A Systematic Review of Climate Technology Transfer for Climate Change Adaptation and Mitigation in Sub-Saharan Africa

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Abstract

Sub-Saharan Africa contributes minimally to global greenhouse gas emissions, yet faces disproportionate climate risks including droughts, flooding, heatwaves, and food insecurity. While international climate negotiations emphasize climate finance, the transfer of climate-relevant technologies remains underdeveloped, despite its central role in both mitigation and adaptation. This review synthesizes literature on climate technology transfer mechanisms, evaluates technological gaps across energy, agriculture, water, and urban systems, and examines institutional, financial, and intellectual-property barriers preventing implementation. We argue that climate technology transfer—supported by capacity building and local innovation ecosystems—is the most cost-effective pathway for achieving climate resilience in Sub-Saharan Africa, while enabling global decarbonization. Without accelerated technology diffusion, global climate targets cannot be met. The author advocates for shifting from transactional technology transfers to collaborative partnerships and regional manufacturing, emphasizing that equitable technology transfer is essential for achieving global decarbonization goals of 1.5–2°C. The paper proposes a cooperative implementation framework combining co-development, open innovation, and regional manufacturing to replace the prevailing donor-recipient model.

Keywords: Climate technology transfer, Adaptation, Mitigation, Climate justice, Sub-saharan Africa, Sustainable development, Decarbonization, Resilience**.**

Introduction

Sub- Saharan Africa (SSA) is one of the most vulnerable regions to climate change in the world, because of rising temperatures, rising sea levels, rainfall anomalies and other extreme climate events, which are leading to immense losses and long-term damage in Africa(Ayanlade *et al*., 2026; Trisos *et al*., 2022; Turay and Ihinegbu, 2025). Extreme weather events such as flood, droughts, heat waves, and tropical cyclones, are occurring more regular than previous times in Africa, the resulting impacts are damages to the environment, production systems and livelihood. The vulnerability of SSA is high, which is because of low capacity to adapt to climate change (Ayanlade *et al.*, 2023), will place an additional stress on water resources, food security, human health and infrastructure. Though, Africa contributes minimally to cumulative greenhouse gas emissions, yet faces disproportionate exposure to climate hazards, including intensifying droughts, heat extremes, rainfall variability, sea-level rise and food insecurity. The consequences of climate change is experienced differently at various locations, thus, there is a large dissimilarity between the developed and the developing countries, not only due to the differences in the projected change of climate parameters, but also because of the variation in vulnerabilities and adaptive capacities between nations and regions.

Resilience and coping mechanisms in sub-Saharan Africa remain limited. Adaptation policies in Africa often focus on funding, while access to technology is actually more vital for adaptation. Climate finance is less useful without appropriate technology. The technological gap in the continent is different from one country to another, but anyway, the more advanced climate technologies are simply not available in the majority of African countries. Thus, technology transfer, as the way to mitigate and adapt to climate change, has been and continues to be, the primary and only realistic means, through which African continent can accelerate its response to climate change. Therefore generally, adaptation is challenging because of African countries' limited capacity of financial resources to acquire many of climate adaptation and mitigation technologies. This thus makes the financing adaptation to climate change to be less extensive for sub-Saharan Africa.

Global climate agreements like the UNFCCC Paris Agreement (Low, 2006) and IPCC (IPCC, 2014; Pörtner *et al*., 2022) see technology sharing as crucial for climate cooperation. International climate agreements recognize technology transfer as a core pillar of cooperation alongside finance and capacity-building. However, implementation has lagged behind ambition, with climate discourse increasingly dominated by financial flows, rather than technological capability formation. Thus, it is pertinent to adapt to the changes through the innovation of new technologies and modification of existing technologies (Hekkert *et al*., 2007). Climate change technology date back to hundreds of years, local communities have, for example, used traditional technologies to cope with regular flooding, by building houses on stilts, and many communities continue to do so, even if they use more modern materials such as concrete pillars or corrugated iron roofs (Roaf *et al*., 2009). However, the extremity and erratic pattern of climate change create the need for more sophisticated technologies. For example, the use of earth observation system that can provide more accurate weather forecasts, or crops that are based on genetically modified organisms; artificial intelligence in carrying out production to reduce the need of machines run by fossil fuel; adopting electrical transportation mode and generation of electricity using solar panels and many more (Dale, 1997). Thus, there are several mechanisms designed to address climate change and exchange technologies from developed to developing countries, some of which are: Special Climate Change fund, Least Developed Country Fund, Adaptation Fund, and Capacity Development Initiative (Smit and Pilifosova, 2003). These international bodies noted that the present level of commitments made by the industrialized countries is inadequate to make any significant impact on mitigation, adaptation and sustainable development in agrarian countries. To promote the transfer of climate technologies and investment capitals to developing countries, there is a need for a much greater level of commitment from the developed countries and responsiveness from the recipient countries. The mechanisms under the climate convention and the Kyoto Protocol have to be used by developing countries to meet the investment and technology-need to address the adaptation issue. To assess the potential impact of climate change on natural and human ecosystems, and to develop and implement adaptation technologies to counter the impacts, developing nations have to focus more on capacity building, which will also attract financial flow (Ravindranath and Sathaye, 2002).

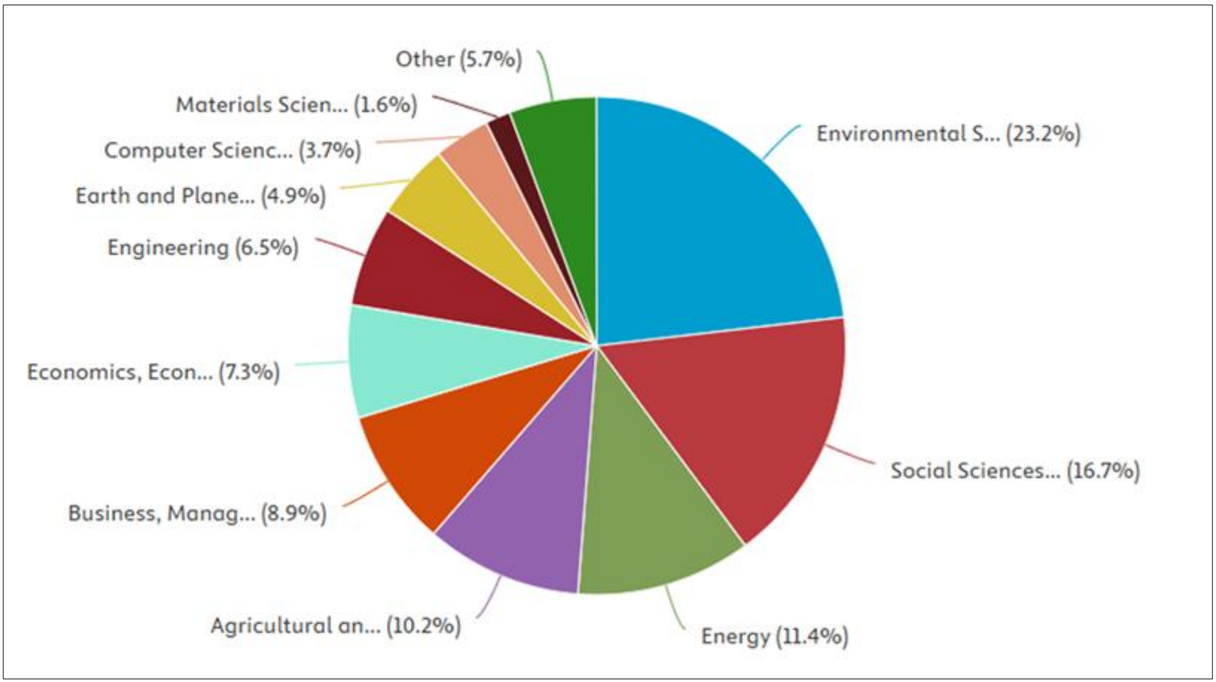
This review study thus argues that climate technology transfer is not a peripheral mechanism, but a structural prerequisite for both global mitigation and regional adaptation. This study synthesizes evidence on technological needs across energy, agriculture, water and urban systems; analyse institutional, economic and intellectual property barriers; and assess why current market-led diffusion models are insufficient.

