Drivers and barriers to electrification | Ahlborg H | 2014 | 352 | 17.60 | [31] |
| Biofuels and sustainability in Africa | Amigun B | 2011 | 269 | 13.46 | [121] |
| Ecological impact of the Hydroelectric | Kuriqi A | 2021 | 1147 | 57.33 | [122] |
| Reassessing the “energy ladder” | Hiemstra VH | 2008 | 215 | 10.75 | [123] |
| sustainable tourism and economy | Pan S-Y | 2018 | 563 | 28.17 | [124] |
| Barriers to biogas dissemination | Mittal S | 2018 | 557 | 27.83 | [125] |
| modern cookstove design | Kshirsagar MP | 2014 | 328 | 16.40 | [126] |
| Trade openness, urbanization | Ozatac N | 2017 | 426 | 21.29 | [127] |
| Decentralized renewable energy | Yaqoot M | 2016 | 370 | 18.50 | [11] |

Table 8. The 20 Most locally cited documents for consecutive 2020 consecutive years from 2002 to 2022

| The main discussed topic | Author | Year | Citations | Citation/Year | Ref. |
|---|---|---|---|---|---|
| Solar Power Potential of Tanzania | Aly A | 2017 | 760 | 38 | [95] |
| Renewable energy in Rwanda, Tanzania and Malawi | Marie-Louise | 2011 | 700 | 35 | [128] |
| Rural electrification in Tanzania and Mozambique | Ahlborg H | 2014 | 460 | 23 | [31] |
| Energy and developmental challenges in Africa | Mohammed YS | 2013 | 360 | 18 | [129] |
| Rural electrification initiatives in developing countries | Almeshqab F | 2019 | 280 | 14 | [130] |
| Barriers to Large-scale Solar Power in Tanzania | Aly A | 2019 | 280 | 14 | [18] |
| Renewable energy in Tanzanian villages | Ahlborg H | 2015 | 280 | 14 | [131] |
| Renewable energy mini grid in Nepal | Yadoo A | 2012 | 280 | 14 | [132] |
| Adaptation of Feed-in Tariff for remote mini-grids | Moner-Girona | 2016 | 260 | 13 | [133] |
| Small-scale biogas digesters in Sub-Saharan Africa | Jecinta Mwirigi | 2014 | 260 | 13 | [134] |
| Solar Power in sub-Sahara Africa | Aly A | 2019 | 240 | 12 | [135] |
| Power planning in sub-Saharan Africa | Trotter PA | 2017 | 220 | 11 | [109] |
| Renewable energy resources in Nigeria | Mohammed YS | 2013 | 220 | 11 | [136] |
| Selection for a Solar PV Power Plant using AHP | Ozdemir S | 2018 | 200 | 10 | [137] |
| Barriers to biogas dissemination in India | Mittal S | 2018 | 200 | 10 | [125] |
| Village level-Power in Africa | Ulsrud K | 2015 | 200 | 10 | [138] |
| Biogas as a sustainable energy source | Surendra KC | 2014 | 200 | 10 | [138] |
| Independent power project in Sub Sahara Africa | Eberhard A | 2017 | 180 | 9 | [139] |
| Renewable Energy development in Uganda | Okello C | 2013 | 180 | 9 | [140] |
| Biogas technology in Sub-Sahara Africa | Parawira W | 2009 | 180 | 9 | [141] |

### 6.8. Keywords analysis and occurrence network

The phrase co-occurrence mapping is a proximity network that depicts the relation between both phrases inside the selected bibliographies [149]. If the phrases appear in the same sentences, then they are given a higher relevancy score [144] As a result, terms that are linked and close together on maps are more related [102].

