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The development and future direction of renewable energy in Ethiopia, Kenya, Uganda, and Botswana

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ABSTRACT

Renewable energy (RE) solutions can reduce the climate change effects and their adoption can help local villages to improve community's energy security. This research aims to identify the challenges and future development paths for African nations based on practical project experience and a systematic literature review. This will help researchers and others (such as policymakers) to implement national and international projects in Africa RE development. The literature and project experience show, the main challenges noticed in Africa are 1) resistance to change and lack of acceptance of RE by local communities; 2) the prohibitive cost of RE technologies and a lack of financial supports and insurance; 3) a lack of knowledge/knowledge gaps in RE production and management; 4) limited willingness and knowledge to share data and lack of knowledge in the energy consumption by locals and no available weather data; 5) a lack of RE infrastructure; 6) the difficulty of establishing contacts with locals; and 7) security issues. The significance and novelty of this research lie in identifying the practical challenges faced by locals and international organizations when implementing RE projects in African nations; providing recommendations for possible solutions and the future direction of African RE development; and planning international continuous collaboration through the creation of a collaborative network. The Energy Village concept was helped Finland and one case study is Jeppo biogas plant, which is build based on this concept and its projects. Despite the numerous challenges facing the development of RE in Africa, African nations hold significant untapped RE potential that can be harnessed systematically. The challenges noticed can be reduced by using the recommended solutions described in this article.

Abbreviations: AASTU, Addis Ababa Science and Technology University, Ethiopia; AU, Africa Union; BERA, Botswana Energy Regulatory Authority; BIUST, Botswana International University of Science and Technology, Botswana; CIVETS, Colombia, Indonesia, Vietnam, Egypt, Turkey, and South Africa; COVID-19, Coronavirus appears in 2019; CSP, Concentrating solar power; CRGE, Climate Resilient Green Economy Strategy; EV, Energy Village; EVAN, Energy Village African Network; EVC, Energy Village Concept; EU, European Union; GET FiT, Global Energy Transfer Feed-in Tariff; G7, Group of Seven; G20, Group of 20; LEAP-RE, Long-term Joint European Union – African Union Research and Innovation Partnership on Renewable energy; LEAP-RE - WP-14 - Work Package – 14, The Energy Village Concept in Africa project; LCOE, Levelized cost of energy; Mak, Makerere University, Uganda; MENA, Middle East and North Africa; MU, Moi University, Kenya; N/A, Not available; OECD, Organization for Economic Co-operation and Development; PV, Photovoltaic; RE, Renewable energy; RES, Renewable energy resources; UWASA, University of Vaasa; VEBIC, Vaasa Energy and Business Innovation Centre; WP, Work Package.

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1. Introduction

Greenhouse gases and CO_2 emitted from the use of fossil fuels are the main contributors to climate change [1]. One of the main solutions to this problem is the replacement of fossil fuels with renewable energy (RE) resources. van Wijk et al. [2] stated that "the transition to renewable energy has become the backbone of the global energy transformation in an attempt to reduce energy-related CO_2 emissions". Energy is a crucial component of a country's socioeconomic stability and industrial growth [3]. Developing nations can benefit from RE resources, allowing them to contribute to reducing climate change effects. Introducing and developing RE technology can bypass the use of fossil fuels in Africa, leading to the use of safe, natural energy sources that can be accessed anywhere in Africa and that are not harmful to the environment, contributing to the incomes of local communities, and helping future generations of Africans. Addressing rural areas of Africa is important because the electricity grid does not service rural areas in most developing nations. Africa as a whole has the potential to greatly benefit from RE resources, but this capacity is significantly under-exploited. A greater understanding of this potential could open the door to additional energy sources, new employment opportunities, and improved economic stability in local communities. This could lead to new sources of energy potential, especially in terms of meeting the widespread demand for electricity, which has been unavailable in several African nations.

According to Girgibo et al. [4], "the EV concepts mapping joint research and innovation actions for next-step development of RES specific challenges and smart stand-alone systems. As Africa's population rapidly grows and urbanizes, its need for reliable and sustainable energy supply will become greater than ever. This energy is needed not only to drive the continent's economic development, but also to offer modern energy services to the large population presently living without them. The EV concept recognizes the following as a starting point as it all directly related to the work programmed and the specific challenge. Firstly, RES potential - the continent is endowed and has the potential of RES, including biowaste, the solar, wind, geo and hydro energy that exceeds the demands, especially in rural regions."

The creation of job opportunities is an especially important aspect of RE in Africa. Retaining the money generated from RE in local areas increases the importance of these resources to the local community as well as their economic development. However, managing renewable energy resources requires a significant amount of experience to ensure the sustainability of the RE project. In addition, the energy systems in developing countries have become increasingly important in the global transition to more environmentally friendly and sustainable energy systems [5]. Therefore, focusing on developing the energy infrastructure of developing nations is extremely important for both these nations as well as the world as a whole. The relationships between RE, economic growth, and CO_2 emissions are markedly different between nations due to economic differences as well as the differences in the availability and cost of RE [6]. Korhonen et al. [7] stated that "the use of fossil energy can be reduced by the development of technology and by increasing the share of renewable energy sources". This is true for all nations of the world and would significantly contribute to reducing the causes and effects of climate change. In addition, the use of RE can improve the energy security of African nations. Furthermore, the replacement of fossil fuels by RE resources can be facilitated by international projects such as the "Long-Term Joint European Union (EU)-African Union (AU) Research and Innovation Partnership on Renewable Energy", also known as the "LEAP-RE project".

The members and partner institutions of the LEAP-RE project aim to develop RE as a sustainable source of energy for all Africans [8]. The project has "85 research partners in Europe and Africa supporting innovation and building renewable energy solutions together" and is expected to run between 2020 and 2025 [8]. In particular, the University of Vaasa (UWASA) proposed the "Energy Village (EV) concept", which aims to help rural areas transition to 100 % RE by providing them with the experience as well as cutting-edge methods and technologies to do so. The application of this concept to African nations falls under work package (WP) 14 of the LEAP-RE project. WP-14 (Energy Village Concept in Africa) has five partners: UWASA, Finland; Addis Ababa Science and Technology University Ethiopia (AASTU); Moi University (MU), Kenya; Makerere University (Mak), Uganda; and the Botswana International University of Science and Technology (BIUST). The official duration of WP-14 is between 1st September 2021 and 31st May 2025. The partner institutions and their respective African nations created a shortlist of potential EV sites and selected 18 EVs in on-grid and off-grid sites representing both urban and rural villages across the four African nations, respectively.

The research aims and objectives are as follows: 1) Review the development of African nations by using four African nations (Ethiopia, Kenya, Uganda, and Botswana) as a case study; 2) complement the review with the practical experience of members of the LEAP-RE: WP-14 projects based on challenges to RE development identified in African nations; 3) identify the reason why these challenges are present and propose solutions; and 4) recommend future paths for RE development policies and initiate the Energy Village African Network (EVAN), which would allow for continuous collaboration between EU and AU nations and their institutions in the future.

The significance and novelty of the article are as follows: 1) identifying the practical challenges faced by locals and international organizations when implementing RE projects in African nations as well as their underlying causes; 2) providing recommendations for the future direction of African RE development in terms of potential policies and practices based on previous experience and literature findings; and 3) planning continuous international collaborations on RE development. The research questions addressed in this article are as follows:

RQ1. What are some examples of RE development in Africa?
RQ2. What are the main challenges and difficulties faced by renewable energy projects in Africa (e.g., WP-14 in the LEAP-RE project)? What are the underlying causes of these challenges and difficulties in countries such as Ethiopia, Kenya, Uganda, and Botswana?
RQ3. What does the future look like in Africa in terms of the adoption of RE, the future direction in RE policies and practices, and international collaboration on future RE development?

2. Methods

- The following procedures were used to address the first research question posed by this study:
  - For using systematic literature review techniques – search words were generated by constructing mind maps; a shortlist of search words was created based on their relevance to the topic. This stage helped identify and select the important search words used to gather relevant articles and documents.
  - Appropriate search words and phrases were selected based on the previous step. An example of a search phrase used was: "Renewable energy development + Africa, Kenya, Ethiopia, Uganda or Botswana". Other RE-related search words were also considered. The African nations used in the search words referred to the partner nations involved in the LEAP-RE: WP-14 project.
  - Documents related to RE were obtained from sites such as Scopus, scholar.google.com, and the Science Direct databases. More than 400 articles about the development of RE in Africa were gathered during this step. The literature database was built between 19th July 2022 and 15th September 2022; the literature search took about two hours per working day.
  - The articles and documents collected were mostly published between 2000 and 2022, with a few articles published between 1994 and 2000. The choice of these years is to focus on the recent year

publications. The database was updated regularly with new, recent articles.
  - The selected articles were filtered by their title, abstract, and an assessment of the full text. Any documents that were found to fit the topic and that were useful in answering the research question were used in this paper in some form – all such articles are cited in the reference section.
  - If an article was found to be interesting, the 'snowball' method was used to obtain more articles; this method involves identifying relevant references in these interesting articles to gain a more in-depth understanding of the topic.
  - An Excel database was built to store information about the collected articles.
  - A systematic literature review was conducted to analyze and synthesize the information on RE contained within the relevant documents, especially with regard to RE development in the year 2018–2022.
  - This review article was constantly rewritten during the analysis of the literature to ensure that it contained the most relevant and up-to-date information.
- The next step aimed to understand the challenges, difficulties, possible solutions, and the future direction of RE policies and international collaboration in Africa. Plans to create a collaborative network based on our experience of the LEAP-RE project were created. Specifically, work experience gained during the LEAP-RE: WP-14 project, as well as previous work experience, were used to inform this step.
- Based on these findings, a plan and start-up procedures for the EVAN project were outlined.
- Finally, the paper was reviewed, edited, finalized, and communicated with co-authors; additional co-authors were invited to contribute before the paper was prepared for publication.