Methodology

This study employed a systematic review approach to assess the impact of climate technology transfer on mitigation and adaptation efforts in Sub-Saharan Africa. It aimed to synthesize peer-reviewed evidence regarding technological diffusion mechanisms, capability development, and institutional barriers affecting climate outcomes, focusing on closing the technology gap through cooperative and capability-based strategies. The study's structure thus matches the aim of fixing the climate technology gap with teamwork and skill-building. The Web of Science and Scopus, two big academic databases, were used. These databases were picked for their wide coverage of subjects like climate science, energy, environmental rules, development, and innovation (Figure 1). Sticking to these databases kept the research consistent, and repeatable.

Figure 1: The disciplinary distribution of the reviewed literature on climate technology transfer in Sub-Saharan Africa

A structured search strategy was applied to search and select relevant published literature used for this review paper. The following combinations of keywords were used: “climate technology transfer” OR “low-carbon technology diffusion” OR “clean technology” OR “renewable energy transfer” OR “adaptation technology” AND “Sub-Saharan Africa” OR “Africa” AND



“mitigation” OR “adaptation” OR “capacity building” OR “innovation systems.” The search period covered publications from 2008 to Feb 2026. This is done in order to capture literature emerging during the operationalization phase of global climate technology frameworks under the United Nations Framework Convention on Climate Change and the implementation era of the Paris Agreement.

The initial search returned about 7,900 records. After removing duplicates and screening titles and abstracts, articles were excluded if they lacked technological aspects, only discussed financial mechanisms, or examined regions outside Sub-Saharan Africa (SSA) without relevant insights. After this screening, 276 articles underwent a full-text review based on stricter criteria: Studies had to: (1) explicitly address climate technology transfer or diffusion; (2) focus on mitigation and/or adaptation technologies; (3) provide empirical or conceptual analysis relevant to SSA; and (4) discuss institutional, regulatory, financial, or capacity-building components associated with technology adoption.

Full-text evaluation excluded 118 articles that did not adequately address technology transfer mechanisms or lacked regional specificity. Ultimately, 124 peer-reviewed articles published between 2008 and February 2026 were reviewed, of which 46 focused on Africa or sub-Saharan Africa. Table 1 shows the **s**ummary of study identification, screening, eligibility assessment, and inclusion, based on PRISMA 2020 study selection process. The selected 46 studies encompassed empirical case analyses, comparative regional assessments, sectoral evaluations, and theoretical contributions relating to climate technology governance. To systematically organize evidence, studies were coded using a thematic analytical framework, based on the "Technology Transfer Capability Ladder." Categories included hardware deployment, operational assimilation, institutional embedding, industrial integration, and innovation sovereignty, along with sectoral focus and intervention scale. Barriers such as intellectual property constraints and financing limitations were identified to facilitate comparison across cases and technologies, analyzing both quantitative assessments of impact and qualitative institutional analyses for balanced synthesis. The research used qualitative comparative analysis, not statistical meta-analysis, to combine results, since study methods and outcomes varied too much for quantitative pooling. This review examines why technology transfer is crucial for climate change efforts in Sub-Saharan Africa. It identifies technology gaps in important sectors and explores institutional models for fair and real transfer. The aim was to find patterns between technology skills, lessening impact, and adapting to climate change. This led to a practical framework for working together, based on solid proof and aligned with worldwide climate goals.

Table 1: Summary of study identification, screening, eligibility assessment, and inclusion: PRISMA 2020 study selection process.

Stage	Description	Number (n)
Identification	Records identified through database searching (Web of Science and Scopus)	7,900
	Duplicates removed	1,864
	Records remaining for screening	6,036
Screening	Records screened (title and abstract)	6,036
	Records excluded	5,760
Eligibility	Full-text articles assessed for eligibility	276
	Full-text articles excluded	152
	– Insufficient engagement with climate technology transfer mechanisms	83
	– Lack of regional specificity to Sub-Saharan Africa	44
	– Absence of institutional, regulatory, financial, or capacity-building analysis	25
Included	Studies included in qualitative synthesis	124
	– Focused specifically on Africa or Sub-Saharan Africa	46
	– Globally comparative or conceptual studies with direct relevance to SSA	78

Results and discussion

As stated earlier, the results from this study were synthesized using qualitative comparative analysis, instead of statistical meta-analysis due to varied methodologies and outcome measures. The synthesis focused on identifying structural patterns that link technology capability formation with mitigation performance and adaptation resilience. The literature on climate technology transfer in Sub-Saharan Africa is spread across many fields, with Environmental Sciences leading at 23.2% (Figure 1). This suggests the research focuses on environmental systems, climate impacts, and sustainability, often framing tech transfer in terms of environmental results instead of just economics or politics. The literature on climate technology transfer highlights a strong focus on Social Sciences, which account for 16.7% of publications.

This underscores the socio-political and institutional dimensions of technology diffusion, emphasizing themes such as equity, justice, and international cooperation. Energy (11.4%) and Agricultural Sciences (10.2%), collectively representing over 20% of the research output, reflect priorities in renewable energy deployment and adaptation technologies in Sub-Saharan Africa, showcasing the convergence of mitigation and adaptation goals. Business, Management, and Economics contribute somewhat to the literature (8.9% and 7.3%, respectively), showing a growing interest in market mechanisms and private-sector involvement in technology spread. Engineering (6.5%) and Earth/Planetary Sciences (4.9%) offer technical and geophysical views. Computer Science (3.7%) and Materials Science (1.6%) are less represented, suggesting the research focuses more on policy and sector studies than technology advances.

Energy Systems, climate change adaptation and Mitigation Sectorial technology Needs

Africa's emissions trajectory hinges on meeting energy demand through low-carbon technologies. Key technologies identified include grid-scale battery storage, smart grids, green hydrogen, utility-scale solar manufacturing, and wind systems, along with carbon capture for industrialization. However, these renewable technologies are currently import-dependent, costly, and poorly localized (Appiah *et al*., 2026). The capacity for technology transfer will significantly influence whether Africa can leapfrog to sustainable growth or become entrenched in carbon-intensive development paths. Various technological approaches have been adopted for the reduction of GHG emission globally (Appiah, *et al*., 2026; Huisingh *et al*., 2015). One of this approach is the technology-oriented agreements that was initiated due to the disposition of United States and some fast developing countries, to work together to share ideas and make a progressive change in GHG emission, this initiative is similar to the Kyoto Protocol and the European Union (EU) Emission Trading System (ETS). The only disparity is that Technology-oriented agreement (TOA) attains its purpose by technological development activities or technology-specific mandates and incentives, rather than in terms of emissions alone (McLaren and Agyeman, 2015). Achieving an appreciable reduction in greenhouse gases (GHG) emission between 450 and 750 parts per million (PPM) is utmost in the course for adaptation to and reduction of climate change (Biswas, 2013).

