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Research article

Global assessment of technological innovation for climate change adaptation and mitigation in developing world

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ABSTRACT

Concerns about mitigating and adapting to climate change resulted in renewing the incentive for agricultural research investments and developing further innovation priorities around the world particularly in developing countries. In the near future, development of new agricultural measures and proper diffusion of technologies will greatly influence the ability of farmers in adaptation and mitigation to climate change. Using bibliometric approaches through output of academic journal publications and patent-based data, we assess the impact of research and development (R&D) for new and existing technologies within the context of climate change mitigation and adaptation. We show that many developing countries invest limited resources for R&D in relevant technologies that have great potential for mitigation and adaption in agricultural production. We also discuss constraints including weak infrastructure, limited research capacity, lack of credit facilities and technology transfer that may hinder the application of innovation in tackling the challenges of climate change. A range of policy measures is also suggested to overcome identified constraints and to ensure that potentials of innovation for climate change mitigation and adaptation are realized.

1. Introduction

Climate change has obvious and direct effects on agricultural production. Intergovernmental Panel on Climate Change (IPCC) in its fourth assessment report cited that agricultural production in many African countries would considerably be influenced by climate change (Mbilinyi et al., 2013).

Accordingly, concerns about the possible impacts of climatic variability on agriculture have considerably changed research interests over the last decade (Aydinalp and Cresser, 2008). Concerns about mitigating and adapting to climate change resulted in renewing the incentive for agricultural research investments and developing further innovation priorities. In the near future, development of new agricultural measures and proper diffusion of technologies will greatly form the ability of farmers in adaptation and mitigation of climate change. This adaptation and mitigation capacity is more obvious in developing countries with low level of agricultural productivity; in which poverty, vulnerability and food insecurity is large; and the direct impacts of climate change are going to be particularly severe (Lybbert and Sumner, 2012). The adoption of improved technology based on best agricultural management practices and technological innovation will increase the crop production and reduce GHG emissions. For example, Lal (2011) emphasized the need to respond to climate change through carbon sequestration based on the existing and new technologies. New technological innovations that suit or adapt to warming climate present an opportunity to build resilience to the impact of climate change in the future, especially due to the substantial challenges that climate variability imposes on agricultural production in developing countries. Indeed, while most agricultural technologies have direct linkages with climate change, there are emerging technologies that are relevant to agriculture practices in developing countries with great potential to offer a substantial mitigation and adaptation benefits (Khan and Hanjra, 2009). Nevertheless, constructing the essential agricultural technologies and supplying them to developing countries in order to be able to adjust their

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agricultural systems to the changing climate will further need institutional and policy innovations. In this regard, policies and institutions are crucial at various scales. Obstacles to creating, diffusion and utilizing related technologies can show up at multiple levels – from the starting point and innovation steps to the technologies transfer and the accessibility of agricultural innovations by small-scale farmers in developing world.

In other words, innovation is not just about new outcomes and processes introduced to the world (absolute innovation), but also includes those that are new to a specific company or country (diffusion). Further to absolute innovation, diffusion of innovative technologies throughout countries is considered as an important part in tackling the challenges of climate change mitigation. The dissemination of available technologies might be sped up through providing practical support policies which benefit from normal capital substitution. The position of emerging markets may be suitable so that the adverse impacts of existing technologies that hinder the diffusion of innovative alternatives would be avoided. Available infrastructure may not support the innovations, but deployment of existing technologies in emerging markets would need utilizing suitable financial resources and dealing with other general barriers to adoption of new technology. In order to be able to transfer into a low-carbon economy, there should be the possibility of development of new technologies and implementation of available measures on a larger scale. To achieve this, new technologies as well as new solutions for managing economic practices will be required. Such substantial changes will ask for developing a policy and institutional framework that supports innovation and also diffusion of available technologies. If this needs to be fulfilled, first, it is important to create the right impetus and structures to enhance large-scale, global change.

Bosetti et al. (2009) emphasized that any cost-efficient policy framework to tackle climate change should accelerate useful research and development (R&D), innovation and diffusion of technologies developed for reducing GHG emissions. Different approaches have been developed in different disciplines to protect human environments from the adverse extensive effects of climate change and natural hazards such as a modeling management tool for agro-watershed management. Likewise, nowadays, there is a wide variety of innovations and new advanced technologies utilized in different sectors to reduce GHG emissions. For example, Papageorgiou et al. (2009) evaluated the emission impacts of three technologies including Mass Burn Incineration with energy recovery, Mechanical Biological Treatment via bio-drying and Mechanical Heat Treatment that could be used for the treatment of Municipal Solid Waste in order to recover energy from it. Among all the existing innovative techniques in different fields and sectors, the need to sequester carbon in agricultural practices is one of fundamental ways to respond positively to the challenges of climate change in developing countries while changing lifestyle through the adoption of integrated soil management practices (Lal, 2011). Moreover, in the context of climate change adaptation and mitigation, biotechnology stands out as a promising set of tools that can positively be utilized for decreasing vulnerability of human and natural systems to climate change impacts by enhancing crops adaptability, food security, and productivity as well as contribution to the greenhouse gas reductions (Godliving and Mtui, 2011; Adenle, 2011). Information and communication technologies (ICTs) is also expected to be an effective tool in communication of technologies related to the climate change mitigation that are definitely with low carbon effects in order to mitigate GHG emissions. Agriculture has the potential to adversely affect the environment through land conversion from wetlands and forests. Yet, GHG emissions from land use change are substantial in developing countries, and so are emissions from energy systems, industrial motors, transportation, and manufacturing, among others. Considering the existing worldwide reality of climate change and its harsh impact, the trend of GHG emissions in developing countries needs to be inversed, and ICTs have been demonstrated to provide such advantages (Niyibizi and Komakech, 2013). Moreover, the traditional energy system is another main contributor to GHG emissions and consequently, to climate change while renewable energy produce no or assist in GHG emission reductions. Further to this advantage, renewable energy technologies (RETs) create several socio-economic benefits in many rural areas and may perform as a safe option for adaptation to climate change. Renewable energies increase agricultural productivity by producing energy for postharvest processing and irrigation pumping. These productivity enhancements can decrease the needs for converting forests to croplands while necessarily keep or raise productivity.

This paper emphasizes the possible role of innovative agricultural measures and technologies in climate change adaptation and mitigation and aims to develop policy and institutional changes that are needed to promote the innovation and diffusion of these practices and technologies in developing countries. We describe some technologies that seem particularly promising in mitigating or adapting to climate change including integrated soil management practices, biotechnology, information and communication, and renewable energy technologies and use these as a basic for identifying the policies and institutions required for supporting the development and diffusion of existing technologies in order to provide some guidelines for technological advances in the future.

2. Methodology

In this paper we use triangulation, academic journal publications and patent-based data relating to these four technologies to indicate the degree to which capacity exists in developing countries. Bibliometric approaches have widely been employed to assess the impact of R&D and public policies in the field of innovation studies especially for both existing and emerging technologies (Johnstone and Hascic, 2013; Meyer and Persson, 1998). Accordingly, this paper begins with discussion on several technologies that may be useful to climate change adaptation and mitigation in developing countries. Keeping in mind these technologies, Section 3 explores the main constraints of technology development, transfer and use that create a platform for our discussion in the section of policy implementations that could facilitate climate change mitigation and adaptation in developing world. The final section provides policy recommendations to increase R&D investment for agriculture technologies toward tackling climate change.

3. Agricultural technologies for climate change mitigation and adaptation

3.1. Integrated soil management practices (ISMP)

The use of ISMP strategy will require practices such as zero to conservation tillage, minimal application of fertilizer, nutrient management, crop residue incorporation, manure, mulch, compost, cover crops and appropriate supplementary irrigation (Follett, 2001; Lal, 2008; Machado and Silva, 2001). The ISMP interventions require integrated utilization of mineral and organic fertilizers and comprise their wise manipulation to gain sustainable as well as productive agricultural systems. The main claim of the ISMP paradigm is that no single determinant of sustainable soil management can meet solely the necessities of sustainable soil management (Mugwe et al., 2009). There is considerable evidence demonstrating the important contributions of ISMP in reducing carbon emissions in agricultural practices. The adoption of ISMP through conservation and zero tillage can reduce energy consumption and increase carbon storage in soils. For example, zero-tillage has been proved to be widely adopted by different groups of farmers in Asia, Latin America, North and South America (Erenstein and Laxmi, 2008; Machado and Silva, 2001; Triplett and Warren, 2008). However, the adoption of conservation agriculture including zero tillage in Africa has been widely criticized as access to inputs, trainings and labor constraints has been realized as a big challenge (Giller et al., 2009). Furthermore, the important role of ISMP in sustainable use of lands has been evidenced by Yitbarek et al. (2013) who evaluated the land use-induced changes in soil properties of western Ethiopia considering three adjacent land use types, namely forest, grazing and cultivated lands. They found that the influence on most parameters was negative on the soils of the cultivated land, indicating the need for employing integrated soil fertility management in sustainable manner to optimize and maintain the favorable soil physicochemical properties.