3. Results

3.1. Review of RE developments in selected African nations

This section addresses the following research question (please also see Section 1): What are some examples of RE development in Africa? The systematic literature review described in the methodology was applied to investigate RE developments in four case study nations in Africa: Ethiopia, Kenya, Uganda, and Botswana. These nations were represented by local universities and are partners in the LEAP-RE: WP-14 project led by the UWASA. It should be noted that the status of RE in most African nations was previously reviewed by a graduate student from Aalto University, Espoo, Finland, [9]).

3.1.1. Ethiopia

Hydroelectric, wind, and solar energy are among the most promising RE resources used to address the global energy and environmental challenges of the present day [10]. Like most of sub-Saharan Africa, Ethiopians use biomass as the dominant energy source for cooking [10]. However, Tucho et al. [10] also concluded that existing Western solutions for RE supply systems were not compatible with the energy problems faced by developing countries; specifically, the production of electricity from RE sources is prohibitively expensive for cooking purposes. Indeed, rural areas typically only receive enough electricity for lighting and the charging of electronic devices [10]. Boke et al. [11] and Tesfaye et al. [12] studied the optimization of RE in Ethiopia and concluded that Ethiopia's national target plan could increase the coverage of electric grid connections to 96 % by 2030 due to the high RE potential of the country. This is true of a majority of African nations. Ethiopia is also planning to initiate a nuclear program for the peaceful application of nuclear science and technology as part of a strategy that aims to hit its energy mix targets as well as achieve its sustainable development goals [13]. There are a few other challenges in solar connection to gird in sub-Saharan regions as listed in the discussion section of this article. In terms of RE, Ethiopia has an annual exploitable electric energy potential of 7.5 PWh from solar energy, 4 PWh from wind energy, and 0.2 PWh from hydroelectric energy [10].

Although Ethiopia is considered to be a growing leader in the energy sector in sub-Saharan Africa, it faces several problems that are common to other African nations [14]. The potential of RE resources must be utilized to overcome these numerous problems in the energy sector. Tesfaye et al. [12] noted that Ethiopia plans to address energy, water, and food – helix problems to become a middle-income country by developing its untapped water and land resources. Tesfaye et al. [12] suggest that "Ethiopia has adequate physical water supply potential and renewable energy resources to develop and satisfy the growing demand until 2050". Allington et al. [15] noted that Ethiopia and Kenya have extremely high RE resource potentials, including solar power, wind power, a wide range of hydroelectric power sources, and geothermal power. The implementation of a standard energy mix is an important target for nations like Ethiopia, which are regularly affected by severe droughts that can significantly disrupt hydropower resources [16]. Previous studies have also noted that there is likely to be a significant decline in energy production from hydropower by 2065 and this can be somewhat compensated by using a mix of RE resources [16]. Mekonnen et al. [16] also highlighted the influence of climate change on the severity of droughts as well as their impact on hydroelectric sources in Ethiopia. However, it is also important to note that climate change can create exploitable opportunities in RE technologies. An increase in solar intensity can benefit solar energy production, while increases in surface temperature can improve the production of geo-energy; for example, an increase in water temperature can benefit heat energy production from sediments in summer [17–20]. The beneficial effects of climate change must be exploited by African nations.

Ethiopia's energy consumption has historically been dominated by the use of biomass resources, including fuels such as wood, charcoal, tree branches, dung cakes, and agricultural residues [21]. This may still be true in 2024, especially considering the full spatial extent of nations in the region. The Ethiopian government already proposed the use of a national energy mix based mainly on RE resources in 2015 [22]. However, not all areas have access to the national electrical grid. One solution to this issue is the generation and use of local RE resources, which has been strongly encouraged by the Ethiopian government [22]. Indeed, the Ethiopian government aims to encourage more citizens to use RE resources, which would not only safeguard the environment but also improve the economy of local populations and improve the issues associated with the distribution of electrical energy across the nation.

Ethiopian energy policies were focused on providing a reliable supply of energy at affordable prices, even in 1994 [21]. These policies encouraged the shift to modern energy sources to reduce waste and increase the efficiency of energy utilization. Issues that were present at the start of Ethiopia's energy policy development can now be resolved using RE technology; indeed, the development of technology, the price reduction, and improved understanding of RE resources since 1994 have increased the utilization of RE energy in Ethiopia. Indeed, the Ethiopian government has highlighted the increase in the use of RE at the national level in 2024 compared to 1994 and has made considerable efforts to improve the governance of the energy sector as well as increase access to energy, such as pushing the Growth and Transformation plan as well as Climate Resilient Green Economy Strategy (CRGE) [23,24].

3.1.2. Kenya

The energy sector plays a critical role in the socio-economic development of a country. In Kenya, the availability of petroleum and electrical energy are the main drivers of the economy, while biomass is mainly used in rural communities and a small section of the urban population. The major challenges facing the energy sector include: 1) improving the competitiveness, quantity, quality, and reliability of the national energy supply; 2) high initial capital outlay and the long lead times from feasibility studies to development of energy infrastructure; 3) mobilizing adequate financial resources to undertake massive investment in the power sector; 4) high cost of energy, low per capita incomes, and low levels of industrialization. Energy is an important component in achieving sustainable development and poverty reduction. Kenya can benefit from the utilization of RE technologies and services in the following ways: 1) increased access to modern energy services in rural and remote areas, 2) increased investment in energy generation capacity, 3) more opportunities for empowering the people through engagement in productive, energy-related activities, and 4) the enhanced delivery of social services such as health, education, water, transport, and agricultural production.

At the national level, wood fuel and other biomass resources account for approximately 68 % of the total primary energy consumption, followed by petroleum (22 %), electricity (9 %), and other energy sources (including coal; <1 %). Solar energy is also extensively used for heating and lighting while electricity remains the most sought-after energy source in Kenyan society; however, the national access rate is only 15 %, while the rural access rate is estimated at 4 %. However, there has been a rapid shift in the accessibility of electrical energy as the country has invested more resources into power generation as well as the adoption of new providers.

Ngusale et al. [25] studied the production of briquettes made from biomass residues in Kenya as a sustainable supply of biomass energy. This method uses a compacted form of biomass energy in a variety of applications (e.g., fire for cooking) in developing nations. Ngusale et al. [25] concluded that the potential for this technology was immense and could help reduce deforestation, consequently preventing environmental degradation. In particular, this innovative method of producing briquettes from biomass wastes/residues is essential in the replacement of firewood as an energy source. In addition, the briquettes produce minimal greenhouse gases compared to other local fuels, especially when used in well-ventilated spaces [25]. Ngusale et al. [25] also noted that the characteristics of briquette emissions may be less than those of firewood; consequently, the partial or full replacement of firewood can contribute to declining greenhouse gas emissions. They also noted that one of the major challenges facing the use of RE resources in Kenya is the lack of investment in wind, solar, hydropower, and biomass electricity [25].

Ulsrud et al. [26] reported on the implementation, management, and supply of solar energy to a rural village in Kenya and presented a conceptual framework that could be adapted to other villages. However, it should be noted that, based on the study conducted in Nairobi, Kenya, the energy mix used for cooking has been greatly affected by the COVID-19 pandemic [27]. In general, the primary changes due to COVID-19 involve the type and amount of fuel used for cooking, although this has now returned to previous behaviors due to the end of COVID-19 lockdowns in most nations. Specifically, wood or kerosene fuels were used rather than liquified petroleum gas (LPG) during the lockdown period [27]. Household energy access is a multifaceted issue that is influenced by fuel availability, rural and urban differences, price, proximity, family composition, cultural preferences, convenience, and major events such as the COVID-19 pandemic [27]. In general, Kenya has been very progressive in setting emission reduction policies [28]. On other hand, the International Energy Agency (IEA) found that, on a global scale, the amount of greenhouse gas emissions decreased during the COVID-19 period, due to the decrease in commuting and general transportation [29]. Moreover, in the context of socio-demographics, women were less likely to have a positive attitude toward both geothermal and wind technologies [30].