In SSA, this will require innovation and comprehensive adoption of GHG reducing technologies throughout the global energy system (Naphade *et al.,* 2011). From this agreement, there are five broad classifications: Knowledge sharing and coordination amongst involved countries; research on factors promoting climate change; development and demonstration of new innovations; technological transfer from developed countries to developing countries; and technological deployment mandates, standards and incentives. The technology-oriented agreement works in partnership with other organizations aimed at GHG emission reduction like the Montreal protocol, Convention on Biological diversity and the World Trade Organization (Aurélien, 2025; De Coninck *et al*., 2008). Climate change technology exchange is vital for the attainment of sustainable development. Sustainable development is the promotion of economic, social and environment development while considering the future generation. Adaptation and mitigation to climate change are factors of sustainable development (Peterson *et al*., 2011). Technology exchange within countries ensures sustainable development. Reducing the impact of climate change in a particular region ultimately affects other regions in the world, the earth is a function of interrelated activities that is most times affected by man (McCarthy *et al*., 2001). Ensuring climate change reduction in a particular location by transferring technologies, indirectly affects the some other countries (Barrett and Stavins, 2003).

According to Hoffmann (2011), a pivotal method of tackling climate change is innovation. The significance of innovation to energy sector and the implications it holds for national and international policy responses to climate change are: the solution to climate change is not in the "identified" technologies, but through a rich portfolio of options matched to the various major sectors of energy production, conservation and use through a global system modelling studies

(Banuri *et al*., 2001). Climate change technologies are safeguarded through various measures. Under the supervision of The World Intellectual Property Organization, intellectual property (IP), which is invention of climate change, is referred to as "creation of minds". Intellectual property rights (IPR) are granted to innovators as patent, copyrights and trademarks to protect climate technological innovations (Banuri *et al*., 2001).

The popularity of the use of patent data has been expanded in recent empirical literature (Stuart, 2000), patent data emphasize on the outputs of the inventive process (Stern *et al*., 2000). Most prominently, they can be dispatched to specific technological areas. Lastly, they specify not only where the technologies are being used, but the countries where inventions were made. Evidently, patent data also present drawbacks, but they are requirement for developing more technologies (Stern *et al*., 2000). A weakness of patent use is that there are certain forms of knowledge that are not patentable, which includes: know-how, learning-by-doing, which cannot be easily codified because these are expertise personified in individuals (implicit knowledge). However, researchers have shown that patent knowledge and implicit knowledge are positively correlated. Another setback is that patent endorses the exclusive right to use the technology only in a given country; however, this does not mean that the patent owner will actually use the technology in that country.

Access to climate technology shared by various stakeholders also includes license. License requirements are occasionally used for transfer of technology for climatic purposes (Bozeman, 2000; Burrell *et al*., 2023; Karakosta *et al*., 2010). Technological transfer is a fundamental process for access to adaptation and mitigation technologies around the world. A prerequisite for increased energy demand is population growth, which presents a need for agreement for the dissolution of climate change. The dissemination of these technologies internationally will be necessary for the mitigation and adaptation to climate change. The developed countries have more sophisticated technological innovations and capabilities than the developing countries (Ayanlade *et al*., 2022; Olawuyi, 2018; Saggi *et al.,* 2004).

Agriculture and Food Systems climate change technology transfer Priority

In Sub-Saharan Africa, agriculture, which employs over half the workforce, is very sensitive to climate. Agricultural production is directly affected by climate and agriculture also contributes to climate change (Akpodiogaga-a and Odjugo, 2010). According to a report by the Intergovernmental Panel on Climate Change, agriculture is responsible for over a quarter of total global greenhouse gas emissions (Bogner *et al*., 2008; Pörtner *et al*., 2022). The share of agriculture in the global gross domestic product (GDP) is about 4%, proposing that agriculture is extremely GHG intensive. Investment in agricultural research and innovation is motivated by the concern about mitigation and adaptation to climate change. The ability for farmers to mitigate and adapt to climate change is largely shaped by the dissemination of new agricultural practices and technologies in the next imminent decades (Lybbert and Sumner, 2012). The need for this adaption and mitigation potential is pronounced in the developing countries than any other regions, because the effects of climate change are expected to be harsh and regional differences around the global average impact are substantial. Africa is projected to see reductions of agricultural output by 30% or more, agricultural productivity is low and poverty, vulnerability and food insecurity remain high (McCarthy *et al*., 2001; Trisos, *et al*., 2022).

Technologies needed include drought-resistant crops, better irrigation, precision methods, weather Artificial Intelligence (AI), and soil monitoring. Without these, food insecurity will rise, no matter adaptation funding. The inputs of agriculture are modified by new technologies, especially in means that can change the influence of weather on agricultural production and carbon emission. Creating these agricultural technologies will require innovations, possible limitations to innovation involve both the private and public sectors in developing countries.

Invaluable assistance has been granted to developing countries by Consultative Group for International Agricultural Research (CGIAR) overtime as a source of agricultural innovation for nearly 40 years. Government intervention in input and output of agricultural produce in the market is a trend in many countries, this has subdued the establishment of effective private firms and accompanying incentives for innovations (McCarthy *et al*., 2001).

Agronomic constraints control the process of transferring agricultural innovations across agro-ecological and climatic zones (Chhetri *et al*.,, 2012). Different locations are known to produce specific crops that only grow in certain climatic regions. Technologies are most times crop specific, therefore these technologies are useless to such locations where specific crops are not grown. Some of these agronomic constraints have been reduced by agricultural biotechnology and biodiversity. Although, this biotechnology advances a new form of impediment in form of biotechnology regulations, another constraint to technology transfer is intellectual property (Sunding and Zilberman, 2001).

Biotechnology provides wealth of benefits, there is an extension of the mitigation of potential new crops and varieties to direct carbon sequestration and maybe an additional generation of biofuel crops (P. Smith and Olesen, 2010). There are other second generation biofuel crops, apart from sugar cane and maize, that appears to be profitable as fuel sources (e.g., miscanthus, with focus on Mendel Biotechnology). Genetically modified crops is another technological innovation for climate change, only 7% of genetically modified crops were grown in 2001 on arable lands in the world, the total reduction due to the emission of these specific crop types amounted to 14,200 million kg of CO_2, this is equal to removing over 6 million cars from circulation. Genetically modified crops are pest resistance, herbicide tolerant and conventionally bred, making them environmentally adaptive. Another innovation is the drought and salt tolerant traits that are emerging as the products of biotechnology, supported by the Water Efficient Maize for Africa (WEMA) project and other international partnerships between public research institutes and private agricultural biotechnology firms such as Monsanto.

African farmers urgently need techniques, technologies and investment that will increase water management efficiency, access to irrigation or find ways to improve incomes with less secure and more variable water availability. This is because Africa only irrigates 6% (13.6 million hectares) of its arable land in contrast to 20% worldwide. Water availability is projected to decline intensely, given the rate of population growth in the next several decades across the Middle East and North Africa, Central Asia and southern Africa. The Monsanto firm announced its interest for public private partnership to cultivate tolerant maize varieties for Africa. Also, The Bill & Melinda Gates Foundation and the Howard G. Buffett Foundation are contributing $47 million to fund the first five years of the project. With the use of conventional breeding, marker-assisted breeding and biotechnology, WEMA aims to develop drought–tolerant African maize varieties. The proposal is to ultimately offer the drought-tolerance trait to small farmers in sub-Saharan Africa in order for them to produce more reliable harvests. The yields of these new varieties are expected to be within 24-35% during moderate drought seasons.

