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A Snapshot of Renewable Energy Research in Sub-Saharan Africa

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Abstract: Global concern over energy security and climate change has resulted in the need to adopt renewable energy technologies. The sub-continent of Sub Saharan Africa (SSA) has lagged in terms of renewable energy development and research, despite having great potential for renewable energy resources. We examined emerging trends in renewable energy research in peer-reviewed publications in-order to identify research gaps, research perspectives, current knowledge and development of renewable energy research over time. We used the bibliometric mapping approach to extract and map the most frequently used keywords. This approach was useful in providing a guideline for insights on current geographic and sectoral hotspots. Temporal analysis confirmed that renewable energy publications experienced a substantial growth with biomass energy publications being the most dominant for the study period. The bibliometric maps confirmed this finding as most of the terms pertained to biomass-related topics. It is notable that there has been a shift of the discussion from the traditional sources of biomass (firewood and charcoal) to modern bio-fuel crops in SSA. From this quantitative review it was evident that the key solutions to bridging development gaps for renewable energy in SSA are interconnected. Adequate research stems from sufficient funding that results in bridging technical gaps (in terms of skill and technology), and information (data and awareness). There is a need for a suitable policy framework backed by political will, enforcement and facilitative governance framework to channel the limited resources towards maximizing gains in renewable energy development in SSA.

Keywords: Quantitative Review, Bibliometric Mapping, Renewable Energy, Sub-Saharan Africa

1. Introduction

Climate change remains one of the greatest challenges facing the world, especially developing countries that are also the least contributors to climate change [1]. Climate change is characterized by increases in global temperatures, sea level rise that may trigger events such as floods, droughts and heat waves [1]. This has led to rapid consensus among nations worldwide to shift from traditional carbon-based energy technologies to more environmentally friendly technologies [2]. Sub-Saharan African (SSA) countries will be the most vulnerable to the catastrophic consequences of climate change such as heightened threat of food security, scarce water resources, deterioration of natural resources productivity, shrinking biodiversity, decline in human health, land degradation and desertification [1-2]. Most SSA countries are yet to come in terms with the reality of climate change and its consequences. Despite, developed countries pledging support to the tune of US $ 100 billion dollars by 2020, SSA countries on their part need to put effort in terms of finances and institutional commitment towards the effort of averting the impacts of climate change [1]. Renewable energy technologies have the capacity to bridge the development gap in the region where there are abundant untapped renewable energy resources [3]. The advantage that SSA countries have over developed countries is that they can leapfrog directly and adopt innovative technologies instead of going through the learning curve of energy systems that had resulted in great environmental impacts [3].

Global investments in renewable energy projects in 2015 rose 5% to 285.9 billion from the previous record of US$ 278.5 billion in 2011 [4]. Within the same year, investments in renewables in developing countries outweighed those in developed economies with a total investment of US$ 156 billion, with China, India and Brazil leading the group. In the Middle East and Africa, renewable energy investments increased by 58% to US$ 12.5 billion, with most of the investments originating from South Africa and Morocco. South Africa has made remarkable progress in recent years by investing as much as US$ 4.5 billion in clean energy initiatives [4]. However, there is a significant global disparity in renewables investment, with only one out of 48 countries in Sub-Saharan Africa (SSA) making significant strides [4]. The reasons for the disparities in renewable energy investments have been put forward as poverty, unstable economies, lack of foreign investment, slow economic growth, deficient infrastructure, lack of access to capital, insufficient governance, poor energy planning, financial misappropriation and lack of institutional capacity in some SSA countries [3, 5, 6]. What is concerning is the fact that the renewable energy sector in SSA is primarily dominated by traditional biomass such as charcoal and fuelwood harvest. The excessive use of traditional biomass resources can be attributed to low levels of education and lack of economic empowerment among the rural population to pursue greener alternative forms of energy [3]. The slow pace of technological diffusion and application has further impeded progress in the renewable energy sector [6]. The dependence on fuelwood has led to environmental degradation in the region, and now requires rigorous policy initiatives aimed at increasing access to modern renewable energy services [3]. The diverse nature of renewable policies pursued by SSA countries also poses a challenge for regional integration of renewable energy approaches that could benefit the countries through cooperative mechanisms such as sharing of resources, information, technology, and ideas [3, 5, 6].