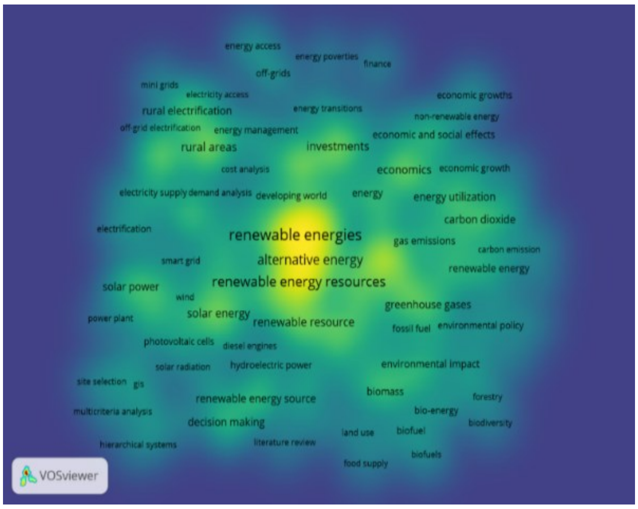


Fig. 8. The density visualization of the most keywords used

Keyword analysis employed by researchers is an essential method for investigating trending topics and researchers' interest in the field [41,141]. This analysis is crucial since keywords can quickly identify the subject and emphasis of a publication. The text corpus in Fig. 8 illustrates density visualization of the keywords used regarding renewable Energy, related topics, or even derived keywords.

The results obtained from VOS viewer showed that there are many keywords used by the authors in theirs which are very near to the term "Energy." these keywords are "Energy excess (27)", "biogas (28)", "biomass (20)", "Solar (12)", "hydropower (15)", "Wind Energy (12)", "Rural electrification (139)", "energy policy (21)". The results also show that the most keyword used by the authors is Renewable energy documents, which have 297 documents with a total occurrence of 486. In the density visualization, the most visible nodes are the most common keyword used by the authors, and the fainted nodes mean that the keyword is not yet mostly used by authors as seen in the density visualization.

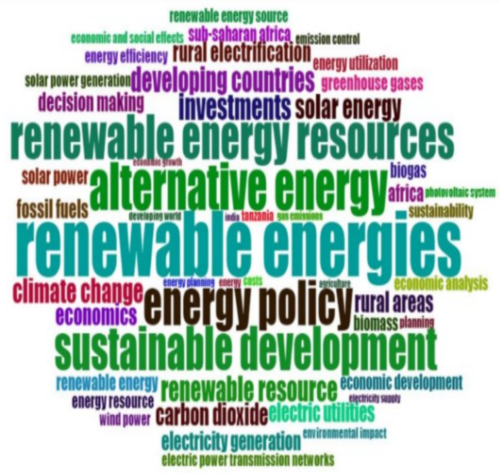


Fig. 9. The word clouds generated from data (Source: BUI till 2022

The captured text above in Fig. 9 shows the word clouds results from BUI. Through the bibliometric software tool, The value of the strength of the burst keywords is indicated by the frequency or occurrence of the keyword [145].

Also, Table 9 shows the 20 keywords used by different authors in their works and their occurrences from the year 2002 to 2022. In addition, the Biblioshiny User's Interface's word cloud was employed in search [92] it appears in the text being analyzed [146] Density visualizations are becoming increasingly popular as a simple technique for determining the topic of the written text. In this study, most 60 keywords were taken using a keyword plus in Biblioshiny User's Interface; the table below shows the Renewable Energy from the year 2002 to 2022

Table 9. The most keywords with top of 20 used by the authors

| Keyword | Frequency |
|---|---|
| Renewable Energy | 486 |
| Energy policy | 143 |
| Sustainable Development | 139 |
| Renewable Resources | 81 |
| Solar Energy | 78 |
| Fossil Fuel | 60 |
| Solar Power | 52 |
| Biogas | 49 |
| Biomass | 48 |
| Energy sources | 46 |
| Energy utilization | 45 |
| Energy | 29 |
| Energy Efficiency | 44 |
| Energy generation | 59 |
| Electricity | 23 |
| Electric utility | 61 |
| Rural electrification | 65 |
| Renewable Energy Source | 43 |
| Energy Technologies | 23 |
| Wind Power | 12 |

*6.9. Trending topics analysis*

Trend topics analysis can show the most rending research for a selected time interval [147]. The trending topics analysis can also be indicated by the keywords used by the previous research [148] In this study, the trend analysis was done using a Biblioshiny User's Interface in accessing the 20 years ago till October 2022. The most common trending topics are indicated in the trending topics data graph in Fig. 10.