The adoption of ISMP via increased soil organic carbon (SOC) can lead to the removal of atmospheric CO_2 (Follett, 2001; Lal, 2011). The SOC is one of the most important terrestrial pools to store and enhance carbon stock through carbon sequestration (CS). The CS is fundamental to soil management for sustainable agricultural practices in developing countries (Lal, 2008). There is a significant potential for the application of ISMP including composting technologies in controlling CS and GHG fluxes from land cultivation through the maintenance of SOC. A study analyzed the effect of different integrated nutrient management practices on SOC and its suitability for rice-wheat production in India (Nayak et al., 2012). The authors showed that SOC is important in influencing crop yields as well as maintaining better soil quality. They conclude that SOC can play an important role in maintaining soil health and mitigating GHG emissions.

The need for technology development to enhance sustainable management of soil and water resources as part of ISMP is also critical to adaptation strategy as they can promote carbon sequestration and improve agro-ecosystem function (Lal, 2011; Smith et al., 2007). The selection of new technologies that can enhance soil structure and water conservation is an essential tool for soil restoration from biological and physical degradation. The introduction of integrated water management practices such as drip irrigation, changing crop patterns and selection of new drought tolerant crops are important for climate change adaptation. For example, micro-irrigation (sub-surface drip irrigation) is an important modern innovation that can enhance water conservation and water use-efficiency (Aujla et al., 2008; Molden, 2007). Crop-shrub intercrops, for examples, Guiera senegalensis and Piliostigma reticulatum may enhance nutrient cycling and water use that serves as a vital component in semi-arid ecosystems (Kizito et al., 2007). The adoption of land-saving technology can and does play an important role in adaptation and mitigation of climate change. For example, a study by Martha et al. (2012) showed that the growth of the Brazilian beef production between 1950 and 2006 period resulted to a land-saving effect of 525 million hectares. They argued that an additional pasture area of 25% would be needed to meet current levels of beef production in Brazil without land-saving effect. The authors concluded that incorporating more land into productive process could be significant in intensifying pastoral land areas as well as avoiding loss of vegetation. As another example, Lobell et al. (2013) analyzed adaptation investments, yield growth rates, land conversion rates and land use emissions in Sub-Saharan Africa (SSA) and Latin America. The authors showed that adapting agriculture to climate change, resulted in 61 Mha less conversion of cropland and have mitigation co-benefits, estimated at 0.35 $GtCO_2e\ yr^{-1}$ while spending \$15 per ton CO_2e of avoided emissions in adaptation. They concluded that investment in climate adaptation could be a good opportunity for climate mitigation.

To understand the capacities that exist and how ISMP has been applied around the world, the data on the number of publications related to ISMP were obtained. Fig. 1 shows the regions and countries in which academic research relating to ISMP is being undertaken. The search was obtained from the Thomson Web of Science database using "Integrated Soil Management" as the keyword search between 1980 and 2014 (up till March). The map shows that the European and North American regions are responsible for 34% and 26% of academic publications activity concerning ISMP, respectively, both accounting for 60% of the total 6697 publications. Of this 60%, the US is the largest contributor, accounting for 21% (1412) of the world's publication, followed by top five European countries (Germany, England, Netherlands, France and Italy) (Fig. 1) in integrated soil management. Asia accounts for 19%, with India, China, Japan, Philippines and Pakistan whereas Africa accounts for 8%, with Kenya, South Africa, Nigeria, Ethiopia and Zimbabwe leading region respectively. Oceania accounts for 6%, with Australia and New Zealand and South America accounts for 5%, with Brazil, Mexico, Argentina, Colombia, and Costa Rica leading the region, respectively. Finally, the Middle East region accounts for 2%, the smallest of the total publication share, with Israel and Iran leading the region, respectively.

3.2. Biotechnology

The application of modern biotechnology can play an important role in climate change adaptation and mitigation (James, 2013). These are opportunities unique to agriculture. For example, the application of modern biotechnology such as bioinformatics and genomic could produce a greater array of nitrogen-fixing crops (Bull et al., 2000), thereby reducing the need for chemical fertilizers. The development of new biotech crops of different varieties that can withstand biotic and abiotic stress due to climate change also has an important role in combating poverty and support food security in developing countries. This has often led to debates about the use of modern biotechnology, particularly GMOs, to create crops with the ability to adapt to possible changes such as insect pests, pathogens, weeds, water quantity and soil erosion.

A few salt-tolerant cultivars of some potential crops have been produced by the plant breeders through conventional breeding during the last century (Ashraf and Akram, 2009). Conventional biotechnology such as tissue culture has been useful in creating drought tolerant crops such as millet, sunflower and sorghum (Apse and Blumwald, 2002) and has been successful in solving some pest problems in many developing countries (Gressel et al., 2004). However, this approach seems ineffective due to a number of reasons. Conventional breeding; 1) can take many years of preparation to create pure lines of hybrid; 2) hybridization of the two pure lines is sometimes done manually; 3) inferior yields and vigor represent a significant constraint among the hybrids. As a result, the development of new crop varieties to address agronomic problems has consistently failed. For example, several attempts to improve nitrogen use efficiency (NUE) in crops through conventional breeding strategies have experienced a plateau (McAllister et al., 2012). Also, the inability of conventional breeding to develop a new variety against pest and diseases such as striga and stem borer has partly contributed to poor yields and low crop productivity in SSA (Gressel et al., 2004). This challenge will be magnified by climate change in view of more extreme weather predicted and the requirement for new varieties by 2050 that are more resilient to abiotic stress (Battisti and Naylor, 2009; Lobell et al., 2013). Hence the need for advanced technology to tackle this challenge is required.

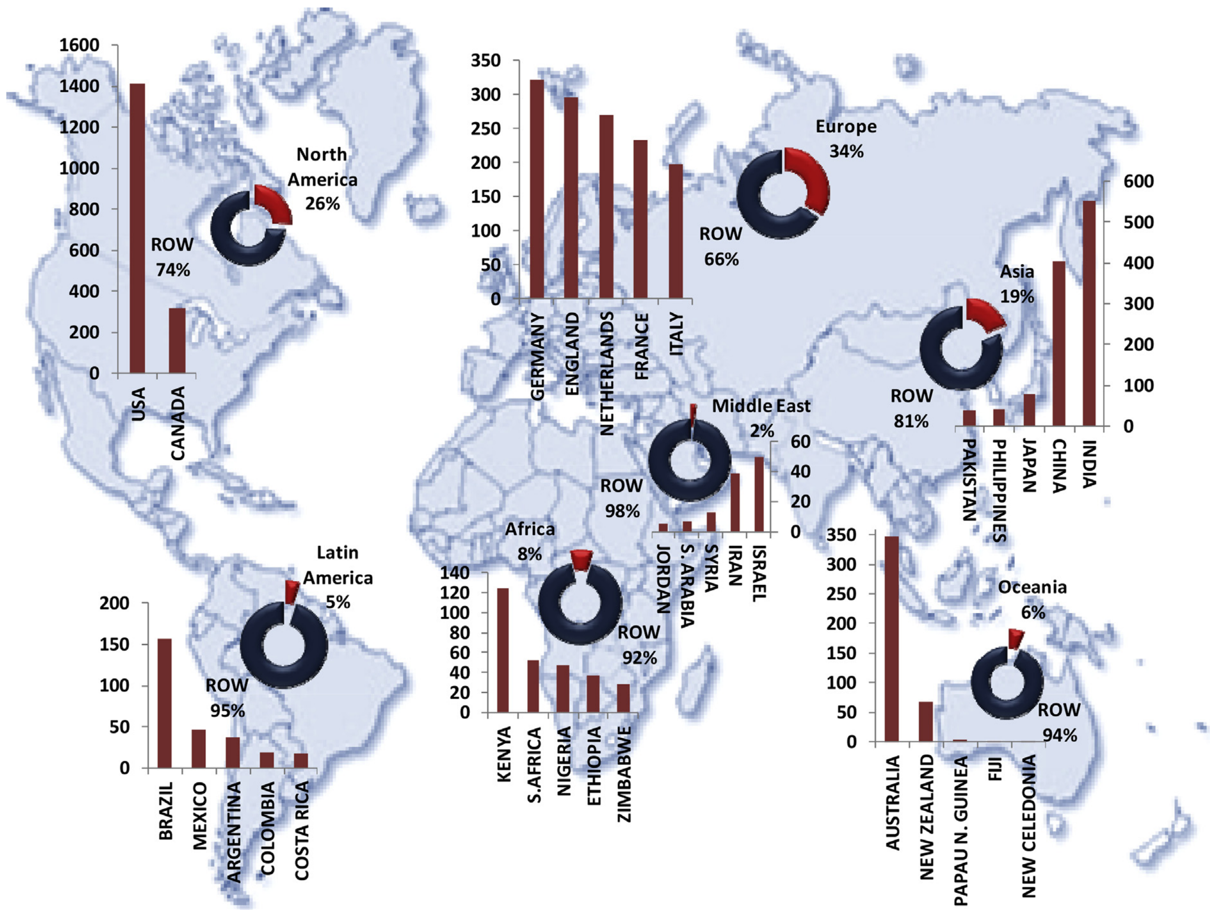

Fig. 1. A map indicating the regional distribution of academic publication activity relating to integrated soil management practices (ISMP) between 1980 and 2014 based on Thomson Web of Science database sear.