There remains a large population in SSA without access to electricity. Securing electricity access for population groups provisioned through renewable sources is increasingly sought after by SSA nations, as it could help address the twin problems of affordability and alleviating environmental degradation. Wide disparities in electricity access have been documented, and the underlying factors that cause them have been delineated in many energy studies [3, 7, 8]. Hancook [9] observed that although there are many journals that focus on environmental and energy issues in SSA, the region remains the least represented in major energy-focused journals globally. Furthermore, most of the journals that cover the topic of energy in SSA cover mostly narrow options such as cookstoves or very generic topics on sustainable energy, while often lacking specific renewable energy solutions [9]. With this backdrop in context, we set forward to investigate various trends in renewable energy research in the region using quantitative publication reviews. As quantitative reviews on research trends in renewable energy in SSA are lacking, we seek to bridge this research gap.

The goal of our study was to assess renewable energy system development in SSA through the lenses of a bibliometric mapping approach. This paper quantitatively reviewed scientific publications in-order to establish the current state of science pertaining to renewable energy in SSA. In this study, we used VOSviewer, software designed for quantitative review by constructing and viewing bibliometric maps [13]. VOSviewer facilitates construction and clustering of term maps providing visual representation by showing important terms in titles, keywords and abstracts of publications [13, 20]. Extraction of the most frequently used keywords can be used to identify the key issues in renewable energy research, and provide insights regarding current geographic and sectoral hotspots in renewable energy research.

2. Background

Quantitative review is a research technique that provides a comprehensive picture of a specific subject area by mapping scientific publications. The technique facilitates an objective categorization of works and items in numerical terms [10]. Quantitative review broadly encompasses text mining, systematic reviews, longitudinal reviews and bibliometric mapping. Text mining is the process of deriving high quality information from text by devising patterns and trends through means such as statistical pattern learning [10, 11]. Bibliometric mapping is similar to text-mining, but the information retrieval is focused around the title, keywords, author, type of journal, year of publication and abstract. It enables the extraction of information from large amount of textual data to give an overview of the subject area [12]. Bibliometric techniques have two aspects that involve construction and the graphical representation of these maps [13].

In the field of environmental management, quantitative reviews have been used extensively in studies involving ecosystem services [14, 15] and sustainability [16, 18]. In the domain of renewable energy, a study by Puzzolo et al. [17] used systematic reviews to investigate the barriers and enablers of adoption and sustained use of clean fuels in resource-poor settings. They focused on household fuels such as LPG (Liquefied Petroleum Gas), biogas, solar cooking and alcohol fuels in middle-income countries in Africa, Latin America, and Asia. Rizzi et al. [19] argued for the need for a study such as ours by stating that despite the need to incorporate quantitative review techniques in the field of renewable energy research to analyze scientific knowledge production, its applications are rare. Our specific objectives are to investigate research trends based on geographical distribution of publications, methods used, subject area categorization based on renewable energy types, distribution of studies per year, and area of interest (biomass, hydro-electric energy, wind energy, solar energy and geothermal energy) in SSA.

The paper is structured as follows; Introduction section which includes a brief background that discusses renewable energy in SSA, study motivation, and objectives;

Methodology section that outlines quantitative review approach used to analyze renewable energy development in SSA; and results, discussion and conclusions section that summarizes how this study contributes to the knowledge and outlines the way ahead.

3. Methodology

The literature search encompassed publications from the Science Direct database, which is a subscription based, professionally curated collection of publications base provided by Elsevier. We chose Science Direct because other search engines such as Google Scholar include extraneous publications and gray literature. Databases such as Springer Link, Web of Science, and Scopus had lower numbers of publications of interest, many of which overlapped with Science Direct. We included a wide range of publications, defined as original research, commentaries, symposiums, reviews, case reports and short communications in order to conduct a comprehensive review of publications in this field. The study papers included those written in English, within the period of 1990-2016 as the last two and half decades capture significant research on renewable energy conducted. The search was refined to capture publications in renewable energy by using the term, 'renewable energy' and 'SSA'. After applying the above-mentioned exclusivity criteria, our final analysis corpus consisted of 373 sources, down from an original 1954 retrieved publications, representing 19.1% of the corpus. The 373 selected publications were categorized based on the geographical distribution, publication dates, methods used, renewable energy by type (wind, solar, biomass, hydroelectricity and geothermal), and name of journal. The criteria for reporting geographical distribution of renewable energy studies were based on the country the research focused on. For geographic distribution of publications in the corpus, we color-coded the countries using the software Tableau 10.0 to map the number of publications per country in SSA. For Bibliometric mapping, the portable document format (pdf) files were downloaded and converted into text files and analyzed using VOS viewer 1.5.4. Using this technique, we identified a list of 'words' commonly encountered in renewable energy research in SSA over the past 26 years. We used density visualization to illustrate specific word patterns that appeared most frequently in the literature.