The national energy mix in Kenya is composed of hydroelectric power (52.1 %), fossil fuels (32.5 %), geothermal energy (13.2 %), biogas co-generation (1.8 %), and wind energy (0.4 %) [3]. Moi University (the Kenyan partner in the LEAP-RE: WP-14 project) reported that Cheboiwo village (one of the selected EVs) utilized 180 tonnes of biomass resources annually, including agricultural residues, cow dung, market waste, and kitchen waste. This village also used about 12 hours of solar energy per day at a solar intensity of 5.6 kWh/m^2/day. The average wind speed at Cheboiwo village was 5.29 m/s, representing a mean wind power density is 182 W/m^2. These potential estimates are representative of large areas of Kenya.

The Kenyan government has been encouraging the generation of electricity from green sources (e.g. geothermal and other RE resources) through a variety of environmentally friendly policies, including the National Green Fiscal Incentives Policy Framework [31]. According to these incentives, Kenya anticipates a transition to clean cooking by 2028. The main industries targeted by these policies include electricity (transition to green electricity); clean cooking (transition to modern and clean cooking); manufacture (greening of industries and investment in manufacture and green production); and transport (promoting sustainable transportation for both public and private) [31]. These initiatives, first published in 2022, show that the Kenyan government is planning to implement sustainable energy and green technologies. Similar initiatives are common across many African nations, with many nations doing so for economic, health, and environmental concerns. In general, these policies can support the development of and transition to RE in many African nations.

3.1.3. Uganda

The number of people with access to electricity in Uganda has significantly increased in 2020 compared to 2001 [32]. This increase includes off-grid clients. During the expansion of mini-grids and the development of RE resources in Africa, one of the major shortcomings of the solutions implemented by foreign companies was a lack of understanding of local communities, which could lead to the failure of the community to adopt these practices [33]. Indeed, attempting to introduce innovations to developing countries is more akin to a process rather than a product breakthrough; although the locals mentioned several reasons for not adopting electricity, it was found that financial issues were the primary reason that electricity was not utilized in many Ugandan villages [33].

The factors that influence the adoption of RE resources can be technological, economic, and/or social. To encourage the adoption of innovative technology in rural villages, energy service companies must promote a technologically reliable service, a sustainable energy generation method, technological awareness, and functionality as benefits, as well as showcase examples of productive usage [33]. In addition, there are major economic factors that affect the adoption of electricity in villages. For example, Eder et al. [33] described the four factors that affected the adoption of electricity in Tiribogo village, Uganda: affordability, payment systems (i.e., how to pay), investment costs, and tariffs. Eder et al. [33] also noted that it was important to understand the preferences of the locals, especially in terms of whether they preferred monthly payments or usage-based tariffs. Socially, foreign energy companies must collaborate with local actors, especially in the context of emerging new social systems that are potentially disruptive [33]. Partnering with local experts, incorporating local inhabitants, utilizing proper communication channels, and managing users' expectations properly are some methods that could be used to great effect. Bogomin and Nziu [34] and Mohamad et al. [35] also provided summaries about the development and current state of RE technology and solar chimneys in Uganda, respectively.

There have been significant advancements in bioenergy use and development in Uganda [36]. Firewood continues to be the dominant source of energy production in many households, with many households citing the high capital costs, and lack of technical expertise as the main reasons for why the adoption of improved bioenergy technology has remained relatively low [36]. Simulation analyses have shown that the use of waste for energy generation is viable in Kampala village, Uganda [37]. In particular, coffee husk gasification can be a sustainable energy source in Uganda is readily available, presents significant the source of energy, can help in come for rural communities and bioenergy from biomass is important in Uganda [38].

There are significant amounts of RE resources that are easily accessible in Uganda. Researchers at Makerere University found that the average monthly wind speed in the Yumbe district (one of the EVs selected for the LEAP-RE: WP-14 project) was 2.6 m/s with a peak speed of 3.5 m/s (collected between November to March, from this research project results). The same researchers also reported that the average number of sunshine hours was 8 hours per day, with the longest sunshine duration experienced between December and January (9 hours per day); they also reported that the average daily solar irradiation was 5.35 kWh/m^2 at a tilt angle of 15° In addition, Uganda possesses a significant amount of biomass, bio-waste (including animal manure and household waste), and forest biomass that can be used as a bio-energy resource.

Uganda's RE policy is primarily focused on the generation of energy from hydroelectric, solar, bio mass, and geothermal sources; however, they do not have any plans for the use of wind energy [32]. Nevertheless, more research into wind energy could potentially allow it to be including Uganda's RE policies in the near future [32]. The "Renewable Energy Policy for Uganda" was approved on 29th March 2007 [39]. According to this document, the government's vision for RE was to "make modern renewable energy a substantial part of the national energy consumption". The overall goal of the policy was to "increase the use of modern renewable energy, from the current 4 % to 61 % of the total energy consumption by the year 2017" [39]. This represented one of the largest policy initiatives of the Ugandan government and highlights the fact that the government was already working toward sustainable energy resources in 2007. The document also stated that the "overall objective of the renewable energy policy is to diversify the energy supply sources and technologies in the country" [39].

The key areas addressed by the Renewable Energy Policy for Uganda are as follows: 1) investment into small renewable energy power (e.g. small hydropower plant or other RE technologies), 2) solar energy technologies, 3) biofuels, 4) the development and utilization of biomass energy, and 5) sustainability measures. The government of Uganda also approved seven different pieces of legislation to facilitate the operation of the initiatives aimed at tackling the key areas addressed by the policy. There were four main reasons why the Republic of Uganda initiated this renewable energy policy in 2007: 1) the decline in the water level of Lake Victoria (associated with climate change effects) that resulted in the installation of 100 MW diesel generators, 2) the increase in the price of oil on the international market, 3) to increase the accessibility of electricity to the rural population, and 4) to fulfil the government's commitment to the reduction of greenhouse gases under the Kyoto Protocol and the fight against climate change [39].

The implementation of RE policies in Uganda was supported by the presence of legal and policy instruments, a growth in local organizational capacity, and an increase in ongoing research efforts [40]. However, there were also several key drawbacks: the high investment costs of renewable energy technologies (prohibitively expensive investment and operation), inadequate human capital and training, a weak regulatory framework, poor enforcement, a lack of coordinated institutional action (bureaucracy and overlapping roles of the government agencies), limited resources, and weak private sectors [40].

3.1.4. Botswana

In Botswana, another sub-Saharan African nation, wood is the "energy of the poor" and is considered to be a threat to environmental and development goals [41]. The higher population growth rate of sub-Saharan African nations reduces the prospects of achieving energy sustainability [42]. It is crucial to consider energy efficiency in the context of energy sustainability, with a 1 % rise in the energy efficiency level resulting in an increase in the energy sustainability index by around 11 % [42]. As is the case in most developing nations, biofuel development in Botswana is driven by rural development, employment, greenhouse emissions, and increasing energy security [43]. Depending on the location of the plantations, biofuel plants can be invasive species (i.e., they are plants that are not originally from the local area)—this was one of the major risks of RE as outlined by [19,44]. This can pose risks to RE resources by inhibiting the growth of energy plants.

Botswana has no hydropower or petroleum resources: The main resources available are coal, solar energy (a significant potential resource), and biomass energy [45]. Wind energy is not an option due to the low wind speed in the region (about 3.5 m/s), which is insufficient for energy production [45]. Consequently, 21st-century waste management techniques and the exploitation of waste-to-energy technologies are important for Botswana's growth as a developing nation [46]. Botswana possesses an as-yet unexploited source of energy: solar irradiation [47]. The significant potential of solar energy in Botswana should be harnessed across projects to overcome the lack of electrical power faced by the nation in recent years [47]. Tlhalerwa and Mulalu [48] suggested the use of concentrating solar power (CSP) systems, which was found to be a potentially useful technology in Botswana.

Botswana's national energy policy aims to provide an affordable, reliable, and adequate supply of energy for sustainable development [49]. The Rooftop Solar program was created to support this main objective, which aims to provide grid-tiled roof or ground-mounted solar photovoltaic (PV) systems (with or without energy storage) that are owned by consumers at the same location at which they receive their electricity bill [49]. This program highlights the Republic of Botswana's commitment to transitioning to green energy sources.

The Botswana Energy Regulatory Authority (BERA) was founded by the Botswana Energy Regulatory ACT 2016 and began operations on 1st September 2017 [49,50]. It is involved in the regulation of bio-energy, solar energy, and RE resources to maintain a competitive environment that is still in accordance with international best practices in terms of protecting the environment. BERA is involved with the Rooftop Solar program and is "responsible for developing the necessary regulations aligned with the Rooftop Solar Guidelines as needed to guide the interconnection process" [49]. Establishing this government agency highlights the commitment and willingness of the Botswanan government to adopt green technologies and resources. Recently, BERA planned to request significant financial investment from the government for research into RE technologies [50].

3.2. Challenges of renewable energy projects in Africa

This section addresses the second research question of this paper (see Section 1): What are the main challenges facing RE projects (e.g., the LEAP-RE WP-14 project) in Africa? Why are these challenges and difficulties present in the case study nations of Ethiopia, Kenya, Uganda, and Botswana? This section consolidates information from the systematic literature review as well as the experiences from current projects initiated by LEAP-RE WP-14 partners as well as previous experiences with RE development in Finland and the EU.