Unlike conventional breeding, advanced biotechnology, namely genetic modification (GM) technology provides opportunity to transfer gene from organism to another or between species that cannot cross naturally (Adenle et al., 2012). This innovation broadens the potential sources of characteristics for improved varieties of crops that can withstand pests, diseases and environmental stresses. In particular, GM technology offers a directed approach to target specific traits for adaptation and mitigation to climate change. Crops have been genetically modified to enhance their NUE by effectively limiting the input of N fertilizers in crop production (McAllister et al., 2012; Strange et al., 2008). For example, analysis of life-cycle assessment of GM canola targeted for nitrogen use efficiency showed reduced impact of freshwater ecotoxicity, eutrophication and acidification (Strange et al., 2008). There is some evidence that GM technology has made a significant impact in contributing to the reduction of GHG emissions both in developed and developing countries. For example, the adoption of GM crops have reduced GHG emissions by lowering the amount of fertilizer and pesticide applications and simultaneously increasing the yields mostly in developing countries in the past 17 years (Brookes and Barfoot, 2010, 2012; James, 2012). In fact, James (2013) claims that resource-poor farmers from developing countries benefit most in terms of GM adoption. He argues that adoption of GM crops is five times larger in developing countries (8.7 million hectares) than industrialized ones (1.6 million hectares), and that GM crops deliver substantial and sustainable socio-economic and environmental benefits. Brookes and Barfoot (2012) point that CO_2 emission was reduced by 19 billion kg in 2010 -the equivalent of removing about 9 million cars off the road and conserving biodiversity, thereby saving 91 million hectares of land in the world. Moreover, a recent analysis of environmental benefits of bt cotton production from 1990 to 2010 in six provinces in China shows decreased abundance of aphid pests associated with widespread adoption of bt cotton and reduced levels of chemical spray (e.g., insecticide) (Lui et al., 2012). This advantage can be understood as an energy efficiency technology, saving natural gas and reducing fuel consumption through agricultural science.

A complimentary of both techniques (conventional and transgenic approach) has been employed to develop drought tolerant maize (currently undergoing confined field trials) in a new public-private partnership called *Water Efficient Maize for Africa* (WEMA) project (WEMA, 2011). A similar approach has been employed to study the performance of improved crops under environmentally stressed conditions (e.g., drought tolerance) through indirect manipulation of quantitative trait loci (QTLs) (Collins et al., 2008). The complementary approach applied in developing different crop traits is expected to play an important role in climate change mitigation and adaptation in developing countries in the future.

GM technology is one of most powerful modern biotechnology tools with great potential to contribute to climate change mitigation and adaptation (James, 2013). Here, we analyze current literature and report on global adoption of GM crops. Fig. 2 shows a diagram representing the technology ownership and biotechnology R&D of current GM crops. Region and countries are divided into three groups.

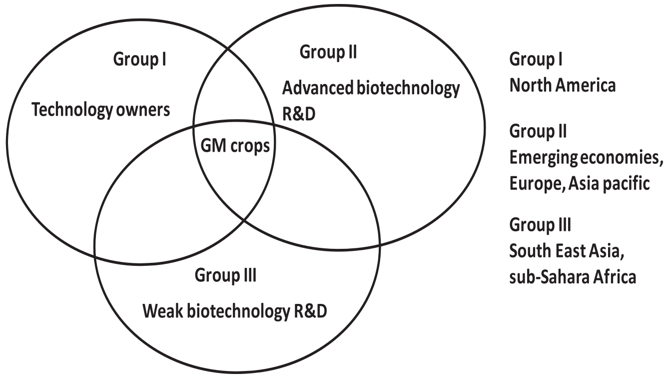

Fig. 2. Assessment of biotechnology R&D in the major regions and countries around the world.

Group I includes countries such as the US that has the largest GM crops R&D and GM crop is owned by the country largest private sector namely Monsanto. This company owns 90% of GM seeds and their licenses around the world. The highest percentage of the adoption of GM crops also comes from the US (Fig. 3). Group II is made up of emerging economies such as China, Brazil, India, Argentina and South Africa with relatively advanced biotechnology R&D represent almost 46% total adoption of GM crops in 2012 and these countries have emerged among top 10 of GM producing countries over the past decade. The growth of GM crops in these countries over the past ten years lies in their ability to provide necessary scientific capacity and expertise to regulate and release GM crops that are lacking in many developing countries. The Europe and Asia Pacific such as Japan have advanced biotechnology R&D, but their opposition and strong precautionary approach to GMOs have resulted in little or no adoption of this technology in these regions and many developing countries including countries in SSA (Adenle, 2014; Adenle et al., 2014). Group III is composed of countries in South East Asia and SSA (apart from South Africa) with weak biotechnology R&D and the majority of countries in these regions have taken the EU strong precautionary stance, resulting to slow adoption of GM crops. The lack of scientific capacity and poorly equipped laboratories particularly in SSA may present a major barrier to the development, regulation and adoption of GM crops in the future, hence limiting the opportunities to make better use of this new innovation to tackle climate change.

3.3. Information and communication technologies (ICTs)

Access to information can create awareness about adaptation

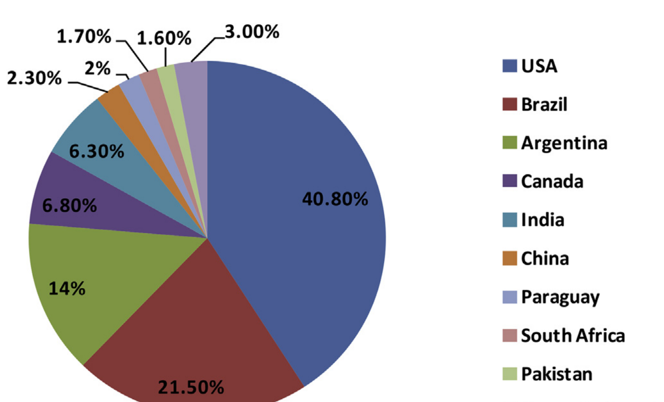

Fig. 3. Top producers of GM crops in the world, 2012
Source: Adapted from James, 2013.

and mitigation to climate change. The role and potential of ICTs as an innovative approach to respond to climate change challenges are being increasingly recognized by the international communities. For example, the importance of ICTs in achieving sustainable development goals, particularly with regards to climate change adaptation and mitigation was emphasized in Rio+ 20 documents, Brazil, June 2012 (UNCSD, 2012). Emphasis is being placed on the contribution of ICTs within the context of e-resilience frameworks that can strengthen and increase the ability of developing countries communities to survive and adapt in the face of growing threat of climate change. There are several ICT tools available due to the large number of crops and the difficulty of expanding the similar conditions throughout various regions (Sala, 2010). Major ICT solutions that can be used in climate change adaptation and mitigation are namely geographic information systems (GIS), e-governance, early warning systems (including telemetry), and wireless communications frequently adopted by local governments all around the world for assisting their regions in tackling with the impacts of climate change. The International Bank for Reconstruction and Development of The World Bank (2012) further asserts that GIS and e-governance are usually used for preventing disasters as well as recovery goals, while wireless communications and early warning systems are implemented to facilitate effective disaster warning and emergency reactions.

GIS and satellite remote sensing technologies are emerging ICT tools that have a potentially significant role to play in adaptation and mitigation to climate change. A growing body of literature has reported potential benefits of these new and emerging ICT tools for identification, monitoring and assessment in agricultural practices (Aubert et al., 2012; Kroschel et al., 2013; Wang et al., 2010). Precision agriculture is a relatively new farming management concept which is synonymous with the application of GIS and geographic positioning systems (GPS) (Aubert et al., 2012). Precision agriculture monitors crop yields and supports farmer decision on the spatial allocation of input for crop productivity, for example, the quantity of fertilizer and pesticide that can be used for a specific crop based on soil conditions.

A study by Kroschel et al. (2013) provides detailed analysis of possible climate change-induced potato disease infestation, distribution and damage potential in Latin America using GIS to map the data and quantify changes for climate change scenarios by the year 2050. The authors showed that the cultivation of potato on 44,281 ha, 9569 ha and 39,646 ha, respectively for Bolivia, Ecuador, and Peru will be under new risk of infestation. They concluded that, GIS can be a very helpful tool to understand the risk of infestation as well as providing adaptation planning for integrated pest management. Similar observation was made by Wang et al. (2010) in which a GIS-based land uses decision support system to understand the cooling effect of carbon sequestration in forests in the Guizhou province, China and proposes that the tool can be useful in supporting decision-making on how to adopt forestry land use options.