With funding from the United States Agency for International Development and collaboration from Cornell University, Syracuse University and the_University of Wisconsin-Madison, the International Livestock Research Institute (ILRI), as part of the Consultative Group on International Agricultural Research (CGIAR), has been able to help vulnerable pastoralists to cope with severe drought losses through the development of an index-based livestock insurance contract. In Kenya, livestock insurance, based on satellite data, are used by pastoralists to adapt their source of revenue to an extraordinarily harsh situation. Still, regional climate change is expected to make instability in rainfall patterns that are extreme, even in East African standards. This problem in Kenya aided the introduction of ILRI.

The Paris Agreement emphasizes technology transfer to boost climate change resilience and cut emissions. Its Article 10 says nations should work together to create and share technologies. It establishes a technology framework to guide the Technology Mechanism and help the Agreement's goals. Article 10 also says that developing countries should get financial support to implement these technology transfers. Technology transfer is also mentioned in the Kyoto Protocol, urging parties to work together to promote and fund access to environmentally sound technologies, especially for African countries. In order to achieve the goal, the United Nations formed the “United Nations Framework Convention on Climate Change” (UNFCCC). The principles guiding specific technological transfer are: (1) utilizing agricultural biotechnology as a possibly important choice (2) promoting good relationship between public and private agricultural research, reducing associated risk (3) participating in better information and forecasts (4) making investment in public agricultural R&D in developed countries, (5) promoting investments that improve spatial market incorporation (6) assisting competitive & responsive agricultural markets and (7) transforming and increasing public agricultural research capacity in developing countries.

Discussions

Approaches to technological development in relation to climate change vary at different locations. In the United States, the Climate Change Technology program (CCTP) was adopted, CCTP is a multi-agency development and management body (Council, 2004). Technology transfer, defined as the sharing of equipment, skills, knowledge, and intellectual property, is the main way for Africa to speed up its climate change response. Acceleration of development and deployment of technologies that reduce, avoid or capture and store GHG is the purpose of the formation of CCTP. Some of the technologies that have been innovated are the electrical cars, solar panels, and the adaptive environment suitable for the growth of various crop species. Canada is in the forefront of generating electricity free of carbon emissions, the target of Canada, concerning the reduction of climate change, is to produce a commercially viable nuclear-fusion-energy power plant (Smith and Taylor, 2008). Emission from fusion produces only Helium as exhaust and zero greenhouse gases and the land requirement for building this technology is lesser than some other renewable technologies (Goeppert, Czaun, Prakash, & Olah, 2012). Transportation generates 23% of global energy relating to CO_2 emissions, consistent population growth inevitably leads to increase need for transportation. In the University of Surrey England, a new material known as a super-capacitor has been discovered, this new technology has the potential to run electrical cars for long distances, for a period of 6 to 8 hours at a stretch, without the need for a recharge, this invention limits the emission of CO_2 from vehicles (Wilcox & Tunnicliffe, 2002). Methane, a supplementary form of CO_2, is generated from cattle dung. The exponential growth of population has encouraged the demand for meat, and thus increases the number of cattle being reared. Lab-grown meat have been endorsed for production in Manhattan California, this is an enterprise supported by Bill Gates, with the production of lab-grown meat, the generation of methane from animal wastes will be reduced (Augustyn, 2017). Carbon Engineering, which is the removal of carbondioxide directly from the atmosphere to produce fuel, is a phenomenon practiced in the United States, Canadian and some European countries.

Assessing developing countries, there is a wide variation in technological achievements. Bangladesh suffers recurrent flooding in the coastal areas every year. Even though this is partially beneficial for irrigational purposes, sometimes it can be disastrous, resulting in epidemics and in thousands of deaths, as well as causing serious damage to habitats, agricultural production, fisheries and livestock. Due to the aforementioned occurrence, there was a need for the development of an early warning system, which includes: a five-year project. This was developed by the community flood information system (CFIS), funded by the United states agency for international development (USAID) and operated by the United states company riverside Technology, in partnership with two Bangladeshi institutions. Technological expansion was achieved through partnership with two Bangladeshi institutions: the centre for environmental and geographic information services, and the Bangladesh disaster preparedness centre. In Bangladesh, experience showed that local people are paramount in carrying out research on disaster. Prior to the project, indigenes generated forecast data from traditional methods like: interactions within themselves, traditional knowledge of location and local media (Augustyn, 2017). However, the results from the first two methods are usually unproductive and disorganized for carrying out analysis, whereas local media reports can be difficult for people to understand.

In east Africa, innovation system was adopted to deal with the problem of climate change (Maddison, 2007). Innovation system are sets of actors, institutions and skills that function and interact to create conditions and medium for innovative social, environmental or economic solutions (technologies, ideas etc.) to emerge and successfully thrive in a particular context, in this case, climate change (Coenen *et al*., 2012). The need for improvement in different aspects of climate action was deliberated upon, it was argued that there should be strong technological innovations, institutional innovations and policy innovations for a successful climate action (Grubb, 2004).

Moreover, undoubtedly, advanced irrigation technology is helpful in improving agricultural yields during periods of drought in Africa, but the problem is to make the technology affordable to farmers in SSA. Whilst FLID allows farmers to find a reliable water source, it is still difficult to know the proper water usage for certain crops. Hence, “sensorless” water-saving irrigation systems are introduced to some African farmers. For instance, Israeli smart farming startup SupPlant has invested a lot to accelerate its R&D, and intend to expand distribution of its sensorless irrigation technology to more farmers around the world. The technology integrates real-time and forecasted climatic data with agronomic algorithms, artificial intelligence, and cloud-based data, to determine particular parameters, such as water content and fruit development trends.The farmers can then access this data, which is updated every 10 minutes on the cloud, to receive simple and precise irrigation suggestions. All of this contributes to water conservation, increased productivity and increased yields, while lowering farmers’ expenses.

The “sensorless” technology, on the other hand, reminds people about digital technology that can transform the agricultural sector through the application of innovative tools and new business models. Digitalized agriculture process allows many stakeholders throughout the value chain, including smallholder farmers, to have access to real-time data and computing capability, allowing for more effective product-to-market choices, finance availability, and access to micro-insurance. Therefore, farmers can sell their products at a better price, extra money they earn can then be invested in new equipment that can improve the crop yields, a virtuous cycle is thus generated that makes the society more resilient to extreme weather.

Eleblu *et al*. (2021) report on climate smart agriculture technologies, whose precise objective it is to address the threat of climate change, presented the following technologies: Sustainable breeding that can address climate change concerns by providing breeders with tools to develop climate smart crops that are designed to adapt to harsh and extreme weather conditions. Further, these crops can produce higher yields than currently available varieties. Examples of these tools and resources are gene banks and hybridization techniques, In vitro propagation techniques and sequencing. Other approaches concern efficient resource management, integrated renewable energy technologies of farming systems, resource conserving technologies, as well as land use management. Cropping season variation and crop relocation are also approaches and techniques that aim to improve yields. Another important aspect of agriculture that is impacted by climate change is pest management. There are no botanical or environmentally friendly chemicals available to farmers. This means that the focus should lie on efficient pest management, for instance, by focusing on resistant variants and a strong pest adaption mechanism. Geographical Information System (GIS) mapping is designed to capture, store, manipulate, analyze, manage, and present geographical data. It can help by creating hazards and risk maps at many possible scales. For example, the basis for these maps is estimations and the computations of storm causes and flooding.