Due to the previously described findings, certain topics of future study in the field of renewable energy technology (RE) from the standpoint of sustainable development might be suggested[96] This study discovered a lack of research based on the analysis and assessment of each energy source[97] For example, if wind energy is taken as an instance from 2002 to October 2022, the author's search terms "Wind energy/wind power"[149] confirmed only 12 publications found in a time frame of 20 consecutive years, and for these 12 articles, it was also discovered that the more than eight inquiry assessed wind energy durability for only three months, which is equivalent to only one year [150–153]

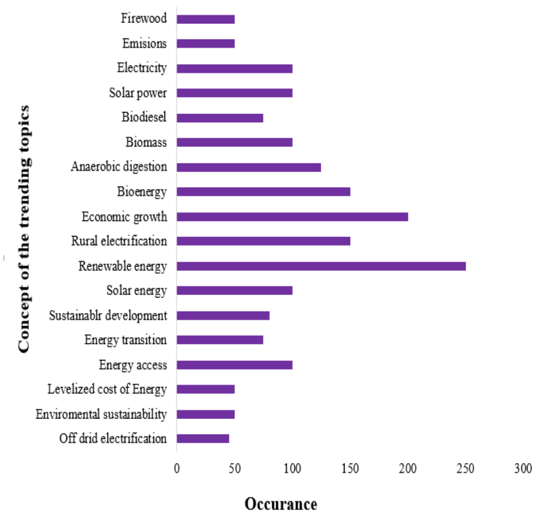


Fig. 10. Most trending topics

In other words, most of the research that has been done was based on renewable energy in general, policy-making, investments, environmental sustainability, energy access, economic growth, rural electrification, biodiesel, biomass, emission, and firewood [154,155].

Until the data retrieval date, there was no study that assessed or analyzed the sustainability of hydroelectric power, oceanic energy, or geothermal energy, even though hydroelectric power plants have been the leading installed.

## 7. Research Gaps Exist from Previous Studies

The analysis of this study shows that most of the locally published papers were directed to the environmental impact assessment, generalized impression of the renewable energy collectively context of a particular renewable energy source like "Renewable energy in Rwanda, Tanzania and Malawi" written by Marie-Louise (2017), "Rural electrification in Tanzania and Mozambique" by Ahlborg H (2011), "Barriers to Large-scale Solar Power in Tanzania" by Aly A (2019), "Adaptation of Feed-in Tariff for remote mini-grids" by Moner-Girona (2016), "Renewable energy in Tanzanian villages." Also, most authors concentrated on the exploration of the global context of energy rather than the local context. The local authors concentrated on the global energy context, including "Small-scale biogas digesters in Sub-Saharan Africa "by Jecinta Mwirigi (2014), and "Independent power project in Sub Sahara Africa" by Eberhard A (2017).

In conclusion, most of the local trending topics were not discussed in the analysis of each energy source to trace or predict the sustainability of the respective energy resources like "Analysis of wind power potential," "Analysis of Solar power potential," "Analysis of Oceanic power potential," "Analysis of Geothermal power capacity." The analysis of the power potential of each energy source will predict the real image of energy sustainability and future investment as well as is a key motivational factor for local and international investors.

### 7.1. Research gap from academic/research institutions

Research institutions, including academic research and consultancy, play a vital role in the research and development in different sectors to input positive economic development and associated or related matters [156,157].

The funding and academic infrastructure for renewable energy research in Tanzania is insufficient, hindering progress in this critical field. Among over 100 academic institutions in the country, a notable portion lacks programs dedicated to energy and renewable energy studies. This absence not only deprives students of the opportunity to engage with these vital topics but also limits the potential for groundbreaking research and innovation in the renewable energy sector. Without adequate support and resources, Tanzania's academic community faces challenges in addressing pressing energy-related issues and contributing meaningfully to sustainable development initiatives. Urgent action is needed to bolster funding and establish comprehensive academic programs focused on renewable energy, empowering students to explore and advance solutions to the energy challenges facing Tanzania and the wider global community.

While some risks are inherent in any research and development endeavor, addressing weaknesses through rigorous scientific methodologies, validation, collaboration with industry partners, and thorough market analysis can enhance the prospects of success and increase investor confidence**.** Lack of research conducted on the analysis of renewable energy resources sustainability can cause the following investment consequences.

#### 7.1.1. Uncertain or unreliable results

Energy research often involves exploring new technologies, materials, or approaches that may not have been thoroughly tested or proven in practical applications. If the research produces uncertain or unreliable results, it can create doubts among investors about the feasibility or effectiveness of the proposed solutions. This uncertainty can deter potential investors from committing their resources to the project. Renewable energy research heavily relies on technological advancements to improve efficiency and reduce costs. However, the pace of technological progress is challenging to predict accurately. If research fails to anticipate breakthroughs or overestimates the potential of certain technologies, it can lead to inaccurate predictions about energy sustainability.