The bibliometric search was conducted in an effort to understand R&D around the world by obtaining data on the number of publications relating to GIS through the Thomson Web of Science database. The search term used was “Geographic Information System” resulting in a total of 46, 349 publications between 1980 and 2014 (up till March). Fig. 4 shows the regions and countries in which academic research relating to GIS is being undertaken. The map shows that the European and North American regions are responsible for 36% and 27%, respectively, together accounting for 63% of the global publications. Of this 63%, the US is the largest contributor, accounting for 23% (10,680) followed by the top five European countries (England, Germany, Italy, Spain and Netherlands) (Fig. 4) in GIS. Asia represents 25% of the total global

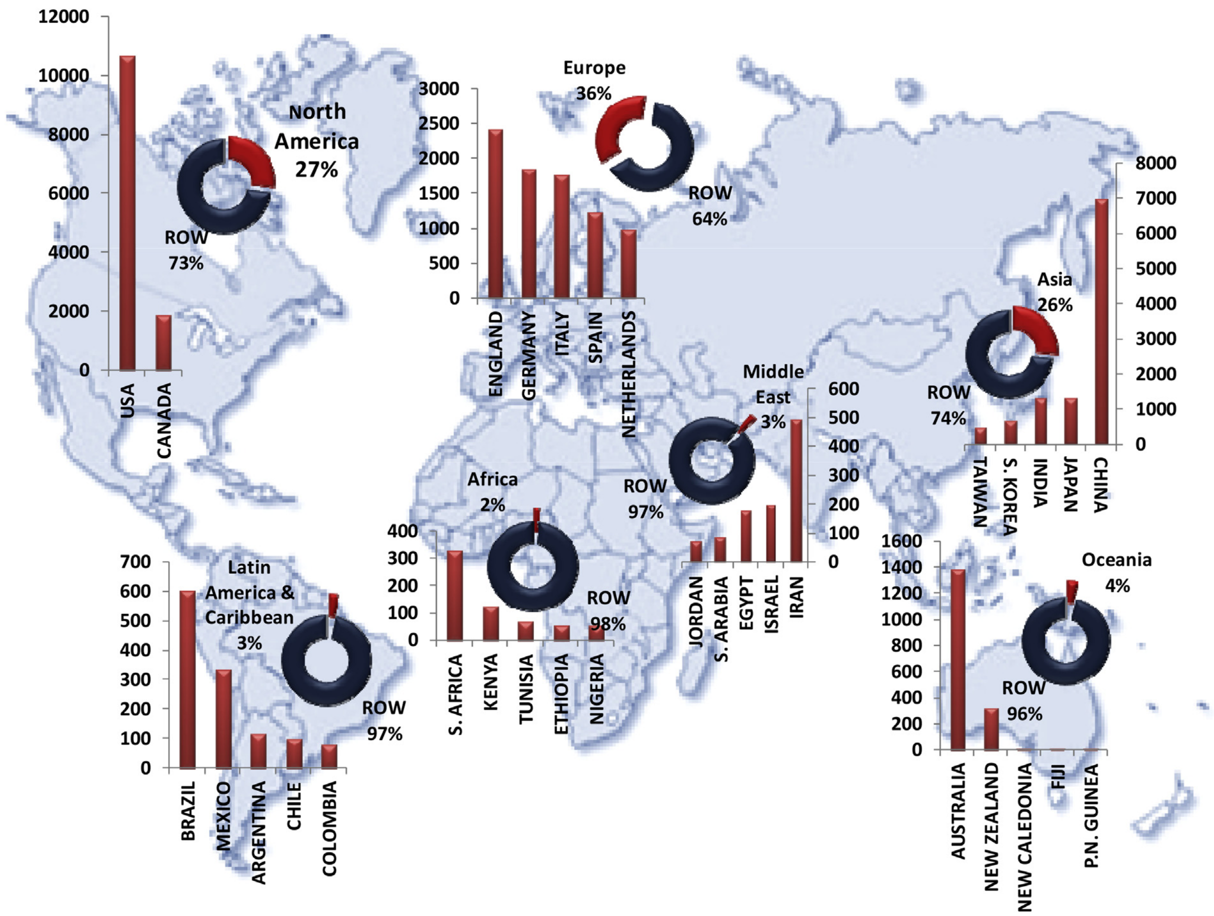

Fig. 4. A map indicating the regional distribution of academic publication activity relating to GIS between 1980 and 2014 based on Thomson Web of Science database search.

publications. China is leading the region with 15% of these publications. Other Asian countries with significant contribution include Japan, India, South Korea and Taiwan (Fig. 4). Oceania represents 4% of the total global publications with the majority coming from Australia (3%). The Latin America and Caribbean and Middle East regions share 3% each, with Brazil and Iran leading respectively. Africa has the smallest number of publication accounting for 2% of the total global publications. Among others, South Africa has the majority of publication, followed by Kenya, Tunisia, Ethiopia and Nigeria.

Further, IPCC (2007) reports that the capacity of ICTs in climate change adaption is currently obvious in utilizing devices such as mobile phones and other applications utilized in adapting to climate change. The use of ICTs such as internet and mobile phones will play an important role in sharing and disseminating climate change messages from one community to the other, particularly among vulnerable people. The application of mobile internets can help engage one another on exchanging important information on specific issues such as migration, invasive plant diseases, production levels, biodiversity, land distribution and water availability that may be affected by climate change, particularly among rural agricultural communities, thereby reducing the vulnerability to climate variability and change. The rapid growth and adoption of mobile phones in the global south has been a success story in contributing to the socio-economic development of the poorest regions in the world (Aker and Mbiti, 2010; ITU, 2010). In many cases, mobile phones are replacing messages usually transmitted through the traditional radio programs. Through mobile phone application and localized seasonal forecasts, remote population can reach each other and provide vital information on vulnerabilities, risk and crisis management regarding climate variability and change (Ospina and Heeks, 2012; Rafoss et al., 2010). Mobile phone application provides important services that facilitate access to local agricultural market information in many developing countries. A recent study of 92 m-ARD apps by the World Bank shows that Africa, Asia, Latin America and Caribbean are benefitting in terms of increasing access to market information, facilitating access to extension services and market links (Qiang et al., 2011). Similarly, the African Soil Information Service (AfSIS) initiated pilot program that serves about 2000 farmers to provide agronomic advice on market information, fertilizer application pest control and soil management through mobile phones (AfSIS, 2013). All such efforts indicate that ICT tools have great potential to strengthen the capacity of developing countries to respond to the threat posed by climate change, hence promoting livelihood adaptation.

Here we analyze the percentage of individual internet users around the world based on the data obtained from International Telecommunication Union (ITU) (Fig. 5). As shown in the figure, it is obvious that developed economies such as Europe and North America have more and better access to internet than other continents. Africa has overall lowest penetration rate of internet in the world. However, the percentage of individual internet users has increased over the past 10 years, compared to the percentage in 2000. Since the penetration of internet may vary among different countries, we look at the regional penetration of internet in Africa and Asia. Fig. 6 shows percentage of individual internet user across different regions in Africa and Asia. In average, 8% of individuals from each 100 persons in SSA with the exception of South Africa use

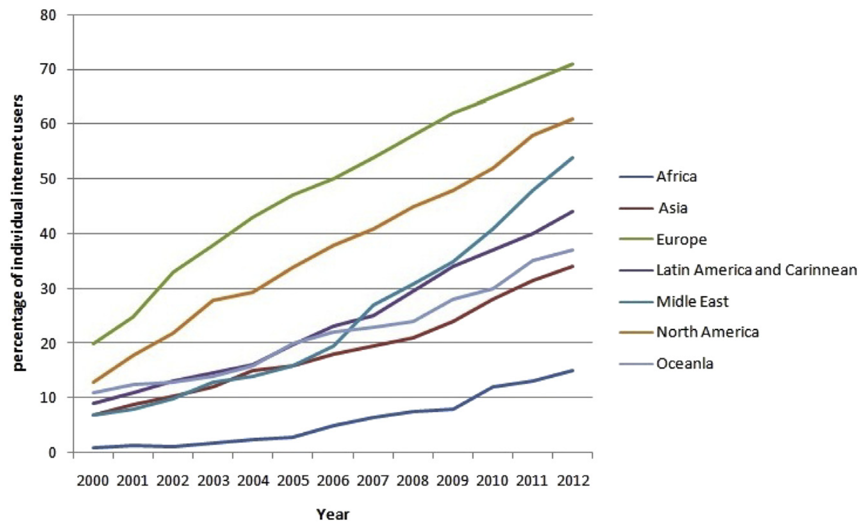

Fig. 5. Global percentage of individual internet users by the region between 2000 and 2012.
Source: (Authors' calculation based on ITU data)

the internet on a regular basis compared to 14% of individuals in North Africa or 49% of individual in Europe or 43% of individual in Eastern Asia between 2000 and 2012. Compared to SSA region, North Africa performs better with regards to percentage of individual internet users in Africa over the past decade. However, overall ICT infrastructure still remains underdeveloped in North Africa. In fact, the top two SSA countries such as Mauritius (55th) and South Africa (70th) ranked better than top two North Africa countries such as Egypt (80th) and Morocco (89th) in terms of overall ICT infrastructure (GITR-NRI, 2013). Although, many countries from SSA still remain at the bottom of the list compared to the countries in North Africa.

An average of 6% of individuals in Southern Asia or 9% of individual in Central Asia use the internet on a regular basis compared to 18% of individual in Southern-Eastern Asia and 43% of individual in Eastern Asia (Fig. 7). Eastern Asia performs much better compared to either Central or Southern Asia in terms of percentage of individual internet users. Despite some success of building a relatively strong ICT infrastructure in emerging economies such as China and India, most developing countries including these two countries still face some important challenges. For example, 80% of installed software in China is pirated due to weak legal framework for intellectual property protection, while low level of education and lack of adequate representation of digital infrastructure is main constraints in India and other advanced developing countries as many rural dwellers don't benefit from the rapid development experienced in urban centers (GITR-NRI, 2013).