The main challenges facing the adoption of RE technology in both developing and developed nations are the acceptance of renewable energy by society, the cost of RE (including insurance), data availability, the lack of RE production; and a lack of RE infrastructure (e.g., connection to the national electricity grid). In addition, African nations face specific technological, economic, and environmental challenges associated with the relationships between RE, economic growth, and CO_2 emissions, which may differ due to economic differences, renewable energy potential, and the cost of renewable energy between nations [6]. These differences can lead to the reluctance of locals to adopt RE in some nations. Similar problems were also observed during the LEAP-RE WP-14 project. As previously mentioned (Section 3.1.1.3), foreign companies generally do not fully understand the concerns of local communities, which can lead to the failure of diffusion attempts, especially in attempts to expand mini-grids and introduce RE technology in Africa [33]. It is thus important to ensure that local governments, organizations, and institutes are involved in these projects as they were in the LEAP-RE (WP-14) project. Doing so makes is easier to gain the trust of local communities, builds a stronger commitment to the project, instills a feeling of ownership, provides easier access to data, and improves the success and continuity of the project.

3.2.1. Challenges of socio-cultural

Technological barriers are generally expressed in the form of a lack of knowledge, a lack of accessibility to technical equipment, and the expertise of companies who have installed the equipment. This is the case in many developing nations (including African nations) and is relevant to all types of RE technologies. In addition, there is a shortage of trained personnel who can resolve the technical problems associated with these technologies throughout the lifetime of the instrument. For example, there are several technical barriers to the adoption of wind and solar PV systems in Kenya, including a lack of energy storage [3]. In addition, some renewable energy solutions, such as solar PVs can fail shortly after installation, posing challenges to the average Ugandan company investing in these RE systems [40]. Similar technical problems were observed in some of the EVs in Kenya, with at least one case where the use of the instrument could not be maintained following the completion of the project, resulting in mistrust by the villagers. In addition, the construction of a power-generating facility in Uganda requires the acquisition of a license, a feasibility study, and an environmental impact assessment. This increases the cost of such ventures as it requires the hiring of consultants, it is thus not affordable for local developers with limited funding options [40]. The other technical challenges include the overly sophisticated nature and high cost of the technology, especially for locals. Global technology, especially recent innovations, is generally not suitable to meet the needs of developing nations and their respective technological advancement levels. For example, modern biogas purification methods are generally too sophisticated and are thus unsuitable for developing countries [40].

3.2.2. Challenges of economic, infrastructural and data lack

The main problem preventing most communities from adopting RE is its high cost and the lack of micro-financial schemes [39,40]. Indeed, Takase et al. [3] noted that “the unwillingness of the majority of the banks in Kenya to fund technological investment in some forms of renewable energy generation has been a serious main economic challenge”. In particular, the solar energy sector has been affected by this challenge because it is difficult to justify investment due to the unpredictable variation in solar irradiation levels due to precipitation [3]. Cost is a major roadblock in the widespread adoption of RE, especially with regard to the installation and construction of facilities (e.g., wind and solar farms) [51]. RE generation is also considered a risky venture due to the high cost of constructing these power generation facilities [3]. Furthermore, there is serious competition for the use of land for food and energy crop production. The purchase and implementation of new technologies such as water heat exchangers and sediment heat energy production solutions are also associated with very high costs, even in EU nations [18]. Furthermore, the installation of this technology may also require companies with a high degree of expertise. These are some of the economic challenges associated with the implementation of RE technologies in developing nations.

3.2.3. Environmental challenges

The use of wood in households has resulted in the deforestation of both exotic and indigenous vegetation [3]. This is an example of how the replacement of fossil fuels with RE can still create carbon emissions. Al-Shetwi [51] showed that the use of biomass as fuels has the highest CO_2 emissions among RE technologies, followed by geothermal, wind, solar, and biogas (in declining order of CO_2 eq./MWh). In terms of their use in grid-based electricity production, solar PVs produce the most carbon emissions, according to Al-Shetwi [51] investigation and results. Similarly, Girgibo et al. [44] noted that one of the primary risks of adopting RE is – the use and production of RE might contribute to carbon emissions and its effect on climate change. There are also social challenges related to RE, including a lack of knowledge and experience about RE in developing nations; a lack of awareness about the benefits of RE in daily life; a lack of awareness of the drawbacks of traditional energy sources; a lack of training opportunities on RE technologies and how to manage these technologies; a lack of awareness regarding the financial strain that RE solutions have on locals; a lack experts who can install and train locals on how to run the systems in developing nations; and a lack of thought about long-term economic viability [51,52].

There are also several drawbacks to the implementation of RE and sustainability policies, such as limited resources and inadequate capacity building, the prohibitive cost of investment and operation, bureaucracy and a lack of coordination, high power tariffs and grid unreliability, and ineffectual quality control [40]. Al-Shetwi [51] stated that the major obstacles to RE deployment were economic, social, technological, and regulatory. Peer-to-peer meetings with other projects in Africa revealed that additional challenges specific to African nations, including low attendance and virtual engagement, different spoken languages (and literacy levels), a lack of active participation and representation in the decision-making process, difficulties with contacting key local stakeholders, acquiring building equipment, and communicating with companies to install and support the sustainability of the project, the low usage of RE technology, and the difficulty of conducting surveys.

3.2.4. LEAP-RE (WP-14: ‘Energy Village Concept in Africa’) project challenges

Information about the barriers to the adoption of RE technology in EVs was identified and collected during the initial engagement and data collection period of the Energy Village Concept (EVC) project; these studies were conducted in Ethiopia, Kenya, Uganda, and Botswana. This section presents the obstacles faced as well as the factors that influenced the success of the EVs in the LEAP-RE (WP-14) project. This section describes the outcome of the project in one selected EV for each partner country. Table 1 presents the full list of EVs, the obstacles faced by these EVs, and the factors affecting the success of the project.

Tulefa Energy Village is located 65 km from Addis Ababa, Ethiopia. The area experiences approximately 12 hours of sunshine per day throughout the year, wind is constantly available for energy production, and biomass resources were observed to have high potential. Tulefa village initially relied heavily on wood, charcoal, and kerosene for cooking and lighting. The main energy sources in the village were cow dung, firewood, charcoal, crop residues, solar, electricity, and kerosene. The potential socio-economic benefits that RE could bring to Tulefa village included job creation (e.g., implementation, maintenance, and operation of businesses); increased productivity (business operations, increased income, increased profits, and employment opportunities); reduced energy costs by reducing the dependency of the village on traditional energy sources); improved health by increasing access to clean energy as well as a reduction in air pollution from the use of wood in cooking); improved education (due to the ability to provide regular power to schools); and strengthened community bonds (increased communication, commitment, and collaboration allow for increased social cohesion and support networks within the community). The main challenges identified in Tulefa village include a lack of long-term data on RE resources, a lack of technology to measure some RE resources, public and political acceptance of the EVC, and a lack of financial support.

The Cheboiywo Energy Village is located in the Tulwet ward of the Kesses sub-county within Uasin Gishu county in Kenya. Most households in Cheboiywo depend on firewood for cooking, with a few families using charcoal. Most use electricity for lighting. Most rural residents in Uasin Gishu county have not adopted the use of RE sources. However, results from previous surveys revealed that most residents were interested in solar PV technology and biogas. The area engages in the large-scale production of wheat, maize, and livestock (mainly dairy farming), and thus possesses significant potential for the utilization of biomass (i.e., agriculture residues). The location of the area also makes it easy to use

Table 1
A list of obstacles, solutions, and success factors faced by Energy Villages (EVs) in Ethiopia, Kenya, Uganda, and Botswana.