4. Results and Discussion

4.1. Distribution of Publications on Renewable Energy in SSA

The 373 study publications were distributed across 44 different journals. The Renewable and Sustainable Energy Reviews journal had the largest share of publications at 24.86%, followed by Energy Policy at 16.12% and Renewable Energy at 11.75% (Figure 1). Other journals that had less than 7 publications were placed in the 'others' category that comprised of a grouping of 59 journals together.

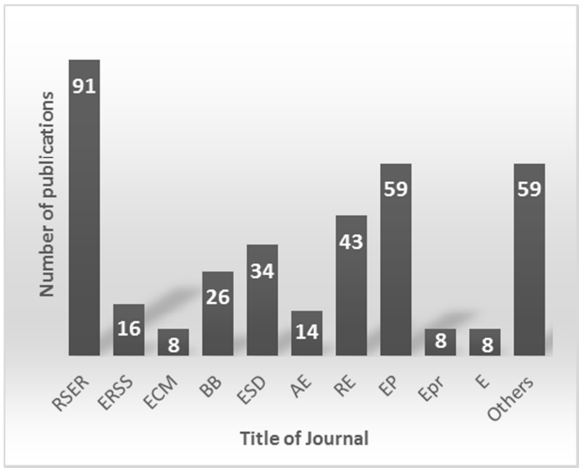

Figure 1. *Number of peer reviewed publications distribution by journals type in SSA (1990 to 2016).*

Note: RSER -Renewable and Sustainable Energy Reviews; ERSS-Energy Research and Social Science; ECM-Energy and Conservation Management; BB-Biomass and Bioenergy; ESD-Energy for Sustainable Development; AE-Applied Energy; RE-Renewable Energy; EP-Energy Policy; EPr-Energy Procedia; E-Energy; Others.

Of the 373 publications, 77.48% were published between 2010 and 2016, with 19.3% between 2000 and 2010 and just 3.28% between 1990 and 1999. The increase in number of publications between 2010 and 2016 could be attributed to increased focus on renewable energy in the region as well as international agreements such as the Kyoto Protocol and Climate Change agreements and discussions that prioritized renewable energy [21]. A delayed spike in publications from 2010 to 2016 in SSA suggests a lag in catching up with the global trends of increased research in renewable energy (Figure 2).

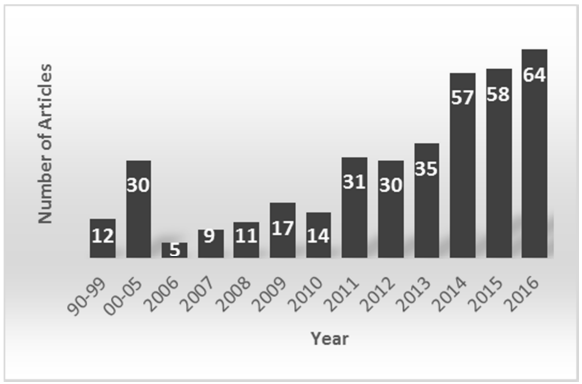

Figure 2. *Number of peer reviewed publications in SSA between 1990 to 2016.*

4.2. Geographical Distribution of Renewable Energy Publications

Renewable energy research was spatially distributed across SSA with few countries acting as research hotspots (Figure 3).

A total of 316 publications researched specific countries within SSA, while the remaining 57 publications focused broadly on SSA representing 15.28% of the total. Out of the 316 publications focusing on specific countries, 14.25% focused on Kenya, 12.02% focused on Nigeria and 10.12% focused on South Africa which is in sync with renewable energy policy discussions and implementation in these countries.