3.4. Renewable energy technologies (RETs)

In order to tackle dependence on fossil fuels, burning wood and coal fired power plants that contribute to the majority of GHG emissions, a wide variety of renewable sources are being encouraged to address the challenge of anthropogenic GHG effects around the world including developing countries. The important renewable sources including solar, wind, hydropower, biomass and geothermal are likely to play an increasing role in energy mix in the future to address the challenge of climate change in developing countries particularly for both adaptation and mitigation. There are larger and cheaper opportunities available in many developing countries to reduce GHG emissions through RETs (Drennen et al., 1996; Edenhofer et al., 2011). Moreover, the existence of arable

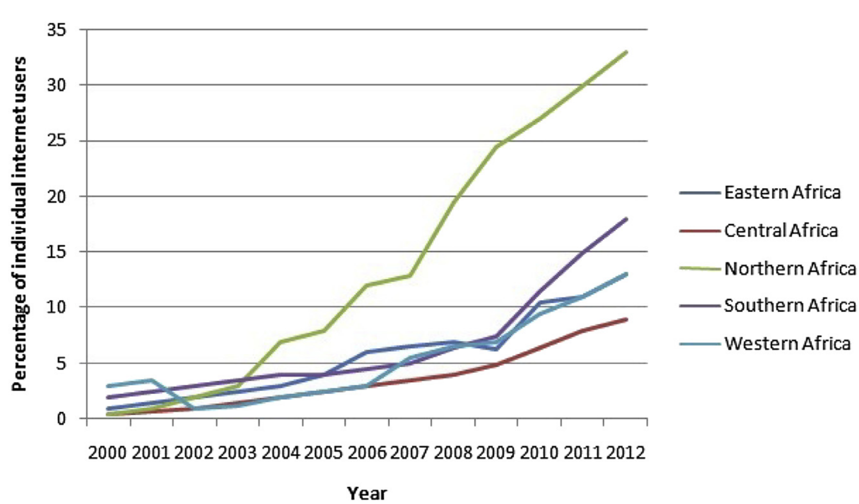

Fig. 6. Africa percentage of individual internet users by the region between 2000 and 2012.
Source: (Authors' calculation based on ITU data).

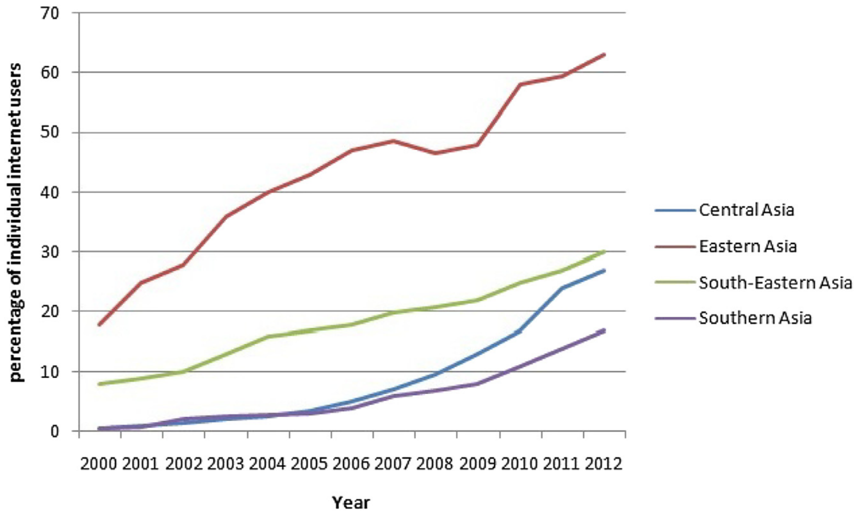

Fig. 7. Asia percentage of individual internet users by the region between 2000 and 2012.
Source: (Authors' calculation based on ITU data).

land, rivers and rain-fed are additional advantages in most tropical developing countries to enhance the proliferation of the renewable energy sectors. The demand for energy will increase as developing countries undergo various stages of development around the world. The renewable energy technologies (RETs) electricity generation capacity continues to grow around the world, and already accounts for 53% in developing countries with the exception of traditional biomass, particularly in meeting the rural energy needs at the household or village level and improving energy security (Edenhofer et al., 2011). Increased access to energy for domestic use and electricity through RETs can provide social benefits such as rural women economic empowerment, improved access to better health services and education, which in turn, reduce the vulnerability, increase the adaptive capacity and resilience to the impacts of climate change.

As described in Table 1, RETs have several advantages, but the analysis in this section is focused on geothermal and solar due to the following reasons; Geothermal energy is a new innovation with increasing capacity for global electricity and could meet 5% of global heat by 2050 (Edenhofer et al., 2011). Geothermal energy could offer opportunities for climate change mitigation and adaptation. IPCC have documented potential role and contribution of the forecasted geothermal energy for climate change mitigation (Bromley et al., 2010). According to Bromley et al. (2010), geothermal has the ability to generate power that is independent of season and is effective for grid development (both on & off), which makes it suitable for climate change mitigation. A growing number of literature showed that the application of geothermal can offer a significant benefit for climate change adaptation in developing countries including. For example, a recent study by Ogola et al. (2012) showed potential contribution of geothermal energy to climate vulnerable sectors such as tourism, forestry and agriculture. The authors concluded that geothermal improved access to electricity to pump water for irrigation, drying of fruits and vegetables, milk pasteurization, processing and juice extraction. A similar finding was reported for the application of geothermal in agriculture and industrial purposes at small-scale levels in China (Zhao and Wan, 2014). Thus, the use of geothermal can strengthen the adaptive capacity of local people by increasing food production, reducing malnutrition and infant mortality and improving quality of life.

Solar energy is the most abundant renewable energy source on the planet and offers range of services including cooking, heating, drying, power generation and water purification. The use of solar energy is increasing with several pilot projects undergoing field tests in many developing countries (Fang and Li, 2013; Ondraczek, 2014; Otte, 2013). The solar energy devices such as solar cookers have been under demonstrations in Africa to solve part of environmental problems associated with firewood demand for cooking and for small-scale food processing in the rural areas. The growing energy need for solar cooking and hot water production is encouraging solar technology development. For example, in China, the production of solar thermal panels for hot water production is rapidly expanding and the country is now the leading producer and exporter of solar PV (Fang and Li, 2013). Also, a study analyzed solar cooker use rates and resulting energy savings in South Africa and showed that electricity, gas and paraffin were the most saved fuels among households using solar stoves (Palmer Development Consulting, 2002). Taken together, the use of solar technology can encourage emission reductions to mitigate climate change, address energy security concerns and reduce air pollution. With regard to adaptation to climate change, solar PV can be used for water pumps in remote rural areas to raise agricultural productivity due to climate variability and change that can result to droughts.

Here, we use patent activity to assess R&D performance and expenditure for the number of patent applications obtained for the two renewable energy sources by querying European Patent Office's esp@cenet database using the keywords; 1) “geothermal” between 1950 and 2014 (up till March); 2) “solar” between 1920 and 2002. Esp@cenet database generated 3, 183 and 32, 487 patents application for geothermal and solar respectively. Our search was restricted due to some technicalities in the database. For example, database does not allow the flexibility of search dates. As a result, the number of patents generated may not reflect the accuracy in the database even though esp@cenet claims the most comprehensive collection of worldwide patents. Therefore, a separate search was conducted of the World Intellectual Property Organization (WIPO) patent database using similar keywords; 1) “geothermal” “solar” between 1930 and 2014 (up till March). WIPO database generated 17, 903 and 308, 270 patent applications for geothermal and solar, respectively. Both data were analyzed. Fig. 8a shows that the majority of patent activity for geothermal has occurred in the China (27.14%), Japan (21.46%) and US (20.39%) followed by the most of European countries. The only Latin America country, Mexico, represents 0.41% and no country from Africa is represented. Fig. 8b shows that the majority of patent activity for solar has occurred in

Table 1
Beneficial characteristics and challenges associated with renewable energy technologies.