Gweyi-Onyango *et al*. (2021: 9), for instance, report on suitable technologies that can be exploited to increase, in this case, root tuber crops adaptability to climate change. These technologies include the use of bio fertilizers, the practice of organic agriculture, tie-ridging, improved seed varieties and the management of community seed banks. Bio fertilizers enable farmers to minimize the use of chemical fertilizers, which improves nutrient availability and reduces pest pressure. They also contribute to the microbial population in the soil which helps with soil fertility. Organic agriculture helps mitigating climate change impacts by diminishing greenhouse gas emissions and sequestering carbon dioxide from the atmosphere. Overall, organic agriculture can improve soil conditions. Tie-ridges are soil and moisture conservation structures that are based on the constructions of small basins. These basins enhance rain water storage and allow the water more time to seep into the ground. Technologies that focus on seeds make use of breeding to address climate change impacts in the seed value chain and the maintenance of seeds to provide local access. Another project focuses on the clean seed production and encouraged seed stakeholders to act as permanent seed producers. Other reported interventions make use of cropping systems, irrigation method, exploitation of abandoned lands, agroforestry practice and Nutrient Use Efficiency (NUE).

Concerning the cropping systems, the aim is to better utilize the environment, achieve greater food yields, increase return per unit area and insurance against crop failure. The main strategy used here is the planting of more than two appropriately chosen crops with different maturity periods. The irrigation method is of utmost interest for semiarid and arid regions facing droughts. The irrigation method should release the exact amount of water required and take into account the time and method of water application. One best practice example is the sprinkle and trinkle irrigation methods. They conserve water, prevent nitrogen leaching, allow for deep water percolation, and reduce erosion. The exploitation of abandoned lands reclaims and increases arable lands through alternative crop productions than those that were used before. Agroforestry resolves around the interaction between agriculture and trees, especially the agricultural use of trees on farms, in agricultural landscapes, in forests, and tree-crop production such as coffee and cocoa. The systems include traditional slash-and-burn agriculture, as well as more intricate fruit trees and vines systems. NUE is an indicator of the crops' ability to absorb and utilize nutrients for yields. Some crops seem to have a higher NUE, which can influence the farmers' utilization of soil and fertilizer recommendations for specific crops.

Case studies of climate technology transfer in practice across Africa

Empirical studies in Africa indicate that climate technology transfer is more effective when it encompasses, not only equipment delivery, but also institutional learning, regulatory reform, and capability development. The discussed cases cover both mitigation and adaptation efforts, showcasing various transfer modalities, such as renewable energy, digital forecasting, and agricultural innovations. Overall, successful technology transfer is integrated within national development strategies, rather than approached as standalone projects. Industrial policy's impact on the quality of technology transfer is illustrated in North Africa, by Morocco's renewable energy development. The Moroccan Agency for Sustainable Energy structured big projects, like the Noor Ouarzazate Solar Complex, to include local content and training (Table

2). In the beginning, solar technology was imported, but local companies learned to build, produce components and manage. This shows that technology transfer can boost supply chains, when linked to industrial involvement.

Kenya's geothermal industry is an example of a long term technical internalisation strategy as the Kenya Electricity Generating Company (KENECO) has developed its skills in geothermal exploration, drilling and reservoir management at the Olkaria Geothermal Power Station, through international cooperation. This resulted in foreign contractor management being transferred to local engineers, which cut costs and boosted the reliability of the network. The Kenyan approach highlights the importance of tacit knowledge transfer in complex decarbonisation technologies. In contrast, decentralized electrification in Tanzania and Nigeria demonstrates the success of modular renewable energy systems. The Rural Energy Agency of Tanzania facilitated the deployment of standardized solar mini-grids, and local capacity building, while Nigeria's regulatory reforms and programs enabled off-grid solar development, highlighting the need for imported technology, coupled with local training and learning-by-doing, to encourage local entrepreneurship and learning. Hydrogen partnerships

Table 2: Climate technology transfer pathways across Africa

Case	Country / Region	Sector	Lead Institutions	Technology Transferred	Transfer Modality	Observed Outcomes	Key Policy Insight
Solar Industrialization	Morocco	Mitigation – Renewable Energy	Moroccan Agency for Sustainable Energy; Noor Ouarzazate Solar Complex	Utility-scale solar generation & engineering supply chains	Local-content industrial policy + deployment	Workforce specialization; domestic supply chain growth	Deployment linked to industry policy creates technological capability
Geothermal Localization	Kenya	Mitigation – Baseload Clean Power	Kenya Electricity Generating Company; Olkaria Geothermal Power Station	Drilling, reservoir management, plant operation	Long-term technical training partnerships	Reduced generation cost; domestic expertise	Tacit knowledge transfer more important than hardware ownership
Drought Early Warning	Horn of Africa	Adaptation – Climate Services	IGAD Climate Prediction and Applications Centre	Seasonal forecasting algorithms & satellite monitoring	Regional data sharing + institutional integration	Earlier humanitarian response	Informational technologies can deliver large resilience gains
Digital Climate Agriculture	Ethiopia	Adaptation – Agriculture	Ethiopian Agricultural Transformation Institute	Mobile advisory & predictive agronomy tools	Data translation & extension services	Reduced crop loss; efficient fertilizer use	Knowledge localization drives agricultural resilience
Flood Analytics	Senegal	Adaptation – Urban Resilience	World Bank	Hydrological simulation & flood modelling	Analytical capacity building	Evidence-based infrastructure planning	Analytical capacity can outperform infrastructure spending
Mini-Grid Innovation	Tanzania	Mitigation – Rural Electrification	Rural Energy Agency Tanzania	Modular solar mini-grid systems	Community-scale technical learning	Lower operating cost; improved reliability	Distributed systems accelerate

							learning-by-doing
Satellite Water Monitoring	Sahel	Adaptation – Water Resources	Gravity Recovery and Climate Experiment	Remote groundwater monitoring datasets	Open scientific data access	Basin-level water planning	Open data can substitute for expensive infrastructure
Green Hydrogen Partnership	Namibia	Mitigation – Emerging Fuels	NamPower	Electrolysis & renewable-hydrogen systems	Industrial co-development agreements	Workforce training; value-chain formation	Early participation prevents technological dependency
Solar Mini-Grids Expansion	Nigeria	Mitigation – Energy Access	Nigerian Electricity Regulatory Commission; Rural Electrification Agency Nigeria	Solar-battery decentralized grids	Regulation-enabled private deployment	Local technical workforce growth	Downstream assimilation strengthens domestic ecosystems
Flood Forecast Modernization	Nigeria	Adaptation – Disaster Risk	Nigerian Meteorological Agency	Hydrological modelling & satellite rainfall analytics	Institutional forecasting integration	Improved preparedness	Governance embedding determines technology effectiveness
Grid-Scale Solar Integration	Ghana	Mitigation – Power Systems	Volta River Authority; Navrongo Solar Plant	Grid stabilization & inverter integration	Engineering partnership + regulation reform	Renewable grid compatibility	Systems management is core to mitigation transfer
Climate-Smart Cocoa Systems	Ghana	Adaptation – Agriculture	Cocoa Research Institute of Ghana	Climate-resilient crops & agroforestry advisory	Research collaboration & farmer extension	Stable yields under climate stress	Adaptation succeeds when tied to economic value chains

are emerging to find ways of reducing the negative impacts. One example is the integration of renewable energy into systems that produce green hydrogen, as is being done in Namibia by international technology companies and NamPower. These negotiations focus on workforce development and job creation, unlike some of the previous energy negotiations. If the skills can be taught from the beginning, the involvement with new technology can help prevent reliance, as this change implies. In addition, there is a focus on digital and information technology in adaptation measures. The IGAD centre in the Horn of Africa provides early warning of droughts through satellites and forecasting. This system has proved to have improved the delivery of aid by bringing science together with government agencies. The reality is that many of the solutions for adapting to climate change do not require infrastructure, but instead tools, information and teamwork.