#### 7.1.2. Lack of scalability

One of the key considerations for energy investments is scalability. It is the ability to deploy a technology or solution on a large scale to have a significant impact. Weaknesses in energy research may reveal limitations in scalability, such as high costs, limited resource availability, or technical constraints. If investors perceive that a research project cannot be scaled up effectively, they may view it as a risky investment with limited potential for returns.

#### 7.1.3. Market competitiveness

Energy is a highly competitive sector, with numerous companies and research institutions vying for funding and commercial opportunities. Weaknesses in energy research, such as a lack of innovation, inadequate intellectual property protection, or inferior performance compared to existing solutions, can make it difficult for a project to gain a competitive edge in the market. Investors may shy away from investing in projects that do not demonstrate a clear advantage or potential for market success.

#### 7.1.4. Regulatory and policy risks

Energy investments are subject to various regulatory and policy frameworks, which can significantly influence their viability and profitability. Weaknesses in energy research may result in projects that fail to comply with existing regulations or that face uncertain policy environments. This introduces additional risks for investors, as changes in regulations or policies can impact project economics or market access. Investors may be hesitant to invest in projects that are vulnerable to regulatory or policy uncertainties.

### 7.2. National energy policy gap

This research identified several challenges confronting the energy sector, such as an unstable and costly energy supply, an excessive reliance on government subsidies, limited access to modern energy services, a shortage of skilled human resources, low levels of government and citizen engagement in the petroleum value and supply chain, inadequate financial resources for sector development, and insufficient research and development. The creation of the NEP 2015 aimed, in part, to eliminate hurdles in the energy sector, enhance productivity, and promote the efficient utilization of energy resources. However, the national energy policy does not effectively address renewable energy sources, owing to the underlying issues outlined

#### 7.2.1. Inadequate research and development support

Continued research and development (R&D) are crucial for advancing renewable energy technologies and making them more efficient, affordable, and reliable. National policies should allocate sufficient funding and resources for R&D initiatives focused on renewable energy. Insufficient support for R&D can slow down technological advancements and impede the competitiveness of renewable energy in the market.

#### 7.2.2. Inadequate regulatory framework

National policies need to provide a supportive regulatory framework for renewable energy. This includes streamlining permitting processes, simplifying grid interconnection procedures, and ensuring fair access to the power grid. If the regulatory environment is complex, burdensome, or favors conventional energy sources, it can hinder the growth and integration of renewable energy into the energy system.

*7.2.3. Lack of grid integration strategies*

Integrating renewable energy into the existing power grid is a complex task. National policies should address grid integration challenges by incentivizing grid upgrades and modernization to accommodate the variability and intermittency of renewable energy sources. Failure to develop strategies and infrastructure for grid integration can hinder the effective utilization of renewable energy resources.

*7.2.4. Lack of long-term planning*

A long-term and consistent policy framework is crucial for promoting renewable energy. However, national policies may suffer from short-sightedness or lack of continuity. If policies change frequently or lack long-term goals, it creates uncertainty for investors and can discourage long-term planning and investment in renewable energy projects.

*7.2.5. Influence of fossil fuel industry*

National policies can be influenced by powerful vested interests, including the fossil fuel industry. Lobbying and political pressure from fossil fuel stakeholders can lead to policies that favor conventional energy sources and create barriers for renewable energy. This influence can slow down the transition to renewable energy and limit the effectiveness of policy measures.

To overcome these shortcomings, national policies need to prioritize renewable energy with clear, long-term goals, provide financial incentives and support mechanisms, streamline regulations, invest in grid infrastructure, promote R&D, and ensure public participation and awareness. Collaboration between governments, industry, and civil society is crucial for designing and implementing effective policies that accelerate the transition to a renewable energy future.

## 8. Direction of the Future Research

Research plays a vital role in promoting investors in the renewable energy sector by providing them with essential information, mitigating risks, assessing financial viability, and facilitating collaboration. It helps investors navigate the complexities of the renewable energy market and make informed decisions that align with their investment goals and sustainability objectives.

To address the research and policy gaps hindering Tanzania's renewable energy sector, a multifaceted approach is necessary. Firstly, substantial investment in research and development is imperative. This entails allocating adequate funding and resources to academic institutions and research organizations to conduct comprehensive studies on renewable energy feasibility, sustainability, and technological advancements. Also, collaboration with industry partners should be incentivized to accelerate innovation and practical application.

In parallel, reforming the national energy policy is crucial. The policy framework must be enhanced to effectively address renewable energy sources. This includes creating supportive regulatory environments, simplifying permitting processes, and ensuring equitable access to the power grid for renewable energy projects. Strategies for integrating renewable energy into the existing power grid must also be developed and implemented to optimize its utilization.