Renewable energy technologies	Beneficial characteristics	Challenges/Barriers	References
Biomass	• Biomass is very abundant and can be easily converted to a high energy portable fuel such as alcohol or gas • Relatively cheap compared other renewable energy sources • Restoration of wasteland (e.g., deforested areas) is one of most significant advantage of biomass production • Biomass ash provides plant essential nutrient and elements such as calcium, potassium, oxygen and others for improving the natural balance in the soil system	• Has much lower energy density compared to other energy sources • The challenges to efficient use include: harvesting, collection, transportation and storage cost • Indirect use such as burning causes loss f nutrient, loss of biodiversity, soil erosion, pollution and could contribute to climate change • The use of biomass energy is limited due to lack of availability in sufficient quantities	(Demirbas et al., 2009; Vassilev et al., 2013)
Biofuel	• Meets rural energy needs and stimulate rural economic growth • High energy to land area ratio-so avoids deforestation impacts and land tenure conflicts • Third generation biofuel such as algae can grow almost everywhere including salt water and sewage and can double their mass in one day under optimized conditions • Algae is free from food vs fuel debate and has ability to produce fuel and food	• Lack of biofuel policies for regulating the development and transfer of biofuel technologies • Direct competition with food (e.g., first generation biofuel) • Controversial due to uncertainty of GHG benefits and potential impact on biodiversity • Land issues: fear of losing lands to foreign companies in developing countries	(Adenle et al., 2013; Jumbe and Mkondiwa, 2013)
Solar power	• Solar power has the ability to eliminate variability in power output (e.g., solo power system) • Solar aided power generation (SAPG) such as thermal, increases the efficiencies of the conventional power station (e.g., coal fire) • SAPG provides the way for efficient use of solar heat in the medium and low temperature range for power generation • Solar new integrative system has lower generation costs compared to conventional counterpart	• It requires sophisticated techniques to operate solar panels (high- tech nature) • Cost of commercialization can be very high • High cost of operation and maintenance • Investment risks due to factors including inflation, tax and political instability	(Hu et al., 2010; Jamel et al., 2013; Komendantova et al., 2011; Yang et al., 2011)
Wind power	• Larger wind turbines capture more energy and produce more power and is more stable at height • Wind farm economies of scale provides relative cost advantages • Saves time and increases the output of electricity • Novel wind turbines and components contribute to the power price reduction	• Poor awareness • Lack of governments' support • Weak infrastructure • Land use controversy and Changes to landscape	(Qiu and Anadon, 2012; Rygg, 2012)
Hydropower	• Hydro provides efficient energy conversion process (more than 90%) • It has the lowest operating costs and longest plant life when compared with conventional large-scale generating options • Has multi-purposes services with important functions such as irrigation water supply, navigation improvement and recreational facilities and ecotourism • Creates new freshwater ecosystem with increased productivity	• Requires long-term planning and investments • High capital-intensive processes • Requires regular management of water resources and monitoring of water quality • Changes to stream flow as a result of dam construction can affect ecosystems, flooding patterns and sediment movement	(Bartle, 2002; IUCN, 2012; Yuksel, 2010)
Geothermal	• Requires very little dedicated land compared to other energy sources • Desalination by geothermal can provide power 24 h a day • Flexibility in capacity, moderate installation and operating costs • Great potential for high value agricultural sector that is sustainable on a long-term basis	• High installation cost-requires huge one time investment and well trained and skilled manpower for installation • Transportation challenge-may not be easily transported once energy is obtained compared to conventional sources of energy such wood, coal and coal which are more easily transported • Local problems- mainly suitable for regions with hot rocks below the earth and the ability to produce steam over a long period of time	(Brophy, 1997; CEF, 2013; Mahmoudi et al., 2010)

Japan (40.99%), US (18.98%) and China (9.04%) and the rest of the majority comes from Europe. Surprisingly, no country from Latin America featured (although patents in either Spanish or Portuguese were not included). Interestingly, African countries such as South Africa and Kenya represent 1.13% and 0.40%, respectively. This finding is consistent with a report that showed solar energy sector remains largely dominated by four developed economies such as the US, Japan, Germany and Italy and one emerging economy such as China-the five largest global investors in 2012 (UNEP-BNEF, 2013). According to this report, $140 billion was the largest committed to solar in the RET sector in 2012 and China, came top of the five investors and rose sharply from $17.8 billion to $31.3 billion. The uptake of RETs including geothermal and solar in developing countries vary by country and region due to different capacity and priority of the governments. Despite the potential of RETs, the disadvantages highlighted in Table 1 can be a serious challenge in introducing RETs in many developing countries.

4. Constraints in using technological innovation

Despite the important role that innovative agricultural practices and technologies can play in climate change mitigation and adaptation, vulnerable smallholders in developing countries have been faced with many challenges to adapt their agricultural systems to changing climate through agricultural innovations. Usually, the most inevitable constraints happen at the adoption stage, with many factors potentially preventing rural farmers' access to and utilization of new technologies. Therefore, current technology

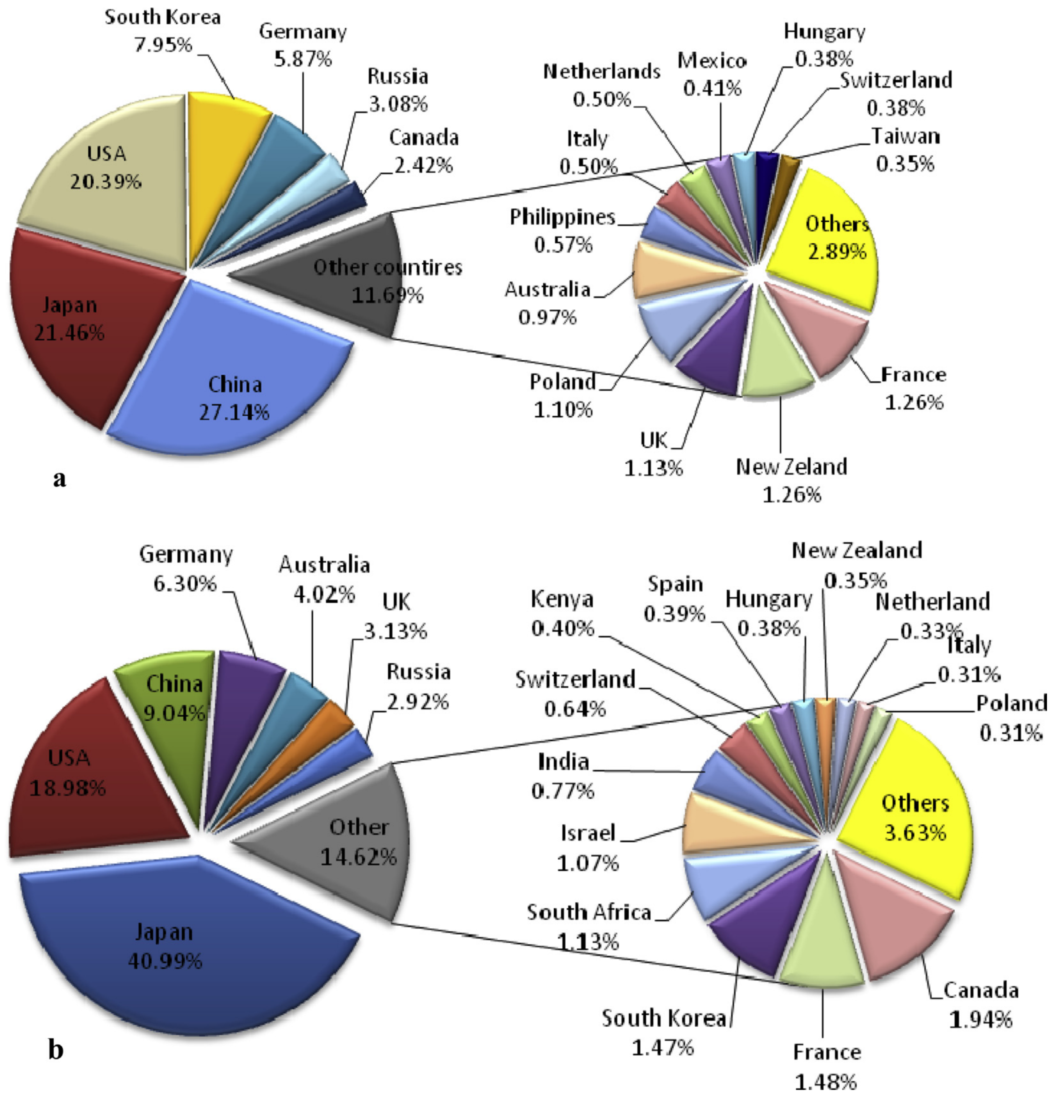

Fig. 8. a. The geographical distribution of geothermal patent applications between 1930 and 2014. b. The geographical distribution of solar patent applications between 1920 and 2014. Note (a&b): The cumulative number of patents granted was determined by querying the Esp@cenet and WIPO database.

options need to be made more accessible considering all required capacities and investments (Lybbert and Sumner, 2012).

With regard to the mentioned technologies in this study, although ISMP are crucially important for coping with the carbon emissions in agricultural practices, structural hardships and unfavorable agricultural price relations have prevented their implementations in many developing countries particularly in West Africa. Widespread adoption of the ISMP paradigm in industrialized countries has been largely facilitated by appropriate policies, resources, culture, and management commitment which are lacking in many developing countries as described above. Several socioeconomic bottlenecks have hampered investments in ISMP in developing world. Most farmers in developing countries are subsistence-based and rarely use or practice integrated soil management. For example, there is lack of uptake of no tillage or conservation agriculture among smallholders in SSA (Giller et al., 2009). Lal (2011) argues that little or no adoption of ISMP in SSA and other developing countries can partly be attributed to impeding factors such as weak infrastructure, limited research capacity, lack of credit facilities, lack of farm inputs and poor marketing system. Even, promising innovations such as composting and agroforestry that are relatively new have a very limited application among poorer households in Western Kenya due to lack of training and labor intensive operations (Place et al., 2003). Moreover, an ISMP approach encompasses significant investment. For soil and water preservation and organic soil fertility practices, this includes mainly of labor time, and money for inorganic fertilizers (Kauffman et al., 2000). The total benefits of such investments only become clear after many years. This is to some extent resulted from participatory learning impacts. Farmers need to spend time to become familiar with new technologies encompass in ISMP, and to adjust them to local conditions. A comprehensive analysis of the importance of local perceptions and regulations for the eastern Burkina Faso region is given by Mazzucato and Niemeijer (2000).