Name of country	On-grid/ off-grid	Name of Energy Village	Obstacles	Success factors
Ethiopia	On-grid	AASTU campus	Lack of long-term data about biomass	Community engagement and support, strong governance and policies, RES (Renewable energy resources) assessment, financial resources, technical expertise, acceptance by the top management
		Wonji sugar	Difficulty in getting fuel consumption data from the keeper and lack of openness. Lack of real-time data, equipment specifications, and red tape	Community engagement and support, strong governance and policies, RES assessment, financial resources, technical expertise, acceptance by the top management
	Off-grid	Langano	Not enough data on geothermal potential, lack of recent data, lack of awareness about efficient energy utilization, lack of investment, security issues	Community engagement and support, strong governance and policies, RES assessment, financial resources, technical expertise
		Amebara	Security issues associated with travel. This village was eventually removed from the Energy Village list. **Decision:** Avoid traveling to or considering this Energy Village	N/A
		Tulefa	Insufficient data, lack of awareness of efficient energy utilization, lack of investment	Community engagement and support, strong governance and policies, RE resources assessment, financial resources, technical expertise, and acceptance by the local administrators
Kenya	On-grid	Cheboiywo	Difficulty in establishing contact with potential villages, difficulty in getting accurate data for modeling, vested interests by various stakeholders	The willingness of communities to embrace renewable energy sources, cascading and replication of RES
		Langas	Difficulty in establishing contact with potential villages, difficulty in getting accurate data for modeling, vested interests by various stakeholders	Cascading and replication of RES, government support
		Nandi hills	Difficulty in establishing contact with potential villages, difficulty in getting accurate data for modeling	Cascading and replication of RES, government support
	Off-grid	Lelan	Difficulty in establishing contact with potential villages, mistrust arising from previous failed projects	A willingness by communities to embrace renewable energy (RE) sources, cascading and replication, Government support
		Kerio Valley	Difficulty in establishing contact with potential villages, mistrust arising from previous failed projects	A willingness by communities to embrace RE sources, cascading and replication, Government support
Uganda	Off-grid	Bidibidi Refugee camp	Resistance to change; land ownership and mobility of the refugees; unpredictable population variations in the settlement; lack of much-needed technologies for the implementation of RE, and open hostility within the settlement	N/A
	Off-grid	Kayanzi fishing village	Limited knowledge of renewable energy technologies, Financial constraints to	Community engagement, and support from development partners and

(continued on next page)

Table 1 (*continued*)

			harness and support existing technology, increased population	the government
Botswana	On-grid	Regent Hill School	Lack of access to financial products to finance and purchase battery storage	Loan products for purchasing RES
		Senyati Lodge	No data accessible. **Decision:** Avoid and if possible, replace this Energy Village for the duration of the project.	N/A
	Off-grid	Matsaudi	Fear of change, knowledge gap regarding renewable energy, lack of access to financial products to finance and purchase renewable energy solutions	Educational training, loan products for purchasing RES, insurance to minimize the purchase risk of RES
		Majwanaadipitse	Fear of change, knowledge gap regarding renewable energy, lack of access to financial products to finance and purchase renewable energy solutions	Educational training, loan products for purchasing RES, insurance to minimize the purchase risk of RES
		Jamataka	Fear of change, knowledge gap regarding renewable energy, lack of access to financial products to finance and purchase renewable energy solutions	Educational training, loan products for purchasing RES, insurance to minimize the purchase risk of RES

solar energy for RE production. The potential socio-economic benefits that RE could bring to Cheboiywo village include increased access to sustainable energy (including improved health, well-being, and affordable energy access); improved education (extended study opportunities and technological integration); job creation and entrepreneurial ventures (local employment opportunities and entrepreneurial initiatives); improved agricultural practices (sustainable farming and agri-processing opportunities); community empowerment (skill development and participatory decision-making); and environmental sustainability (reduced environmental impact and the preservation of natural resources). The main challenges to the adoption of RE identified in Cheboiywo village are the difficulty in establishing contact and engaging in discussions about the project, vested interests in various stakeholders that require careful navigation and balance, mistrust arising from previous failed projects resulting in a lack of interest in the community, and difficulty in getting accurate data for modeling.

The Bidibidi refugee settlement is located in the north-western part of the Yumbe district in Uganda. The primary energy demands in the village include cooking, water pumping, and electricity. The settlement is dependent on the available natural resources for energy but a transition to more efficient types of biomass (e.g., charcoal briquettes) could help the local community. The area has significant potential for biogas generation, including human waste, chicken droppings, cow dung, and goat manure. There is also significant potential for solar power, with an average hourly irradiation of 5.94 kWh/m^2 for an average of 9 sunshine hours per day, although the potential for wind energy is low. The potential socio-economic benefits for the Bidibidi refugee settlement include a reduction in refugee–host community tension, improved social cohesion, a reduction in gender burdens (e.g., women travel distance will be less to fetch water), improved access to education, and an improvement in literacy level. Economically, the project could create jobs, improve livelihoods, incomes, and productivity, and reduce the community's dependence on stipends. The main challenges identified at the Bidibidi refugee settlement village include their resistance to change, land ownership, and mobility issues, unpredictable variations in population, a lack of necessary technologies, and open hostility within the settlement.

Majwanaadipitse Energy Village is a rural, off-grid community in Botswana populated by 500 villagers with low incomes and a high unemployment rate. Most of the villagers in Majwaanadipiste use firewood for cooking, candles and paraffin lamps for lighting at night and self-made PV set-ups with lead-acid batteries for charging mobile phones. There is a 50 kWh solar PV mini-grid with a limited storage capacity that only provides electricity to the primary school and the staff houses. There is also a 60 kVA three-phase off-grid RE system. The energy potential of Majwanaadipitse village lies mainly in solar and bioenergy. The potential socio-economic benefits for Majwanaadipitse village include job creation and entrepreneurial ventures (entrepreneurial initiatives, local employment opportunities, and local business opportunities); improved agricultural practices (agri-solar farming and the ability to cool or heat the environment); increased living standards (affordable energy access, access to educational knowledge, and improved technological integration); and community empowerment (skill development and participatory decision-making). The main challenges identified at Majwanaadipitse village are the non-availability of resilient and affordable technological solutions as well as socio-economic factors specific (e.g., cost of RE and its availability) to rural areas of Botswana that hamper the implementation of self-sustaining RE systems. The lack of innovative investment strategies offered by the banking sector is another major obstacle in Botswana.

The challenges faced by these villages are as follows: difficulty in getting accurate data for modeling, lack of financial loans for RE technologies, no insurance for products, the need for training to operate and maintain the RE technologies, and a need to overcome fears of using RE technologies. Table 1 presents the list of the obstacles and success factors in all EVs in the study area (if available). To compare CO_2 Emissions vs. economic growth one shall take one country at a time, while RE adoption in low-industrialized nations like Uganda may not directly reduce emissions compared to South Africa. These can be supported by how much energy consumption there is including fossil fuels in one nation based on their energy consumption determines the carbon emissions.

Table 2 summarizes the challenges associated with RE development and local engagement in the AU based on the literature review for this article and experience of the LEAP-RE (WP-14) project.

3.2.5. Reasons for the presence of these challenges in Ethiopia, Kenya, Uganda, and Botswana and their possible solutions

The main three challenges observed when engaging with EVs located in Ethiopia, Kenya, Uganda, and Botswana during the LEAP-RE (WP:14) project are as follows: a lack of data availability, lack of access to financial support for RE technology and insurance, and significant knowledge gaps and resistance to change.

Table 2
Challenges associated with RE development and local engagement based on the experience and literature review conducted for the LEAP-RE (WP-14) project (italics indicate challenges that were found in both the literature and the LEAP-RE: WP-14 project).

Challenges based on the literature review	Challenges based on the LEAP-RE: EV project
1) The acceptance of RE by society	*1) Resistance and fear to change the energy resource locals use*
2) The cost of RE technologies and lack of financial means, including insurance	*2) Lack of bank loans, investment, and insurance*
3) Lack of knowledge regarding RE production and management	*3) Lack of knowledge, knowledge gaps in RE, and management*
4) Data availability	*4) Lack of long-term energy and weather data*
5) Lack of RE infrastructure (e.g., connections to the grid)	5) Difficulty of establishing contact with locals
	6) Lack of willingness to engage and provide data. This can be due to lack of knowledge of relevant data about energy consumption
	7) Security issues

3.2.5.1. Some reasons for the presence of these challenges in the partner nations. Data availability: Wabukala et al. [32] state that the "main obstacles to wind energy development in Uganda are insufficient wind resource data, high initial investment costs, inadequate research and development, weak infrastructure, and unsupportive policies." The lack of data prevents officials from estimating the energy potential of RE resources in some regions, such as a lack of data on wind energy in Uganda [32]. Similar problems were observed in EVs across the partner nations of the LEAP-RE project, with many challenges encountered during data collection. These included the following issues. 1) Locals were unable to provide quantitative energy estimates due to a lack of knowledge, e.g., unable to quantify their cow dung or firewood consumption or their income level. 2) Social and cultural barriers, such as keeping family income a secret from their neighbors, resulting in many locals choosing not to share their energy consumption or income levels. 3) Data collectors were unable to provide financial compensation to the locals, making the task of data collection much harder. 4) A lack of data on available biomass, makes it difficult to estimate the energy potential of this RE resource (e.g., how much cow dung is present on the farm or when the cows were in the field). 5) Cultural and social thinking associated with locals refusing to use biogas generated from waste to cook their food. 6) A lack of readily available data (e.g., about the weather) at the national or local level.

Lack of access to financial support for RE technology and insurance: Takase et al. [3] noted that a majority of banks in Kenya were unwilling to fund certain forms of RE technologies. Indeed, there was a lack of access to financial support for RE technology and insurance across all partner nations in the LEAP-RE project (Table 1). Some reasons for this include: 1) New technologies are very expensive for developing nations. 2) Banks do not want to take on risk by providing loans or investing in new technologies. 3) Banks were unwilling to provide insurance for new RE technologies. 4) Difficulty in finding companies willing to provide training for locals and install new technologies at reasonable prices. 5) Financial structures and national laws preventing international banks from lending money (e.g., under Ethiopian law foreign banks can only lend money if they obtain authorization from the National Bank of Ethiopia, and only if the Ethiopian company cannot find adequate funding from Ethiopian banks [24]. 6) A lack of knowledge on how to manage RE technologies leads to the subsequent disruption of energy production after the project is implemented, resulting in mistrust of such systems among banks.