Long-term planning is essential for sustainable energy transition. Establishing clear, long-term goals and objectives within the energy policy can provide stability and direction, avoiding disruptive policy changes. Additionally, efforts should be made to reduce the influence of vested interests, particularly from the fossil fuel industry, on energy policy. Transparency, accountability, and public participation in policy-making processes are vital to ensure that policies prioritize renewable energy and create a level playing field for all energy sources.

Capacity building and awareness-raising initiatives are equally important. Investing in programs to enhance skills and expertise in renewable energy research, development, and implementation can empower local talent and drive innovation. Simultaneously, raising awareness among policymakers, industry stakeholders, and the general public about the benefits of renewable energy and the urgency of transitioning to a sustainable energy future is crucial for fostering support and driving change.

Individualities of the studies are based on specific analyses of the energy resources. According to [158] the direction of the prospect is explained by examining the gap in the previous research. Therefore, this study proposes that more studies are needed that will analyze the adequacy of each renewable energy source, like sustainability analysis of hydroelectric power, geothermal energy, wind energy, solar radiation energy, and oceanic energy, to make a logical and technical prediction of each energy source and their corresponding sustain abilities [159] research prospect to make a deep assessment or analysis of hydroelectric power, oceanic energy, and geothermal energy, even though hydroelectric power plants have been the leading installed plants in Tanzania's mainland as the second most energy-generating source after fossil fuel but the study shows that there is no enough research has been done based on hydropower generation analysis [160]

This study proposes that much research based on the adequacy analysis and assessment of each energy source should be done with consideration of the climatic change. For example, an assessment of wind energy is not a short-term study, but it has to assess the sustainability of the wind power in different seasons of at least three consecutive years in order to know wind dynamic characteristics variations in the different climatic parameters in both dry and rainy seasons[1,41,110].

Lastly, stakeholder collaboration is key to success. By bringing together governments, industry players, academic institutions, research organizations, and civil society, comprehensive and effective policies and initiatives can be designed and implemented to accelerate the transition to a renewable energy future. Through concerted efforts across these fronts, Tanzania can overcome the research and policy gaps in its renewable energy sector and harness the full potential of renewable resources for sustainable development and economic growth.

## 9. Conclusions

Thes study "A review on the Renewable Energy Contribution of Tanzania was conducted. The research explored global contribution on renewable energy research, Tanzania energy policy, available opportunities and installed renewable energy resources and annual research and publication of the renewable energy publications from 2002 to 2022. A total of 661 documents were bibliometric analysed using different criteria, such as descriptive, yearly publication, citations, author superiority, analysis of the author's keywords, most popular trending topics, keywords, most cited document, country publication status, and author collaboration, were considered in this study.

The results show that the two software programs can be used to correctly manage the Scopus database analysis (VOS Viewer and Biblioshiny). In this context, accuracy is defined as the lack of systematic deviations from the Scopus database. The findings indicate that in the globally publication context there is strong encouragement compare to the continental and country context. Tanzania has published only 32 documents related to the renewable energy, this portray that academic and research institutions in Tanzania have not been strongly engaged in renewable energy research for the previous 20 years due to the fact that there is lack of programs related to the energy and renewable energy as well as lack of funds to conduct the studies.

Also, in the energy policy seems to be biased in fossil fuels, and hydroelectric power generation rather than other forms of energy resources like wind, geothermal and tidal energy, hence the policy has to consider energy mix strategy starting by promoting academic and research institutions to be engaged in energy and renewable energy research. From the results of this research, it shows clearly that there is still a lot of potential for an investigation of the sufficiency and sustainability of the various forms of renewable energy resources surrounding the country. In other words, further investigations into renewable energy sources, like sustainability analysis of the wind, oceanic, hydroelectric, and thermal energy, are still required in Tanzania.

## Nomenclature

| | |
|---|---|
| BUI | Biblioshiny User's Interface |
| EAPP | East African Power Pool |
| EP | Energy Policy |
| EPP | Extraordinary Power Producers |
| IPP | Independent Power Producers |
| NRA | National Renewable Energy Agency |
| PV | Photovoltaic |
| TANESCO | Tanzania Electricity Supply Company |
| USD | United States Dollar |
| NEP | National Energy Policy |
| R&D | Research and Development |
| VOSViwer | Visualizing Scientific Landscape |

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