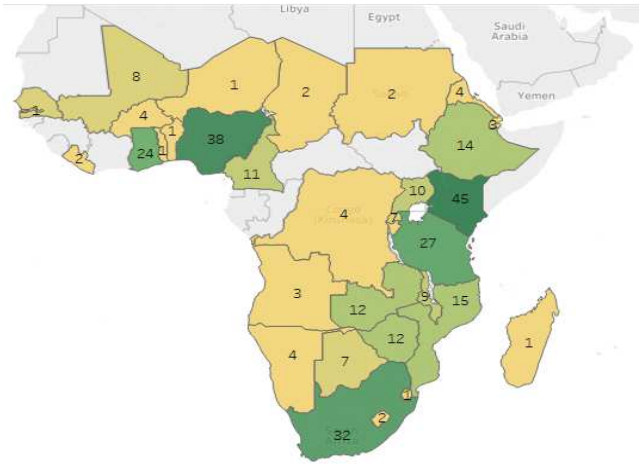

Figure 3. *Illustrating geographical distribution using color coding that represents the frequency of peer reviewed publications focusing on renewable energy in SSA countries.*

Several publications dealt with renewable energy in SSA in general with limited focus on many constituent countries. Our analysis suggests that countries such as Madagascar, Gabon, Democratic Republic of Congo, Chad, Niger, Central African Republic, Somalia, Benin, Cote-D'Ivoire, Togo, Rwanda and Burundi were underrepresented in renewable energy publications, with the number of publications ranging between 0 and 5 within the 26-year period. By focusing on the region, it was easy to gauge that these countries could benefit from additional research related renewable energy deployment.

4.3. Methods Applied in Corpus

The basis of characterization on the methods used in our study corpus of 373 research publications hinged upon how the authors described their publications. Some publications used more than one method; for example, there are studies that had some aspect of surveys and interviews, case analysis or modeling. We identified and focused on the primary study methodology outlined in each 373 publications. This was to avoid overlap and double counting in terms of study methodologies employed. We used 8 categories to classify the publications, namely: reviews, econometrics, surveys and interviews, software and modeling, techno-economic analysis, socio-technical analysis, case studies and 'other' categories (Table 1).

Table 1. *Description of methods used in the corpus.*

Category	Methods used	Representation in the corpus by percentage
Review	Literature review, critical review, longitudinal overview, quantitative review	24%
Econometric modeling	Contingent valuation, regression analysis, macroeconomic assessments, discrete choice, panel data	9%
Software and Modelling	Scenario analysis, satellite derived models, power system dispatch models, spreadsheet models, satellite base irradiance models, system level optimization models, business model, top-down models, spreadsheet models.	14%
Surveys and interviews	Surveys (open ended and closed ended), semi-structured interviews, qualitative studies.	13%
Case studies	Examination, investigation, evaluation, analysis and case study.	20%
Techno-economic analysis	Techno-economic analysis	10%
Socio-technical analysis	Socio-technical analysis	7%
Others	Lead articles, editorials, symposiums, viewpoints, short communications and technical notes	3%

The most frequently used method of study was reviews comprising of 91 studies or 24% of the total publications. This was closely followed by case studies comprising of 74 studies, accounting for 20% of the total. A sizeable portion of publications comprised of 6 other types of methods applied in the corpus that included "software and modeling (52 publications, 14% of total), "surveys and interviews" (48 publications, 13% of total), "Techno-economic analysis" (38 publications, 10% of total), "Econometrics" (32 publications, 9% of total), "Socio-technical analysis (27 publications, 7% of total) and "Others" (11 publications, 3% of total). It is evident from our analysis that the need to bolster energy access within the SSA countries coupled with the climate change concern worldwide has lead to an increase in scholarly literature that are mainly focused on technical and economic aspects [9]. Hancook [9] observes that renewable energy literature with a social dimensions are still lacking in the research literature within the region. This is in agreement with our findings as most literature with a social dimension were covered under socio-technical analysis.