Knowledge gaps and resistance to change: The LEAP-RE Stakeholders forum held in Kigali, Rwanda in 2023 identified three main reasons for this challenge: 1) New technologies such as electricity heating systems often result in different tastes in cultural foods compared to cooking with firewood. 2) Some locals resist the use of energy produced from waste (e.g., biogas produced from household water and human waste from toilets). Similar resistances were observed in previous projects conducted in India by the RE research group at the UWASA. 3) Most importantly, the cost of RE technologies is higher compared to traditional energy production. Indeed, participants at the LEAP-RE Stakeholders forum discussed about – the concern of the locals in most developing nations is how much cost can be saved in the new technologies. Moreover, locals less worry and interested in their own health and environmental problems such as climate change above the cost regarding RE solutions.

3.2.5.2. Some possible solutions for the challenges presented in the preceding section. Possible solution to lack of available data: The following solutions were proposed based on the lack of available data during the LEAP-RE: WP-14 project as well as previous projects. 1) Train the locals to trust project members by convincing the locals that the data would be used for their benefit. 2) If locals do not want their neighbors to know their household information, a signed confidentiality agreement with community members will be used to convince the locals that their data and information will be used only for the purposes of the project. 3) Establish a culture of trust with the community by avoiding mistrustful behaviors, such as simply collecting data and then disappearing; ensure that the locals are provided with feedback after data collection. 4) Build trust with locals by bringing projects to the same site and training them on how to manage the technology during and after the lifetime of the project. 5) Provide the locals with financial compensation during data collection; this can be obtained through project funding if allowed by the funding institution. For example, some EU funding regulations prevent the use of compensation money [discussions with Research Program Manager of VEBIC (Vaasa Energy and Business Innovation Centre)]. 6) Train the locals about the concepts behind the use of energy, such as whether food can be contaminated by the use of energy generated from waste and how it would not affect the health of those consuming the cooked food. 7) Long-term planning in Africa to organize and facilitate the construction of data centers dedicated to collecting data on diverse modern and future energy resources (e.g., weather data).

Possible solutions to the lack of access to financial support for RE technology and insurance: The following solutions were proposed based on the lack of available data during the LEAP-RE: WP-14 project as well as previous projects. 1) The price of new and old technologies should be reduced at both the national and international levels over time. 2) There should be governmental or international subsidies for RE development, especially to locals and banks for projects, loans, and insurance related to RE technology. 3) Governments should invite and invest in companies who can install RE technologies, and inform the locals about the benefits of RE, how to use it efficiently, and how to manage RE technologies. 4) Increased national and local awareness about RE to facilitate the overall implementation and management of RE technology in developing and middle-income nations.

Possible solution to the knowledge gaps and resistance to change: The following solutions were proposed based on the lack of available data during the LEAP-RE: WP-14 project as well as previous projects. 1) There are no easy solutions to the issue of different tastes when cooking with electricity compared to firewood. One option is the use of mixed energy resources (e.g., food cooked with firewood can be used to cook food during important, traditional occasions such as during holidays, while electricity would be used day-to-day). 2) Informing the locals about the benefits of RE technologies as well as how to use and manage them efficiently. As mentioned in the previous section, educating the locals about the important energy concepts is also crucial. 3) Governmental or international subsidies for RE development for locals can encourage them to use RE over fossil fuels. Wabukala et al. [32] stated that "for policy, comprehensive wind resource assessment, energy infrastructure investment, financial de-risking, capacity building, and deliberate wind power policy incentives could accelerate wind energy development and consequently contribute to the country's energy security". Local organizations, governments, and institutes should be involved in the implementation of RE projects in Africa. This allows locals to feel safe, builds commitment and a sense of ownership, and can help locals be more accepting of RE resources.

3.3. The future of RE and international collaboration in Africa

This section addresses the third research question (see Section 1): What does the future look like in Africa in terms of the adoption of RE, the future direction in RE policies and practices, and international collaboration on future RE development? The future direction of RE policies was informed by the experience gained during the LEAP-RE (WP-14) project as well as the current and future plans for international collaboration between Ethiopia, Kenya, Uganda, and Botswana as members of the African-wide Energy Village network (represented by their local educational institutions).

3.3.1. The future direction of RE development and its policies in Africa

Some potential future directions in policies and practices to support and ensure the development of RE in Africa as well as other developing or middle-income nations are presented below. These recommendations are similar to the deliverables of the LEAP-RE (WP-14) project.

1. There was a significant knowledge gap identified during the LEAP-RE: WP-14 project associated with the understanding and acceptance of RE in the partner nations. Policies should focus on supporting and educating local communities about RE. Similar educational initiatives have been included in Ethiopian climate policies, such as the green economy strategy [22]. The recommendations of the LEAP-RE: WP-14 project include the use of educational workshops, demonstrations, open discussions about the environmental and economic benefits of RE, and site visits. It is particularly important to show locals example sites (e.g., successful EVs) to inspire them to use RE technologies. The experience of the LEAP-RE: WP-14 project shows that community sensitization is key in changing mind-set in adoption new technologies. This will also improve on peaceful coexistence between the communities.
2. The availability of data, including meteorological data, should be significantly improved to support the development of RE in African nations as well as other developing nations. This can be achieved by including these important tasks in current and future policies. It is also important to educate people in the monitoring and storage of energy data. One important aspect of data collection in Finland is the collection of lake water data by locals and volunteers near the areas where they live during their spare time. Such innovative practices are important for collecting and storing valuable local data, including energy consumption and meteorological data. This would also significantly reduce the cost of data collection e.g., in Uganda, Energy Village.
3. Innovative energy technology solutions are extremely important. Briquettes made from biomass residues in Kenya ensured the sustainable supply of biomass energy [25]. Such innovative solutions, which involve the conversion of one energy source to a more environmentally friendly and more efficient alternative are extremely important for society as well as the national economy, while also safeguarding the environment. Nations must consider new technological solutions in national and local policies and strategies while continuing to innovate upon existing solutions.
4. Finance is the primary bottleneck in the implementation of RE projects. Having a close working relationship with government agencies for subsidies to support the cost of energy systems is required. International organizations, governments, and refugee agencies should advocate for the use of funding for flexible and sustainable RE systems.

In addition to the future policy direction and recommendations, the members of the LEAP-RE: WP-14 project proposed starting an Africa-wide energy village network (Energy Village African Network; EVAN) because the partner nations believed that it would help overcome the challenges associated with RE development in Africa. EVAN could help to organize capacity-building events to improve the acceptance of and reduce knowledge gaps in RE technology, create a contact point to overcome difficulties associated with establishing contact with locals, help overcome the unwillingness to share dare in African communities, and—in the far future—can educate locals on RE operation and management. EVAN can also help to create jobs and income by finding funding for projects and can help to maintain continuous collaboration between AU and EU nations and their citizens that will not end after the lifetime of a single project. EVAN would be part of the vision of better energy security, improvements in environmental and human health, and increased job opportunities across African nations.

EVAN aims to maintain continuous collaborations between EU and AU nations regarding the development of RE and solve and reduce conflicts and problems appearing in the use of RE within and between nations (e.g., resolving hydropower conflicts associated with rivers passing through multiple nations). Secondary aims of EVAN include: 1) The management of a single central contact point for member discussion about EVs; 2) to help members and developing nations with the challenges faced when attempting to implement the EV concept in their selected villages; 3) encourage the collaboration and publication of journal articles associated with the development of RE in EU and AU nations; 4) secure future project funding and joint applications to future projects; 5) foster communications between member institutions to establish possible collaborations. It required community engagement through social innovation and the acceptance of the social and community is key. Afterwards and while working on community engagement with capacity building, developing these future directions, in government laws, polices and local actors a way forward for future.

4. Discussions

The replacement of fossil fuels with RE is not only important to reduce the effects of climate change but also to help communities utilize locally available RE resources to meet their energy demands. Extending this to rural areas is important because a majority of rural areas in African countries are not connected to national electricity grids due to the prohibitive cost of constructing these grids. One way to help local communities gain access to electricity includes the construction of standalone micro-grids. Nevertheless, most of Africa exhibits a high potential for RE resources. Adopting RE technology also has several socio-economic benefits, such as the creation of new jobs; improvements in income, the local economy, and business development; health benefits through the use of safer technologies; and increased local contribution to climate change mitigation.

The LEAP-RE project was initiated by institutes from EU and AU nations through research and technology collaborations to help Africa's RE development. In particular, the UWASA was involved in the LEAP-RE (WP-14) project, also known as the "Energy Village Concept in Africa" (see Section 1). This project aimed to help rural regions transition to 100 % RE resources. The lessons learned during this project will help researchers understand the challenges associated with the implementation of RE concepts in African nations. Any future projects in African nations must be able to understand the situations faced by locals as well as the importance of involving locals with the projects. The primary insight obtained during the EV project was that African nations have significant yet untapped RE resources. These untapped RE resources can improve the access of remote and rural regions to readily available energy, such as through the use of standalone micro-grid systems. Urban areas throughout Africa are also capable of utilizing these untapped RE resources.