Nigeria enhanced flood risk management by strengthening the capability of the Nigerian Meteorological Agency (NiMet) for flood forecasting and collaborating with countries around the globe to take up impact-based warnings. The use of satellite rainfall data and hydrological modelling in disaster planning has improved anticipatory responses. The experience in Senegal is comparable: World Bank funding enabled Dakar planners to directly implement predictive flood models, from consultants to local engineers. The examples demonstrate that analytic tools that are internalized contribute to strengthening governance through the process of adaptation technology transfer.

Water monitoring is based on open scientific data in the Sahel. NASA's data is becoming a key tool in efforts to monitor groundwater and aquifer depletion by regional hydrologists. Satellite data is now understood through international cooperation and can be utilized for satellite planning. This is an example of how global data infrastructures can be used to help national adaptation at low cost, but at high impact. The examples of agricultural adaptation in Africa demonstrate how biotechnology, extension work, and digital technology can be successfully combined. The Ethiopian Agricultural Transformation Institute supported localized climate advisory systems in Ethiopia, and the Cocoa Research Institute in Ghana integrated climate-resilient cocoa research, agroforestry and mobile service. Some of the key patterns that emerged were that hardware, knowledge and institutional reform were all required for a project to be successful, that domestic capacity was of critical importance over initial infrastructure, and that co-development models involving local participation were advantageous. These findings underscore that effective climate technology transfer, focusing on capability, is essential for both mitigation and adaptation in Sub-Saharan Africa.

However, the expansion of and optimal combination of mechanisms, such as the financial mechanism, carbon market of the UNFCCC, will be necessary to organize the capital and financial flow to address climate change (Hepburn, 2007). The significance of carbon market role in addressing the needs for additional capital in shifting the private capital flows cannot be overemphasized. Intergovernmental policies in the Sub-Saharan African region can contribute to moving capital flow, made by private and public investors, into more climate adaptive replacement, so as to enhance the use of available funds, by distributing the risk across the private and public sectors (Capoor and Ambrosi, 2009). Apart from funds raised internally by Sub-Saharan countries, interregional organizations can be established to raise more funds for capital increase on adaptation to climate change. The problem with this proposal is that most Sub-Saharan countries are incapable of commitment to climate change issues, because there are various immediate challenges to attend to. Capacity building will require an enormous amount of expertise and financial commitment, which many Sub-Saharan countries are not prepared for (Sterk and Wittneben, 2006). These actions include: development, demonstration and cooperation on research, which can be best attained through bilateral and pluri-lateral initiatives; efforts to moderate trade barriers, and reduction in intellectual property issues, which are all best addressed through the recognized forums of the World Trade Organization (Brewer, 2008; Deardorff and Stern, 2009; Ekweozoh and Njoku, 2010). Partnerships between governments in Sub-Saharan Africa and entities like universities and NGOs, such as SEACAP, can lower costs by reducing the need for external consultants. Projects like CCCF have improved community understanding of climate change, enhancing food security and water access. EU-backed initiatives by WWF facilitate the purchase of Solar Home Systems through affordable financing options. Additionally, M-Akiba allows citizens to engage in capital markets at lower rates, promoting local infrastructure and stakeholder involvement. While these pilots in thirteen cities aim to improve independence and efficiency, they remain limited in access and depend on local partnerships. Emphasizing knowledge transfer is essential for farmers' adaptation and economic diversification in the region (Akomolafe, 2023; Akomolafe *et al*., 2024; Olawuyi, 2018).

Technology Paradox Africa and Barriers to Climate Technology Transfer

Sub-Saharan Africa faces a structural asymmetry in the global climate system, that is both historical and contemporary. As shown in the Table 3, developed nations account for high historical greenhouse gas emissions, having industrialized through fossil fuel–intensive growth pathways, over more than a century. In contrast, Sub-Saharan Africa has contributed very little to cumulative global emissions. This imbalance underscores a fundamental equity issue in climate governance: those least responsible for the problem are disproportionately exposed to its consequences.

Table 3: Imbalance produces a climate vulnerability–technology paradox and Policy Recommendation at Governance Level

Imbalance in technology paradox		
Factor	**Developed Nations**	**Sub-Saharan Africa**
Historical emissions	High	Very low
Adaptive infrastructure	Advanced	Limited
Access to climate technology	Extensive	Restricted
Climate vulnerability	Moderate	Severe

Policy Recommendation at Governance Level	
Governance Level	**Policy Recommendation**
International Level	Reform intellectual property rules for climate-critical technologies Establish global climate technology commons Link climate finance to local manufacturing development
National Level	Invest in technical and vocational education Support domestic innovation ecosystems Develop clear technology adoption and regulatory standards
Private Sector	Incentivize co-production and joint ventures rather than export-only sales models Provide risk-sharing guarantees to encourage climate technology investment

The disparity extends beyond emissions to adaptive infrastructure. Developed nations generally possess advanced infrastructure systems—resilient transport networks, climate-proofed buildings, early warning systems, insurance markets, and diversified energy grids—that buffer climate shocks. Sub-Saharan Africa, however, faces limited adaptive infrastructure capacity. In many countries, critical systems such as water supply, irrigation, coastal protection, and energy distribution remain underdeveloped or fragile, increasing exposure to climate-related disruptions such as droughts, floods, and extreme heat events.

Access to climate technology further deepens this structural gap. Developed economies benefit from extensive access to renewable energy systems, climate-smart agricultural technologies, digital monitoring tools, and advanced manufacturing capabilities. By contrast, access in Sub-Saharan Africa remains restricted due to financial constraints, intellectual property barriers, weak industrial bases, and limited technology transfer mechanisms. This restriction slows both mitigation efforts and adaptation planning, reinforcing dependence on imported solutions, rather than fostering domestic innovation ecosystems.

Moreover, the combination of low historical responsibility and severe climate vulnerability produces a profound paradox. While developed nations experience moderate levels of vulnerability, partly mitigated by technological and institutional capacity, Sub-Saharan Africa faces severe climate risks across food systems, water security, public health, and urban settlements. Yet, the region's limited technological capacity constrains its ability to respond effectively. This creates what can be termed as climate vulnerability–technology paradox: exposure is high where technological preparedness is at its lowest.

Intellectual property (IP) constraints constitute a major structural barrier to the diffusion of low-carbon technologies in Sub-Saharan Africa. Many climate-critical technologies, such as advanced renewable energy systems; energy storage solutions; and climate-resilient agricultural inputs, are privately owned and protected by patents or restrictive licensing agreements. As a result, access often depends on negotiated licensing arrangements, whose costs can exceed national adaptation or innovation budgets. This limits, not only immediate deployment, but also the ability of local firms to engage in learning, adaptation, and incremental innovation, thereby slowing long-term technological capability formation.

Financing structures further reinforce this constraint. Much of international climate finance is project-based and oriented toward short-term mitigation outcomes, rather than sustained technological capability building. Funding mechanisms frequently prioritize measurable emissions reductions or infrastructure delivery within fixed timelines, while underinvesting in research and development, skills formation, and domestic manufacturing capacity. Consequently, countries may receive installed technologies without acquiring the technical knowledge, production capacity, or institutional foundations necessary for sustained technological independence.