4.4. Bibliometric Mapping: Density Visualization

Term maps that focus on Density visualization using the methods put forward by Van Eck and Waltman [13] for 373 publication abstracts were created. Density visualization works by displaying the text size and distance between items thereby, denoting its contribution by using color heat maps to represent the density of items

based on the number and importance of the neighboring items (Figure 4). It is a useful tool to get an overview of general structure by highlighting the most key areas of the map [13]. Overall, the terms were placed in six categories based on topic of focus bringing up five distinct categories (biomass, solar, wind energy, hydro-power and geothermal related terms) and one other category for other important terms. The renewable energy in SSA corpus abstract had 8680 terms, of which 642 met the threshold of a minimum occurrence of ten words that were focused around the renewable energy term. Biomass related terms formed 64.33% of the total renewable energy words in the abstract, the most common terms being 'biomass', 'biofuel', 'charcoal', 'biogas', 'Jatropha', 'fuel-wood', and 'biodiesel'. Solar related words formed 5.05% of the total renewable energy words with the most common terms being 'solar home system', 'solar energy' and 'photovoltaics'. Wind related terms formed 3.51% of the total renewable energy words with the term 'wind' dominating the category. Hydropower related terms formed 4.54% of the total number of words with terms such as 'hydro' and 'water' featuring in the abstract. Other important terms in the abstract were 'renewable energy', 'development', 'electricity access', 'energy policy', 'climate change', 'sustainability' and 'greenhouse gas emission. Finally, countries that featured in the density visualization were Nigeria, Kenya, South Africa and Uganda (Figure 4).

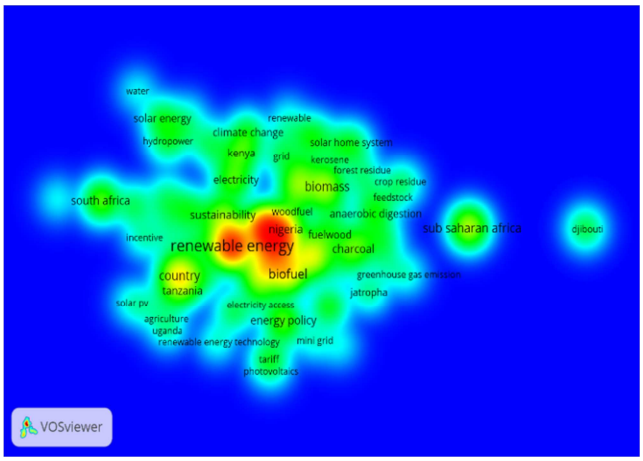

Figure 4. *Density visualization of peer reviewed publications in SSA.*

4.5. Distribution of Publications About Renewable Energy by Type

It is evident that before the year 2000, there were few publications, with fewer than 3 per year. Between 2000 and 2010 there has been a steady increase in growth of number of publications in all domains, especially for biomass energy. There has been a marked increase of number of publications in all domains, particularly for biomass and solar with an average of 19 and 8 articles per year respectively from 2010 to 2016. Being dominant source of renewable energy for the past half century in SSA, we expected that hydropower publications would have higher number of publications over the years [22]. However, our analysis suggests that the renewable energy discussion in the region is mainly focused on biomass and solar (Figure 5).