Economic growth is a requirement for most nations in the modern day; however, this often results in a significant environmental footprint and requires the consumption of energy, water, and food [53]. The use of RE resources, environmental regulations, and democratic initiatives is capable of reducing the environmental footprint (at least in G7 nations); similar results were found in South Asia, though the same was not true of MENA (Middle East and North Africa) and OECD (Organization for Economic Co-operation and Development) nations [53]. Ahmed et al. [53] also found international trade between G7 nations increased their environmental footprint. These results show that the environmental footprint of a nation is dependent on the region, environmental implementation level, economic status, democratic level, and the available types of RE resources. In contrast, the use of RE technology in CIVETS countries (Colombia, Indonesia, Vietnam, Egypt, Turkey, and South Africa) has improved the environmental quality of the region and trade is not particularly harmful to the environment [54].

The consumption of RE can improve the quality of the environment; in other words, the increased consumption of RE can significantly contribute to environmental protection in African nations [55]. However, economic growth and the use of natural resources reduced environmental quality in Africa [55]. There were significant variations in the relationships between energy use and economic growth across 12 African nations between 1971 and 2008 [56]. Chen et al. [57] noted that there "is an absence of a relationship between energy consumption and economic growth. It means that neither conservative nor expansive energy policies would have an impact on economic growth." However, a hybrid mixes of RE and non-RE systems can help protect the environment. This hybrid system is viable both in terms of economic stability and energy production [58].

There are indirect and direct causal relationships between RE and economic growth, investments, and trade in Ghana [59]. However, there were significant variations in this relationship depending on geographical location. This begs the question: Why should a developing nation build its economy on RE? One of the main reasons would be to meet the demands of their current and future energy needs while contributing to climate change mitigation. To the best of our knowledge, it is difficult to identify causal relationships between RE and economic growth as they are incredibly complex. Although RE resources can clearly help local economies, it is difficult to identify causal relationships. One piece of evidence is the study of Kraft and Kraft [60], which found a strong statistical relationship between gross energy input and gross national product but no causality between the two quantities.

Like most African nations, Ethiopia possesses a significant amount of RE potential. Ethiopia uses biomass as the energy source for cooking [10,21]. It is important to replace the use of biomass (e.g., firewood) with bio-energy to reduce deforestation; this is a problem for many African nations as the use of biomass is common throughout Africa. In particular, the cost of RE technologies is prohibitively expensive for many developing nations; this was consistent with the findings of the LEAP-RE: WP-14 project [10]. Other challenges and barriers to the adoption of RE in sub-Saharan African nations (including Ethiopia) can be classified into four main groups: 1) energy policy implementation, 2) a lack of technical capability and knowledge, 3) investment and financing, and 4) the connection of solar energy infrastructure to the national grid [61]. These challenges were all identified as major obstacles during the LEAP-RE (WP-14) project. The use of hybrid energy mixes is a potential way forward for Ethiopia and many African nations. Fortunately, the Ethiopian government has enacted policies that support the use of RE. Other solutions would be to use climate change effects to their advantage: for example, heat and cooling projections from sediment energy production systems [17,18,20]. Exploiting the beneficial effects of climate change can contribute to the needs of the energy mix.

Innovative solutions, such as the use of briquettes made from biomass, can help to ensure a sustainable supply of energy. Kenya has significant RE potential, including biomass resources. Some RE resources have been utilized by the Kenyan government and its people, which includes an energy mix comprised of hydroelectric power (52.1 %), fossil fuels (32.5 %), geothermal energy (13.2 %), biogas co-generation (1.8 %), and of wind energy (0.4 %) [3]. Indeed, the LEAP-RE: WP-14 project revealed that rural villages have significant RE potential. Similar RE resources are widely available for African nations—18 EVs associated with the LEAP-RE: WP-14 project are a few examples. The National Green Fiscal Incentives Policy Framework [31], is representative of the green energy transition movement across many African nations. Such policy initiatives can help the development of and transition to RE in these African nations.

Attempting to introduce new innovations to developing countries is more akin to a process rather than a product breakthrough; this was found to be the case in the LEAP-RE: WP-14 project as well as in several other developing nations [33]. The successful adoption of RE innovations requires technological, economic, and social considerations, including the construction of capacity buildings, collaboration with local partners, the availability of data, the dissemination of RE technical skills, and financial support. The LEAP-RE: WP-14 project showed that Uganda has significant RE potential, particularly in terms of biomass. Ugandan policies support the use of RE resources in the transition to green energy production. Indeed, Uganda enacted a RE policy as early as 2007 [39], which focused primarily on hydropower, solar, biomass, and geothermal resources but did not consider wind energy [32]. In general, Uganda is well on the way to a complete green energy transition.

Botswana has a Rooftop Solar program that is supported by the national energy policy regarding the contribution of RE technology to the nation [49]. This program sets a good example for other nations focused on RE in their policies or programs and helps locals more easily implement specific RE solutions. It is important to note that a 1 % increase in the efficiency of solar panels increases the sustainability contribution of the solution tenfold [42]. The main energy sources in Botswana are coal, solar energy (huge resource potential), and biomass energy [45]. Moreover, petroleum-based fuels producing countries like Botswanan are facing lack of energy security and one solution for this problem suggested replacing fossil fuels with biofuels [62]. An investigation into CIVETS countries found that increased investment in environmentally friendly technologies not only curtailed emissions but also enhanced economic growth [54]. These findings suggest that Botswana (as well as other developing nations) should focus on adopting the use of RE.

The creation of job opportunities is important for all African nations, including Uganda, which has a significant unemployment problem [32]. The accelerated deployment of wind energy technology can help to reduce unemployment rates in Uganda [32]. In addition, the levelized cost of energy (LCOE) of renewable energy is less than that of fossil fuels and nuclear energy in most G20 countries, especially when external and CO_{2eq} costs are included in the LCOE estimations [63]. Indeed, the LCOE estimation shows that renewable energy will be less costly than fossil fuel and nuclear in all G20 countries by 2030 even without external and CO_{2eq} costs [63]. This suggests that all countries should begin to invest in RE sources well ahead of 2030 to take full advantage of this energy source, and is an important message not only for G20 countries but also for African nations.

Policymakers should move quickly to implement RE reforms as well as invest in RE to benefit from the current global costs of RE [63,64]. In addition, the above sentence supported by [65], stating innovative regulations and policies are useful for attaining specific sustainable development goals. The main influence on the enactment of RE policies is the cost of RE technology. As previously mentioned, the production and storage of RE will be cheaper than fossil fuels and nuclear energy in the G20 countries by 2030; however, this may not be the case in all nations due to the differing cost and availability of RE resources. Gyimah et al. [59] recommended a policy that aimed for an increase in "renewable energy penetration by 10 % and provide renewable energy-based decentralized electrification options in 1000 off-grid communities by 2030", which is very much in line with the LEAP-RE: WP-14 project. A summary of the findings of the LEAP-RE: WP-14 project as well as the systematic literature review revealed that the three main RE resources available to all African nations are solar, wind, and biomass energy sources. Some nations in Africa have the potential for hydroelectric and geothermal energy. Policies should focus on the implementation of these RE resources.

The main challenges to RE development can be classified into technological, economic, and environmental issues. In addition, there are social challenges such as gender and human rights issues. Danish Institute [24] states that the "failure to consult adequately and address human rights impacts associated with renewable energy can drive community resistance to renewable energy projects and can risk creating or exacerbating adverse human rights impacts. In turn, this can contribute to project delays, as well as financial, legal, and reputational penalties for companies and investors engaged in the energy transition." For example, human rights can be associated with large-scale RE projects by taking land that would be used for agricultural production by local communities [24]. Such rapid changes in land use can have a significant impact on the rural household's food security, enjoyment, and other human rights, including the right to health, water, and a clean environment [24].

Some solutions to the challenges associated with the implementation of RE in Africa include providing locals with financial compensation, especially in cases where problems with the local communities come in the form of the acceptance of renewable energy implementations [2]. For example, Finland subsidizes RE solutions: biogas plants are given subsidies if built by the farming industry. More information about these subsidies was found in the final report of the previous "Energy Village" project completed in Finland. Another solution to overcome these challenges includes the direct involvement of local stakeholders (e.g., local residents, governments, and partners). Involving local stakeholders can help companies gain the trust of locals, improve their commitment to the project, foster a sense of ownership, allow for easy access to data and the surrounding area; and increase the likelihood of the continued success of the project and associated businesses.