Institutional capacity represents another critical bottleneck. Effective technology transfer requires more than physical infrastructure; it depends on skilled labour, technical training systems, maintenance networks, and coherent regulatory frameworks. Without qualified engineers, technicians, and policy institutions capable of standard-setting and oversight, imported technologies may operate below optimal efficiency or fall into disrepair. Weak institutional environments also discourage private investment and reduce the likelihood of long-term technology integration into national development strategies.

Finally, market structure shapes investment incentives in ways that disadvantage African economies. Many international investors perceive African markets as high-risk, due to currency volatility, political uncertainty, limited credit markets, and small-scale fragmented demand. This perception reduces capital flows for climate technology deployment and local production. As a result, technology providers often favor export-based sales models rather than co-production or joint ventures, limiting domestic value addition and reinforcing dependence on external suppliers.

Addressing this paradox requires reframing climate action beyond emissions reduction targets toward capability-building and equitable technology diffusion. Bridging the gap demands accelerated climate technology transfer, institutional strengthening, and regional manufacturing development to enhance absorptive capacity. Without correcting the imbalance between vulnerability and technological access, global climate strategies risk entrenching inequality and undermining both adaptation resilience in Sub-Saharan Africa and collective progress toward global decarbonization.

Conclusions

Climate change adaptation in Sub-Saharan Africa cannot be achieved through finance alone. The decisive factor is technological capability. Without rapid climate technology transfer, both global mitigation targets and regional development goals will fail.

Technology transfer should therefore be reframed from a diplomatic commitment into a central operational mechanism of climate action. A cooperative innovation model—combining shared intellectual property, local production, and institutional capacity building—offers the most realistic pathway toward climate resilience and global decarbonization.

Climate change technology transfer is necessary for building adaptive capacity. Adaptive capacity refers to the ability of social collectives to adapt in the face of short-term, long-term, and future climate change risks (Bahadur *et al*., 2015: 13). This means that a social system has the capacity to adapt, although their physical environment has changed, predict disturbances and prepare for them in advance.

The previously reviewed initiatives and the challenges they responded to have strengthened adaptive capacities to climate change in the agricultural sector. A selection of examples of climate change adaption in sub-Saharan Africa will demonstrate the positive impact of climate change technology transfer on adaptation.

Climate technology transfer results in immediate reduction in greenhouse gas emissions, promotes the changing of industries and societal behavior towards a more sustainable and green direction, and promotes a "'voluntary standardization' of greener process and production methods, which could eventually facilitate stricter environmental regulations". Several researches have therefore confirmed that the transfer of innovative technology to developing countries has a higher return than innovation, since domestic industries are "far from the technology frontier". Therefore, technology transfer can occur within the private marketplace among firms, between headquarters and subsidiaries, joint ventures, licensing agreements, or foreign direct investments, and of course unsanctioned transfers through imitation.

There are, however, great barriers to technology transfer. Such barriers can be found on the supplier's side as well as on the demand side. On the supplier's side, some of the barriers that can discourage firms from industrialized countries to making their technologies available for developing countries are trade and investment policy barriers, high transaction costs, and the fear of losing control over proprietary technologies. On the demand side, low financial means, as well as human and physical capital, and domestic laws that impede transfers, are great barriers to overcome. Furthermore, “intellectual property rights” is “the most contentious source of conflict on clean technology”. Developed countries have been unwilling to find ways to provide a waiver to development of technologies that are vital to .dealing with the climate crisis”.

Overall, the research landscape in Sub-Saharan Africa is strongly interdisciplinary and focused on environmental aspects, primarily examining climate technology transfer through governance, sustainability, and policy perspectives. There is a notable lack of emphasis on advanced materials or engineering innovations, reflecting a broader trend where capability formation and institutional embedding are viewed as the key challenges for climate mitigation and adaptation in the region.

Recommendation

The review proposes a transition from transactional transfer toward co-development partnerships, regional manufacturing ecosystems and climate technology commons. While international climate agreements emphasize technology transfer, alongside finance, actual implementation has fallen short, often focusing more on financial aspects than on technology capability. This review posits that technology transfer is essential for effective global mitigation and regional adaptation. It analyzes technological needs in sectors like energy and agriculture, and identifies various barriers to current market diffusion models. Without accelerated, equitable and capability-building technology transfer, global decarbonization pathways, consistent with 1.5–2°C targets, are unlikely to be achieved. Thus, the author advocates for a shift from transactional technology transfers to collaborative partnerships and regional manufacturing, arguing that without equitable and robust technology transfer, achieving the global decarbonization goals of 1.5–2°C will be improbable.

Finally, despite decades of global efforts, like the UNFCCC in 1991, to transfer climate technology, Sub-Saharan Africa still has limited access to technology for climate mitigation and resilience. Many programs focus on transfers from developed nations, but this alone isn't working. Africa could therefore close this gap by focusing on four things: boosting local awareness to get community support for technology; updating laws to help absorb and adapt relevant and required technology; encouraging local clean technology businesses to foster innovation; and working with countries and groups like Canada, China, the EU, India, Japan, the U.S. and the G20 on long-term technology plans. This shifts the focus to building skills, which improves resilience and helps mitigate climate change.

References

Akomolafe, B. (2023). Deep decarbonization pathways, strategies, governance, actors and roadblocks in cities: Climate change mitigation perspectives from selected Sub-Saharan African Cities.

Akomolafe, B., Clarke, A., & Ayambire, R. (2024). Climate change mitigation perspectives from Sub-Saharan Africa: The technical pathways to deep decarbonization at the city level. *Atmosphere, 15*(10), 1190.

Akpodiogaga-a, P., & Odjugo, O. (2010). General overview of climate change impacts in Nigeria. *Journal of Human Ecology, 29*(1), 47-55.

Appiah, M., Baffour Gyau, E., Worku, G. B., & Asongu, S. A. (2026). Shaping Energy Transitions: Sectoral Demand, Climate Risk Exposure, and Renewable Pathways in Sub-Saharan Africa. *Business Strategy and the Environment*.

Augustyn, J. (2017). *Emerging Science and Technology Trends: 2017-2047*: FutureScout Providence United States.

Aurélien, A. B. H. (2025). Vulnerability to climate change in sub-Saharan Africa countries. Does international trade matter? *Heliyon, 11*(4).

Ayanlade, A., Nyasimi, M., & Boyd, E. (2026). Extreme Climate Events, Loss and Damage in Africa: Resilience and Adaptation.

Ayanlade, A., Oluwaranti, A., Ayanlade, O. S., Borderon, M., Sterly, H., Sakdapolrak, P. (2022). Extreme climate events in sub-Saharan Africa: A call for improving agricultural technology transfer to enhance adaptive capacity. *Climate Services, 27*, 100311.

Ayanlade, A., SMUCKER, T., Nyasimi, M., Sterly, H., Weldemariam, L. F., & Simpson, N. P. (2023). Complex climate change risk and emerging directions for vulnerability research in Africa. *Climate Risk Management*, 100497.

Banuri, T., Weyant, J., Akumu, G., Najam, A., Rosa, L. P., Rayner, S. (2001). Setting the stage: Climate change and sustainable development. *Climate change*, 73-114.

Barrett, S., & Stavins, R. (2003). Increasing participation and compliance in international climate change agreements. *International Environmental Agreements, 3*(4), 349-376.

Biswas, A. K. (2013). *The Ozone Layer: Proceedings of the Meeting of Experts Designated by Governments, Intergovernmental and Nongovernmental Organizations on the Ozone Layer, Organized by the United Nations Environment Programme in Washington, DC, 1-9 March 1977* (Vol. 4): Elsevier.