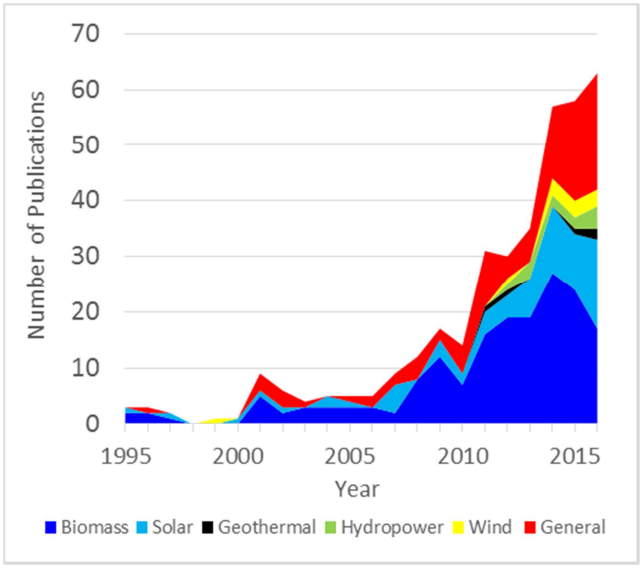

Figure 5. *Area chart for the number of publications by renewable energy type.*

4.5.1. Biomass

A total of 175 publications (47% of total) focused on biomass from 1990 to 2016. Among these publications, 33% focused on biofuels, 16% focused on biogas from municipal solid wastes and animal residues, 20% focused on charcoal, wood fuel, briquettes and wood chip residues and the remaining 31% discussed all biomass sources together. There was an increased presence of biofuel and biogas publications in comparison with charcoal and wood fuel. This suggests increased research transition from the traditional sources of biomass to more efficient biomass options such as biodiesel plants, bioethanol production using crops, grasses, and other feedstocks especially from 2008 onwards.

i. Biofuels

Biofuels encompass broadly available sources of biomass such as biodiesel, bioethanol, biogas, biomethanol and biohydrogen [24]. Biofuel crops in SSA comprise of cassava, *Jatropha curcas*, castor oil, and palm-oil fruit cultivated mainly in Nigeria and Ghana [23]. Other countries with major biofuel production potential comprise of Malawi, Ethiopia, Sudan, Tanzania, Swaziland, Uganda, South Africa, Kenya, Niger and Togo [3]. Interest in biofuel development in SSA is mainly driven by the need to mitigate the impact of high fuel prices and to enhance rural incomes [23]. The criteria of choice of biofuel are based on cost, availability and its economic viability and sustainable growth in SSA. Other suitable attributes are its biodegradability, non-toxicity and lower emission. In cases where biodiesel production stems from edible oil plants such as soybean, rapeseed, sunflower, safflower oil, palm oil and canola there is bound to be competition with food, pharmaceutical and cosmetic uses result in high price of biodiesel generated and high-cost

of these food products. Hence preference in SSA has been for use of non-edible oils from seeds of rubber, Jatropha, castor, linseed, moringa oliefera, cotton, and tobacco plants are being proposed to avoid fuel-food crisis [24]. The publications on *Jatropha curcas* in the mid-2000s rose significantly and constituted 18% (11 publications) of the total publications in biofuels category. This can be attributed to the then prevailing view of Jatropha being a crop that had the potential to tackle the challenges of provision of energy, while providing suitable incomes due to its ability to prevail on marginal land [23]. Most of these publications discussed the potential of successful application of Jatropha in small scale development projects for provision of energy to rural SSA and reduce dependence on fossil fuels [25, 26]. The net positive energy balance and greenhouse gas reduction potential marked this feedstock as an environmentally sustainable option [26, 27]. However, the key challenges to successful deployment of Jatropha were land issues in terms of scale and the time required for the crop to mature [28-30].

The key issues surrounding deployment of biofuel alternatives discussed in the corpus of publications was the reallocation of farmlands dedicated to food crops towards these non-food energy crops. The lack of proper regulatory framework further put pressure on food security and the environment [26, 28, 31, 32]. As most bioenergy policies in SSA were developed in the last decade. The existing government policies continue to have only general statements with regards to biofuel development, that often lack detailed strategies and appropriate institutional framework for implementation [31]. Furthermore, some SSA governments tend to be interested in foreign direct investment deals that facilitate land access to transnational companies rather than protecting customary land rights or ensuring that land for large scale agriculture is secured [32]. This has been attributed to weak links between the major stakeholders (local energy developers, non-governmental organizations, community leaders, researchers) and government that has left investment opportunities exposed to the self-interest of transnational companies, who tend to focus on the extraction of large volumes of resources for export and lack mechanisms to ensure benefit to local populations [32].