In relation to the agricultural biotechnology, despite its great capacity to contribute to crop productivity outcomes and crop enhancement for smallholder farmers in developing countries in response to climate change, there are numerous factors that influence the deployment and transferring of biotechnology for smallholders by both public and private sectors. The first one relates to the amount of funding and investment that influence research capacity and the ability to develop enhanced traits and varieties genetics (Anthony and Ferroni, 2011; Adenle, 2014). A second class of factors results from the lack of foreseeable regulatory structures, as a result of high development costs (Bayer et al., 2010), accountability risks and insufficient supervision expertise for biotech crops. Intellectual property is also taken as an obstacle, however, through conducting some research in many developing countries, particularly in SSA, it can be seen that intellectual property is not necessarily an impediment that cannot overcome with (Farre et al., 2010; Bazuin et al., 2011). A third category of restricting factors that is observed in many developing nations, especially in SSA, comes up from unavailability of effective seed systems and seed markets, without agricultural support services, for farmers to promptly access enhanced genetics (Anthony and Ferroni, 2011).

In addition to challenges mentioned above, the development of ICT is also faced with many challenges in developing nations. Lack of ICT policies, lack of participation of relevant stakeholders, operational cost, donor-based ICT projects with limited duration and funding, government abandoned projects, corruption and lack of proper coordination at different governmental levels undermine the development of ICT (Gichoya, 2005). All of these characteristics define most of impediments developing countries and countries in transition faced with. Taken together, these challenges could significantly hinder ICT development and limit their ability to implement ICT-enabled action with regard to climate change in many developing countries.

In addition, the introduction or adoption of RETs may be hindered by several factors including geographical locations, limited scientific capacity and expertise, weak institutional capacity, poor infrastructure, lack of financial resources, lack of political will, and socio-cultural and environmental problems. Ashraf Chaudhry et al. (2009) argue that poor infrastructural development and lack of human capital development presents one of the biggest constraints to the installation, operation and maintenance of renewable energy products in Pakistan. Otte (2013) analyzed factors that may facilitate the adoption of solar cookers in developing countries and showed that poor infrastructure could be a hindrance in spreading the idea of solar cooking as well as limiting the opportunity of providing maintenance services in Tanzania. Moreover, it may be difficult to introduce renewable energy product such as solar cooker, where majority of the rural households use firewood, due to lack of awareness and benefits that may be associated with the solar cooking (Vanschoenwinkel et al., 2014). The fragmented and unstable market for renewable energy products can make it difficult to attract long-term support from the government and private sector as the market involves a high degree of risk and uncertain profitability due to direct competition with the fossil fuels.

Despite access to these technologies has not always translated into widespread adoption and effective performance mainly due to the factors worked against utilizing agriculture innovations including inappropriate incentives, policy alignment, political and institutional support, and the development of local technological capabilities, there is a wide variety of agricultural technologies that have significant potential for tackling with climate change. The survey of technologies in the prior section showed this large and diverse range, but it clearly misses a major number of technologies that will critically be important to climate change adaptation and mitigation in agriculture. The creating and deployment of all these technologies connected considerably to policies and institutions. In the following section, we start by outlining several policy implications that should be considered in developing new or revising policies and institutions that try to encourage faster innovation, transfer and adoption of agricultural-related technologies. In the conclusion section, we then explore potential policy measures that could contribute to these development and diffusion processes, which should be undertaken due to increasing concerns and new immediacy under pressure from climate change and climate policy.

5. Policy implications

5.1. Science, technology and innovation (STI) policy

The fight against adverse effects of climate change will require overhauling and strengthening of STI policy that integrates ISMP, agricultural biotechnology, ICT and RETs in developing countries. For example, identifying and implementing appropriate STI policy intervention, that promotes adoption of zero tillage as part of ISMP among resource-poor farmers is a wise strategy (Lal, 2011). For the analysis of this study, the evolution of new policy framework is a fundamental aspect of that development process that should prioritize clean energy or advanced climate technologies. The development and implementation of STI in this regard will vary widely across the range of developing countries. For example, Brazil will differ from India as obviously what is appropriate for this country will not be appropriate to an economy such as that of India. This reflects in current attempts to reduce GHG emissions in different countries. Most countries around the world including developing countries are yet to have emission reduction targets under any form of binding agreement. Even the Kyoto Protocol failed to get major polluters from industrialized countries to reach an agreement, as many policies other than climate policies across different regions currently influence GHG emissions (Smith et al., 2007). Nevertheless, some advanced developing countries such as Brazil, India and China are planning and implementing projects that result in the production of Certified Emission Reductions (CERs) through Clean Development Mechanism (CDM).

Moreover, several studies (Brunt and Knechtel, 2005; Karakosta and Psarras, 2013; Teixeira et al., 2006) have reported the potential benefits of small-scale rural renewable energy projects under CDM in many developing countries. However, these studies argued that among others, bureaucratic procedures, regulatory hindrances and lack of proper assessment criteria undermine the original goals (sustainable development path) and implementation of CDM projects at small-scale levels, particularly in Africa. For example, many CDM projects are RETs- and country-specific and only countries with large resource bases and large markets are more capable to adopt new technologies such as RETs, while the high costs of RETs prevent many poor developing countries (Dechezlepretre et al., 2009).

In view of these constraints and fragmented climate policies in developing countries, policymakers must evaluate possible benefits and pitfalls of projects implemented under CDM, and pay attention to new technologies that have broad applications and implication for climate change mitigation and adaptation. This can be harnessed and integrated into STI action plan of individual country. Without a doubt, the objectives of the CDM (if it still continues) need to be reviewed and refined to accommodate cost effective technologies in the light of lessons learned from CDM to improve the effectiveness of new systems. Perhaps successor to the Kyoto Protocol may have to integrate new technologies such as ICT, improved biotech crop varieties, water harvesting and drip irrigation can also form part of adaptation and mitigation strategies with a view to achieving sustainable development path in developing countries.

The co-benefits approach between renewable energy and agricultural production can also be part of STI action plan. A joint report by (UNFCCC-UNCCD, 2010) discussed the concept of co-use and land easements, for example the use of virgin land for energy-generating plants between farmers and project developers. The idea is, a project developer can place a wind turbine on farmer's land through his/her permission and farmers can receive benefits in form of either rent or potentially carbon credits. They argued that the concept of co-benefit has great potential as this kind of partnership can facilitate renewable energy development while engaging the agriculture sector in the rural community. Policy is needed to integrate agricultural and renewable energy partnership that can enhance sustainable development in developing countries.

5.2. Technology development and transfer-building a strong institutional capacity

The R&D that is relevant to emerging technologies, which specifically targets and addresses the challenges of climate change as discussed in this study, is of absolute importance in developing countries. Government policies must support domestic R&D by strengthening the institutional capacity and building new institutions that encourage sustained interaction across different fields such as engineering, law, natural and social sciences. Investments in agriculture have potential impacts on mitigation efforts. A recent study conducted by Burney et al. (2010) for example, estimated that global investments in agriculture over the past 50 years helped avoid emissions at an effective rate of $4–$9 per ton CO_2e—a figure which is competitive with many current mitigation activities. Moreover, training semi-skilled and skilled manpower is extremely important to the deployment of new technologies which must be encouraged at all levels of government institutions, industry and research institutes.

Appropriate policy measure to support technology transfer can play a significant role in introducing new technology from developed to developing countries. Putting new technologies to good use, particularly, in reducing GHG emissions as well as adapting to climate change has been an important deliberation at international levels as led by the UNFCCC. This is reiterated in the Article 4.1c (the parties to UNFCCC) as stated; "to promote and cooperate in the development, application, diffusion, including transfer, of technologies, practices and processes that control, reduce or prevent anthropogenic emissions of greenhouses" (UN, 1992). The term technology transfer can either be "software" or "hardware" and a combination of hard and soft, which requires effective institutions and policy regulations (UNFCCC-UNDP, 2010). In addition, the IPCC argued that providing appropriate expertise is fundamental to technology transfer and its utilization-"learning to understand, utilize and replicate the technology including the ability to decide which technology to transfer and adapt it to local conditions and integrate it with indigenous technologies" (IPCC, 2000). Therefore, enforcement and implementation of new targeted policies as well as incentive for new direction is fundamental to acceleration of technology transfer.