In Uganda for example solving the RE financial problems including Wind energy (e.g. Pallabazzer and Sebbit [66]) one financial solution is GET FiT (Global Energy Transfer Feed-in Tariff). Probst et al. [67] analyzed RE project investment in Uganda and noted that "combined risk-return renewable power support schemes such as the GET FiT program provide effective alternatives to established programs in terms of financial additionally and improving investment conditions (and thereby lowering the required return on investment for investors)". However, they also warned against interpreting their results as strictly causal. Such solutions should be considered in African nations. In addition, Bio-energy solutions such as Biogas [68], Bio-coal [25,69] and Biofuels (e.g. Biodiesel and others) [62] are suggested in order to avoid risks of using fossil fuels, firewood and risks from the storage of wood residues in the whole world [70] to the environment. Global crisis which comes from Ukraine and Russia [71]. Hopefully, through this LEAP-RE kind project the energy crisis will end and energy security will be achieved through time at least in Africa. As well, 100 % RE in Africa is recommended in other articles [72]. There are barriers to install renewable energy source (RES) in EU countries because several reasons and one of the is RE to grid connection luck [73]. These barriers especially the RE to grid connection is a big problem to RE projects in Africa, however it will be overcome.

One limitation of this study is that only four African nations (the partner nations of the LEAP-RE: WP-14 project) were considered for case studies. Nevertheless, the findings from this project are representative of the challenges faced in other African countries. The LEAP-RE: WP-14 project allowed us to gain first-hand experience of local African communities, and has given the team a greater understanding of the challenges associated with the development of RE in Africa. There were four main objectives of this study: 1) to review the development of RE in African nations by using four nations (Ethiopia, Kenya, Uganda, and Botswana) as case studies; 2) to complement the review with the practical findings and experience obtained from the LEAP-RE: WP-14 project, especially in the context of the challenges associated with the development RE technology in African nations; 3) to identify the reasons why these challenges persist and to suggest appropriate solutions; and 4) to recommend future directions for RE development and policies as well as to initiate EVAN for future international collaborations between EU and AU nations and their institutions. The significance and novelty of the article focuses on identifying the practical challenges faced by locals and international organizations when implementing RE projects in African nations as well as their underlying causes, providing recommendations for the future direction of African RE development in terms of potential policies and practices based on previous experience and literature findings, and planning future collaboration on RE development through the creation of EVAN.

The case studies of the selected African nations in this review are helpful to identify the practical challenges associated with RE development. A majority of African nations were found to be attempting to transition to green energy, which necessitates the development of innovative energy solutions to support this growth. The policies enacted by the four case study nations were encouraging, highlighting their commitment to environmental protection and sustainability. According to the literature, the challenges associated with RE development in developing nations are as follows: 1) the acceptance of RE by local communities; 2) the cost of RE technologies and a lack of financial support, including insurance; 3) a lack of knowledge in RE production and management; 4) a lack of available data; and 5) a lack of RE infrastructure (e.g., connections to the grid). One challenge faced by international companies and projects is the lack of understanding of local communities. The main challenges faced by EVs during the LEAP-RE: WP-14 project were: 1) a lack of long-term energy and weather data; 2) a lack of bank loans, investment, and insurance; 3) significant knowledge gaps regarding RE; 4) the difficulty associated with establishing contact with locals; 5) resistance and fear of change, especially with regards to the energy resources used by the locals; 6) a lack of willingness to provide data or lack of knowledge and data about energy consumption; and 7) difficulties associated with security issues. Many of the challenges identified in the literature were observed during the LEAP-RE: WP-14 project.

5. Conclusions

There can be different reasons why the challenges highlighted in last paragraph of the discussion section are present in specific African countries. Difficulties with data availability are often associated with a lack of knowledge about the amount of energy used as well as the difficulty in estimating the RE types used by locals (e.g., quantifying the amount of cow dung used for heating), cultural norms that cause locals to be unwilling to share their data, knowledge gaps leading to an unwillingness to adopt certain solutions; a lack of readily available weather and energy consumption data, even by local government agencies, and the lack of financial compensation to locals, which may lead to an unwillingness to provide data. The main reasons for the financial and insurance challenges include banks being unwilling to give loans to risky and new expensive RE solutions; a lack of trained personnel to implement and manage the new RE technologies, and an unwillingness to invest in untested RE solutions. In addition, some national laws prevent international banks from giving loans in the country. Knowledge gaps and resistance to change are present due to cultural reasons, such as the difference in the taste of food when cooked with electricity rather than firewood, a false belief that energy from waste is contaminated, and the expense of new RE technologies. The latter is the biggest reason for the resistance to change, with many rural areas in developing nations lacking the economic capacity to spend money on new technologies. Contrasting EU-led project with other project such as Botswana solar roof project EU-led projects are efficient with money, resources, researcher's knowledge, experience of other nations, and kindness. However, home based projects only are based on their own knowledge, culture and experience that has very low capacity of solving problems in world scale or in their country.

Practical solutions for these challenges include 1) educating locals about data collection and the handling of energy data, 2) keeping household information confidential and only using it for the purposes of the project; 3) building trust with locals and avoid distrustful behaviors; 4) providing compensation to those providing data (if allowed by funding regulations); 5) long-term plans for African databases systems; 6) reducing the cost of RE technology at the governmental and international levels (e.g., by providing subsidies to companies and local residents); 7) the creation of international markets (e.g., Ethiopia is committed to such a venture in 2024); 8) creating awareness of the benefits, implementation, and management of RE solutions among local communities; 9) creating a mixed energy solution to meet the needs of locals (e.g., only cooking food with firewood during important cultural events); and 10) initiating specific policies at the national level, such as the Rooftop Solar program in Botswana. Other locale-specific solutions should be adapted to support the development and implementation of RE projects in African nations.

These are the main suggestions and recommendations for the future direction of African policies as well as the creation of EVs based on the experience gained from the LEAP-RE: WP-14 project. African nations should focus on supporting and educating local communities to overcome knowledge gaps. Energy and weather data availability should be significantly improved to accelerate the development of RE in Africa as well as in other developing nations. Innovating technologies and the introduction of new RE technologies can improve and support RE development in Africa as well as act as pillars for future policies. African policies should support and promote RE technology investment, loans, insurance, subsidies, and advocacy by international organizations, governments, and refugee agencies to overcome the issues associated with the financial aspect of RE implementation. This article also notes the objectives of EVAN: to build long-lasting collaborations between EU and AU nations with regard to RE development and to solve and reduce conflicts and problems associated with the use of RE within and across nations. EVAN can help to ensure that collaborations do not end after the lifespan of a project and will promote the creation of a responsible RE family among AU and EU nations and their people EVAN would be part of the vision of better energy security, improvements in environmental and human health, and increased job opportunities across African nations. Despite the numerous challenges facing the development of RE in Africa, African nations hold significant untapped RE potential that can be harnessed systematically. The practical implications of this article are the challenges that researchers and project workers should expect to encounter during the development and implementation of RE in African nations. These issues can be resolved using the recommended solutions described in this article.

The most common RE resources used among the 18 EVs from Kenya, Ethiopia, Uganda, and Botswana were biomass, solar, and wind. These RE resources are generally representative of the available resources in most African nations. Future research should investigate how organizations can support locals with the implementation of RE in EVs as well as how to expand the EV concept to other nations. Other studies could focus on the social acceptance of the LEAP-RE and EV projects across Africa. The results from these studies would be useful in guiding the future development of these African projects. The development and future direction in Africa shall follow: community engagement through social innovation and the acceptance of the social and community is key. Afterwards and while working on community engagement with capacity building, developing these future directions, in government laws, polices and local actors a way forward for future. The next step of business model development and the whole steps of LEAP-RE were published in Girgibo et al. (2025 1st) will be published soon and in LEAP-RE project website.

Ethics approval and consent to participate

Not applicable.

Consent for publication

All the authors agreed and gave their consent for publication.

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Availability of data and materials

The data is not available for public use because the research is ongoing, and our research teams would like to continue with it, so we are not currently sharing our data.

Authors statement

The authors agree that this paper can be published in Journal of Renewable and Sustainable Energy Review.

CRediT authorship contribution statement

N. Girgibo: Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **P. Haapalainen:** Writing – review & editing, Writing – original draft, Validation, Supervision. **L. Karita:** Writing – review & editing, Writing – original draft, Validation, Supervision. **P. Peura:** Writing – review & editing, Writing – original draft, Validation, Supervision. **G. Adam:** Writing – review & editing, Writing – original draft, Validation, Supervision. **T. Sissay:** Writing – review & editing, Writing – original draft. **A. Worku:** Writing – review & editing, Writing – original draft, Validation. **M. Girma:** Writing – review & editing, Writing – original draft. **M. Einax:** Writing – review & editing, Writing – original draft. **P. Maphane:** Writing – review & editing, Writing – original draft. **A. Cleophas:** Writing – review & editing, Writing – original draft, Validation. **A. Kiprop:** Writing – review & editing, Writing – original draft, Visualization. **H. Kasedde:** Writing – review & editing, Writing – original draft, Visualization. **J.B. Kirabira:** Writing – review & editing, Writing – original draft, Visualization. **K. Kumakech:** Writing – review & editing, Writing – original draft, Visualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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