ii. Charcoal and Woodfuel

Twenty-seven studies (16% of publications in biomass domain) focused on charcoal and wood-fuel. Most of these publications focused on development of technologies to improve woodstove efficiency. The focus of these studies was on the opportunities, alternative methods of efficient charcoal production, formalization of value chains and livelihood outcomes, governance, policy interventions, changing perspectives, challenges and way forward in the charcoal and wood-fuel industry. An example of this kind of study was the one by Mohammed et al. [3] who reviewed the challenges surrounding the consumption of woodfuel and charcoal in Nigeria, Uganda and Ghana. The proposed solutions by the authors were to increase access to electricity, improve reliability and security of renewable energy options. Given that indoor air pollution from wood smoke results in 600,000 premature deaths annually in SSA [9]. Emphasis has been placed on improved practices in the use of traditional biomass in rural households. Some of the initiatives deployed have been the UN Sustainable Energy for All (SE4All) and the Global Alliance for Clean Cook Stoves, which actively explored technologies that serve to reduce deforestation and indoor air pollution [9, 33]. This focus on initiatives towards improved stoves for efficient use of traditional biomass appears to be both donor driven and based on national government efforts [9, 33]. There is seems to be growing realization that since most rural households depend on wood fuel which is readily available and cheap, improved stoves can be an environmentally and healthy way to harness the energy [33].

iii. Biogas

Biogas and bio-wastes comprise of 30 publications or 17% of biomass domain. Rupf et al. [34], in their review assessed the feasible technologies and feedstocks available for biogas production in SSA. They discussed a range of options such as livestock manure, feedstocks from households, bio-digesters that take up crop residues and municipal solid wastes. They found that the key factors while designing a suitable biogas option included feedstock availability, water supply, energy demand, local materials, labor and level of commitment to operate and maintain the bio-digesters [34]. Other studies focused mostly on the current status and future prospects, policy implications, socio-economic challenges to widespread adoption of biogas digesters, capacity cost, and location-cost analysis for biogas plants in SSA [3, 34, 35]. Biogas as a potential renewable energy source has become appealing to developing country governments as it boosts renewable energy output while easing carbon emissions from fossil fuels [35] Biogas digesters have been installed in Burundi, Botswana, Burkina Faso, Cote d'Ivoire, Ethiopia, Ghana, Guinea, Lesotho, Namibia, Nigeria, Rwanda, Zimbabwe, South Africa, Kenya, Tanzania and Uganda [33, 35]. The key goal behind of most publications on biogas has largely been to understand the underlying factors inhibiting development of biogas, especially why large scaling-up has not occurred, despite the viability, sustainability, and effectiveness of several pilot programs.

4.5.2. Solar Energy

Seventy-one publications in the corpus focused on solar energy, constituting 19% of the publications and making it second largest group of studies related to renewable energy. Solar energy publications seem to follow a similar trend to biomass energy studies, with a small number of publications before the year 2000 followed by a steady increase between 2000 and 2010 and a marked increase in publications from 2010 to 2016 (Figure 5). Most of the publications related to solar energy in SSA focused on off-grid solar solutions that provide basic lighting for rural communities [36]. The publications focused on the key issues surrounding off-grid solar technology such as falling system costs, cost-effectiveness, comparative costs with other regions of the world, affordability, financing options, environmental

impact, effective policy framework for adoption of technology, and poverty alleviation [37-41]. One of the major technical limitations in provision of solar technology has been the ability to store the solar energy from the panels in a battery [38]. The high costs associated with unit installation make it a prohibitive investment for the rural communities. Some communities have come up with innovative small-medium entrepreneurial solutions that provide credit facilities for installation of panels and batteries [38, 40]. Publications have also investigated the techno-economic ability of solar panels, especially in projects that applied cheap solar energy to pump water, drive mills, power refrigeration and heat water. Some studies investigated the efficacy of solar power units for small-scale businesses such as phone charging services, copier and faxing in remote areas, which alleviated the need for consumers to travel longer distances for such services [42]. Grid-connected solar photo-voltaic (PV) studies have been relatively fewer in the SSA as compared to off-grid solar PV solutions. An example was a publication based on prospects of grid-connected solar PV in Kenya, which used a systems approach to evaluate the potential of grid connected solar PV in combination with existing reservoir hydropower to displace diesel generation [43, 44].

4.5.3. Other Forms of Renewable Energy (Wind, Hydropower and Geothermal)

A total of 14 publications focused on wind energy between 1990 and 2016, constituting 4 % of the total number of publications in the corpus (Figure 5). Mukasa et al. [45] provided a comprehensive overview of the region's wind energy sector, exploring the evolution of wind energy markets and structural characteristics affecting development of wind energy projects. From an economic perspective, they found that most of these projects are shifting from concessional funding to private sector funded projects with the public sector providing a significant role in wind energy [45]. Many other publications assessed the wind energy potential in various regions across SSA. It is noteworthy that all sources of wind energy publications were based on-shore wind technology.