In view of weak institutions in many developing countries, government must improve the system by developing the capacities and regulatory frameworks so as to accelerate technology transfer from developed countries. For example, increased intellectual property protection supported by the international cooperation can encourage the adoption of new technologies such as GM technology and ICT in developing countries. The IPCC report outlines the key role of various stakeholders in technology transfer and classifies them into 3 types of pathway; 1) Private sector-driven; 2) Communities-driven; and 3) Government-driven (IPCC, 2000). However, they failed to mention the role of relevant stakeholders such as educational institution, trade and research organizations. Multi-stakeholder partnerships should be prioritized as it can offer an effective pathway to technology transfer. Zhang and Liang (2012) argue that law and regulation addressing the issues in the evolution of green ICT requires government policy support and the participation of key stakeholders to facilitate the technology transfer and diffusion of new technology in China. Policy approaches to integrate these elements can be very important particularly in intellectual property right protection and North-South trade which can impact technology transfer. Improved synergies among relevant stakeholders for deployment of innovation can facilitate better technology transfer to smallholders in developing countries, thereby contributing to wider attainment of development goals.

5.3. Infrastructure development

The availability of technological infrastructure, financial resources, stable economy and human capital is very important to support the innovation, and facilitate the transfer and adoption of ICT but grossly inefficient or lacking in many developing countries. In contrast to developing countries, industrialized countries have better platforms and framework for the development and introduction of ICT. For example, the latter are characterized by high income per capita, high literacy, skilled personnel, and greater expenditure on ICT infrastructure, maintenance, development and services. These are essential ingredients that influence the development and adoption at the different levels of organizations such as industry, research institutes, universities and agricultural communities and can help prepare adequately and respond to the challenges of climate change in developing countries. The availability of these ingredients is critical to the implementation of climate policy in developing countries. Infrastructures such as electricity, sanitation and communication can enhance market development and country's ability to trade while reducing the cost of implementation of climate technologies in developing countries. Good quality road, ports, airports and railways infrastructure will play an important role in the facilitation and adoption of technological innovation. Otte (2013) argues that good road infrastructure is the key to the application and maintenance of solar cookers among the rural poor in Africa. Wickramasinghe (2011) analyzed road infrastructure in Sri Lanka and showed that the development and maintenance of road infrastructure in rural areas increased the efficient use of computers, internets, telecommunication technologies and networking facilities. The development of such infrastructure should be viewed as a critical opportunity for integrating technological innovation into the development and implementation of climate policy in developing countries.

5.4. Integration of local knowledge and awareness creation

Integrating local knowledge and raising the level of awareness among rural communities can increase the acceptance and diffusion of technological innovation. Subbarao and Lloyd (2011) analyzed waste heat recovery CDM project led by a private sector in the district of Saraikela (India) and showed that lack of participation of community members was due to the failure to implement the technology. The authors also analyzed 100 biomass gasification CDM projects in rural areas led by a company (DESI Power) in the district of Araria (India) and showed that partnership with the local community organizations and awareness creation led to successful implementation of the technology. They conclude that the success or failure of any project implementation rest on the ability of providers to integrate local knowledge and key community members including the NGOs in order to make positive impact. Otte (2013) emphasized on the importance of local knowledge in the design process of solar cooker as it can facilitate the acceptance of the new technology. Vanschoenwinkel et al. (2014) argue that paying attention to the assessment of technical, social and cultural factors of new technology including solar which are barely mentioned in the literature, could lead to the implementation of technology in the future. New technologies such as ICT, GM technology and ISMP can benefit from this approach with a view to influencing climate policy development positively. Integrating local knowledge in ICTs such as remote sensing and GIS can lead to better application at local levels particularly in accessing and interpreting climate data. Moreover, knowledge sought from local population can help develop new biotech crop varieties, and improve agricultural practices in water and land management, optimize irrigation and harvesting techniques, and maximize efficiency of use of fertilizers and pesticides. Whilst mentioning all these important elements at the international level policy discussions, mechanisms to integrate them at national and local levels are often lacking in developing countries. In view of urgency to develop and implement climate policy, local knowledge must be coupled with the global and national scale of interventions so as to adapt and mitigate climate change.

5.5. Finance

Overcoming financial barriers can increase the ability of a country to deploy and use new technologies. There is a need for identifying and mobilizing finance for the implementation of climate technologies in developing countries in the light of their limited financial resources. Most climate change projects in developing countries are largely supported through official development assistance (e.g., adaptation funds) and government public expenditure. There are a variety of ways in which governments can help funding climate change projects. In this regard, strengthening public and private partnership through foreign direct investment is one option. However, private sector may not be interested in financing some climate projects (e.g., adaptation) due to poorly established institutions and other militating factors in developing countries particularly countries in Africa. Here, there is a need to carefully assess and take action to improve the policy dialog for local private sector development and partnership strategy through targeting innovative technologies that will attract investment and benefit the rural poor. A well coordinated targeted taxation regimes, incentive programs and market-based instruments for unlocking financial potential can be promoted to create and sustain enterprises that contribute to sustainable development. Indeed, it is a public institution that can offer more incentives to the private sector and thereby provide a greater impact of diffusion. For instance, using carbon taxes or emission trading schemes with a major degree of auctioning of permits can generate an important source of public financing to support climate change measures. Furthermore, providing a clear price signal can direct private sector investment towards innovation, low-emission technologies and measures. In addition, increasing incentives for pension funds and other private financial sources to invest in low carbon development is another effective approach. Green marketing and green pricing programs are other valuable financing mechanisms to enhance the transfer and diffusion of climate technology in developing countries. Green marketing is found to be effective in some countries and is becoming increasingly common. In this regard, the Green Climate Fund (GCF) could provide linkages between mitigation, adaptation and technology transfer and development. This fund, which is an international financial institution connected to the United Nations Framework Convention on Climate Change (UNFCCC), aims to support developing countries to be able to fight against climate change through supplying the funds and other concessional financing for mitigation and adaptation projects, policies, and actions. The GCF is financed by contributions from donor countries and other resources, potentially encompassing innovative technologies and the private sector. Governments that are willing to generate successful green economy and low-carbon energy markets must take the key role, to provide motivations for public-private partnership initiatives. This will include holistic and stable strategies, policies, incentives and funding schemes to support investment and help in promotion of new low-carbon energy markets to be able to enter to the business world.

6. Conclusion

Agriculture has a crucial role in development. It is our major source of food with substantial capacity for mitigation of global GHG emissions. Agriculture is specifically vulnerable to climate change as it significantly relies on water resources and climatic conditions, mainly in regions of the world that are particularly vulnerable to climatic hazards, such as South and Central America, Africa and Asia. Importantly, this study showed that agricultural technologies would play a core role in providing the opportunity to producers to address the main challenges of climate change adaptation and mitigation in agriculture. However, while most technologies have the potential to be implemented in combating with climate change, some of them are particularly appropriate to the context of developing countries' agriculture and climate change. Among all the introduced technologies in this study, agricultural biotechnology has the most potential to significantly enable agriculture to generate more from less whilst decreasing the carbon footprint. The main opportunities derived from agricultural biotechnology encompass enhanced sustainability, CO_2 mitigation and sequestration, higher energy efficiency and improved productivity in comparison with traditional farming practices. Thus, our environment and climate can significantly benefit from biotechnological innovations. As agriculture innovations have been always critical and will be even more necessary in the essence of climate change, judicious policy responses that stimulate the development and diffusion of proper agricultural technologies will be required to be able to respond through effective technological innovations. In this regard, in the followings some specific policy priorities are identified that have not yet received appropriate attention on organizing climate adaptation and mitigation in agriculture.

The application and utilization of existing technologies need to be fostered. Sometimes, existing technologies can be adapted in a different way, instead of replacing them with other technologies. This can be achieved through collaboration with farmers to identify the best solutions for creating such difference. Investing in agricultural R&D for new technologies to reduce GHG emissions and increase productivity is another policy priority. Technology funding is needed to enable participation of developing countries in international R&D projects. For example, resultant intellectual property rights could be shared and patent buyouts could also provide accessibility to privately owned technologies for developing nations. Moreover, there should be global R&D alliance operations for research on main adaptation technologies. Indeed, both government and private funding for R&D needs to be seriously risen up, and more government funding for R&D requires rearrangement mainly for the development of low-emission, energy-efficient technologies. In fact, developing countries will be more dependent on technology transfer from external resources without adequate technology development capacity. Providing more desirable tax treatment in developed world for R&D performed in developing countries can also be an effective policy toward tacking climate change. Reconstructing and improving public agricultural research capacity in developing nations, stimulating proper linkages between public and private agricultural research should be considered as important options. However, R&D alone would not be sufficient to adapt and mitigate climate change in agriculture. Assisting in risk reduction, investing in more suitable information and predictions can also assist in dealing with climate effects. It is also important to notice that encouraging responsive and competitive agricultural markets, providing more investments that enhance integration of spatial market are crucial in order to have a positive and long-term response to climate change. Furthermore, promoting producer resilience to climate change that facilitates adaptation and that can be a repay to the most vulnerable groups is a potential policy priority that can assist in climate adaptation and mitigation in agriculture.

Our study revealed that policy and institutional change are imperative if agricultural innovation systems are seriously thought as one of the main tools to tackle with climate change in developing countries. However, future studies should investigate 'how policy measures as well as technology innovations can affect farmers to mitigate and adapt to climate change'. All these will help clearer understanding of the relationships between policies and practices that is necessary for future development of mitigating and adapting strategies for coping with the impacts of climate change in agriculture sector.

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