Bogner, J., Pipatti, R., Hashimoto, S., Diaz, C., Mareckova, K., Diaz, L. (2008). Mitigation of global greenhouse gas emissions from waste: conclusions and strategies from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report. Working Group III (Mitigation). *Waste Management & Research, 26*(1), 11-32.

Bozeman, B. (2000). Technology transfer and public policy: a review of research and theory. *Research policy, 29*(4-5), 627-655.

Brewer, T. L. (2008). Climate change technology transfer: a new paradigm and policy agenda. *Climate policy, 8*(5), 516-526.

Burrell, R., Jee, S. J., Hötte, K., & Ring, C. (2023). Intellectual property rights, climate technology transfer and innovation in developing countries. *INET Oxford Working Paper*.

Capoor, K., & Ambrosi, P. (2009). State and trends of the carbon market 2009.

Chhetri, N., Chaudhary, P., Tiwari, P. R., & Yadaw, R. B. (2012). Institutional and technological innovation: Understanding agricultural adaptation to climate change in Nepal. *Applied Geography, 33*, 142-150.

Coenen, L., Benneworth, P., & Truffer, B. (2012). Toward a spatial perspective on sustainability transitions. *Research policy, 41*(6), 968-979.

Council, N. R. (2004). *Implementing climate and global change research: A review of the final US Climate Change Science Program strategic plan*: National Academies Press.

Dale, V. H. (1997). The relationship between land-use change and climate change. *Ecological applications, 7*(3), 753-769.

De Coninck, H., Fischer, C., Newell, R. G., & Ueno, T. (2008). International technology-oriented agreements to address climate change. *Energy Policy, 36*(1), 335-356.

Deardorff, A. V., & Stern, R. M. (2009). Multilateral trade negotiations and preferential trading arrangements. *Globalization and lnternational Trade Policies, Singapore: World Scientific Publishing Co*, 153-210.

Ekweozoh, P. C., & Njoku, G. N. (2010). Technology Transfer Issues in Climate Change: Challenges and Prospects for Africa. *SCIENCE WITH AFRICA*, 219.

Goeppert, A., Czaun, M., Prakash, G. S., & Olah, G. A. (2012). Air as the renewable carbon source of the future: an overview of CO 2 capture from the atmosphere. *Energy & Environmental Science, 5*(7), 7833-7853.

Grubb, M. (2004). Technology Innovation and Climate Change Policy: an overview of issues and options. *Keio economic studies*, *41*(2), 103.

Hekkert, M. P., Suurs, R. A., Negro, S. O., Kuhlmann, S., & Smits, R. E. (2007). Functions of innovation systems: A new approach for analysing technological change. *Technological forecasting and social change*, *74*(4), 413-432.

Hepburn, C. (2007). Carbon trading: a review of the Kyoto mechanisms. *Annu. Rev. Environ. Resour.*, *32*, 375-393.

Hoffmann, M. J. (2011). *Climate governance at the crossroads: experimenting with a global response after Kyoto*: Oxford University Press.

Huisingh, D., Zhang, Z., Moore, J. C., Qiao, Q., & Li, Q. (2015). Recent advances in carbon emissions reduction: policies, technologies, monitoring, assessment and modeling. *Journal of Cleaner Production*, *103*, 1-12.

IPCC. (2014). *Climate Change 2014–Impacts, Adaptation and Vulnerability: Regional Aspects*: Cambridge University Press.

Karakosta, C., Doukas, H., & Psarras, J. (2010). Technology transfer through climate change: Setting a sustainable energy pattern. *Renewable and Sustainable Energy Reviews*, *14*(6), 1546-1557.

Low, P. S. (2006). *Climate change and Africa*: Cambridge University Press.

Lybbert, T. J., & Sumner, D. A. (2012). Agricultural technologies for climate change in developing countries: Policy options for innovation and technology diffusion. *Food Policy*, *37*(1), 114-123.

Maddison, D. (2007). *The perception of and adaptation to climate change in Africa*: The World Bank.

McCarthy, J. J., Canziani, O. F., Leary, N. A., Dokken, D. J., & White, K. S. (2001). *Climate change 2001: impacts, adaptation, and vulnerability: contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change* (Vol. 2): Cambridge University Press.

McLaren, D., & Agyeman, J. (2015). *Sharing cities: a case for truly smart and sustainable cities*: Mit Press.

Naphade, M., Banavar, G., Harrison, C., Paraszczak, J., & Morris, R. (2011). Smarter cities and their innovation challenges. *Computer*, *44*(6), 32-39.

Olawuyi, D. S. (2018). From technology transfer to technology absorption: addressing climate technology gaps in Africa. *Journal of Energy & Natural Resources Law*, *36*(1), 61-84.

Peterson, D. L., Millar, C. I., Joyce, L. A., Furniss, M. J., Halofsky, J. E., Neilson, R. P. (2011). Responding to climate change in national forests: a guidebook for developing adaptation options. *Gen. Tech. Rep. PNW-GTR-855. Portland, OR: US Department of Agriculture, Forest Service, Pacific Northwest Research Station. 109 p.*, *855*.

Pörtner, H.-O., Roberts, D. C., Adams, H., Adler, C., Aldunce, P., Ali, E. (2022). *Climate change 2022: Impacts, adaptation and vulnerability*: IPCC Geneva, Switzerland:.

Ravindranath, N. H., & Sathaye, J. A. (2002). Climate change and developing countries *Climate Change and Developing Countries* (pp. 247-265): Springer.

Roaf, S., Roaf, S., Crichton, D., & Nicol, F. (2009). *Adapting buildings and cities for climate change: a 21st century survival guide*: Routledge.

Saggi, K., Maskus, K. E., & Hoekman, B. (2004). *Transfer of technology to developing countries: Unilateral and multilateral policy options*: The World Bank.

Smit, B., & Pilifosova, O. (2003). Adaptation to climate change in the context of sustainable development and equity. *Sustainable Development*, *8*(9), 9.

Smith, P., & Olesen, J. E. (2010). Synergies between the mitigation of, and adaptation to, climate change in agriculture. *The Journal of Agricultural Science*, *148*(5), 543-552.

Smith, Z. A., & Taylor, K. D. (2008). *Renewable and alternative energy resources: a reference handbook*: ABC-CLIO.

Sterk, W., & Wittneben, B. (2006). Enhancing the clean development mechanism through sectoral approaches: definitions, applications and ways forward. *International Environmental Agreements: Politics, Law and Economics, 6*(3), 271-287.

Stern, S., Porter, M. E., & Furman, J. L. (2000). *The determinants of national innovative capacity*: National bureau of economic research.

Stuart, T. E. (2000). Interorganizational alliances and the performance of firms: a study of growth and innovation rates in a high-technology industry. *Strategic management journal, 21*(8), 791-811.

Sunding, D., & Zilberman, D. (2001). The agricultural innovation process: research and technology adoption in a changing agricultural sector. *Handbook of agricultural economics, 1*, 207-261.

Trisos, C. H., Adelekan, I. O., Totin, E., Ayanlade, A., Efitre, J., Gemeda, A. (2022). Africa. In: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. .

Turay, B., & Ihinegbu, C. (2025). Assessment of loss and damage of extreme rainfall events *Climate Change and Rainfall Extremes in Africa* (pp. 293-307): Elsevier.

Wilcox, C., & Tunnicliffe, M. (2002). Prospects For Uk Fuel Cells Component Suppliers. *DTI/Pub URN, 2*, 1438.