Hydroelectric related topics formed 4% of the corpus, with a total of 13 publications between 1990 and 2016 (Figure 5). Hydroelectric sources of energy have been a dominant source of renewable energy for decades in the region [22], but the number of publications has been limited. A decline of hydropower in SSA in recent decades could be attributed to changing climatic conditions due to global warming that has shifted the seasonal patterns [22]. This can also be attributed to erratic precipitation, which in turn translates to sub-threshold energy generation. The concept was investigated, using climate modeling approaches by Demissie and Solomon [47] and Cole et al. [46] focusing on how extreme variation in rainfall increased the vulnerability on hydropower systems. From the model, Demissie and Solomon [47] established that hydro power systems lack resilience to climate change impact. However, Cole et al. [48] found that planned investments are at minimal risk in terms of not generating returns. Their findings seem to contradict the projected adverse effects of climate change on hydroelectric power productions. About 1% of the publications covered the domain of geothermal energy, with just five studies discussing the topic (Figure 5). Due to geographical features, geothermal energy can be exploited largely in Ethiopia and Kenya because of the geological characteristics of the Great Rift Valley that passes through the two countries. In general, there has been a paucity of publications, especially in Ethiopia and Kenya, which have considerable geothermal potential.

5. Conclusions

We examined emerging trends in renewable energy research in peer-reviewed publications with the goal of identifying research gaps, research perspectives, current knowledge and development of research over time. We illustrated that the topic of renewable energy has attracted a growing number of research perspectives in SSA. From the corpus of 373 publications, the Journal of Renewable and Sustainable Energy Reviews formed the largest share with 24.8%, followed by Energy Policy at 16.1% and Renewable Energy at 11.7%. The temporal analysis confirmed that the scientific publications in the renewable energy field experienced a substantial growth during the period 1990 to 2016, with biomass energy publications being the most dominant renewable energy type studied in SSA.

Geographical distribution of renewable energy publications can play a vital role by highlighting the trends that can guide long term regional policy by pointing out spatial gaps and overlaps. Geographical distributions of publications within SSA indicated that Kenya led by14.3%, Nigeria 12%, South Africa 10%, Tanzania 8.5% and Ghana 7.6% of the research publications. Many other countries such as Madagascar, Gabon, Democratic Republic of Congo, Chad, Niger, Central African Republic, Somalia, Benin, Cote-D'Ivoire, Togo, Rwanda and Burundi were underrepresented in renewable energy publications. The reasons for limited representation may be inadequate financing for research and deficit of technical expertise. This could also be attributed to the absence of cooperation with regional and international organizations that facilitate research focusing on renewable energy. Challenges that potentially inhibit peer review research in the renewable energy sector for academic institutions in SSA could be highly centralized institutional arrangements, limited accountability for PhD supervisors, low impact research and poor infrastructure.

The density visualization of publications abstracts revealed that most of the terms pertained to biomass-related topics. A noteworthy insight was the fact that there has been a shift of the discussion from the traditional sources of biomass (woodfuel and charcoal) to more efficient biomass options such as bio-fuels crops. Although, literature reviews formed 24% of the publications there was only one article using the

quantitative review approach. This underscores the need to incorporate more quantitative reviews to assess renewable energy research undertaken in the region. Studies involving techno-economic analysis and socio-technical analysis collectively accounted for 17% of all studies. This could be attributed to development projects in SSA that are geared towards technical feasibility by engagement of local communities. There were also a considerable number of publications involving modeling approaches (14%) to investigate trends, future scenarios regarding policy, projects and climatic situations in SSA.

The fundamental challenges facing development of renewable energy in SSA are interconnected. This is evident as adequate research stems from sufficient funding that often results in bridging the technical gap in terms of manpower (skill), and information (data and awareness). However, this requires a suitable policy framework that is backed by a facilitative governance framework to channel the limited resources towards maximizing gains furthering renewable energy development. Improved energy access through renewable energy will go hand in hand to enhance other aspects of Sustainable Development Goals (SDG) s.

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