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Decomposition of Green Agriculture Productivity for Policy in Africa: An Application of Global Malmquist–Luenberger Index

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Abstract: Previous research on agricultural productivity in Africa has focused on conventional Total Factor productivity (TFP) growth rather than Green Total factor productivity (GATFP) growth, thus ignoring the effect of undesirable outputs such as emissions. This has raised concerns about the sustainability of agricultural productivity growth in the continent. The study was designed to examine GATFP growth in agricultural productivity for 49 African nations from 2000 to 2019. We apply the Global Malmquist–Luenberger (GML) Productivity Index, which complies with the sustainable development agenda that promotes greater production of desirable outputs and minimising unwanted outputs. This approach is also compared to Global Malmquist (GM) Productivity Index which ignores unwanted outputs, yielding to conventional TFP growth. We found an average GATFP growth of 0.6% and TFP growth at 0.9% suggesting that the actual agricultural productivity growth is overstated if agricultural emissions are disregarded. Both estimates fell short of the desired annual target of 7% from the Comprehensive African Agriculture Development Programme (CAADP). Regional growth is mostly characterised by high (low) GATFP and TFP except in Southern Africa and East Africa. The two regions represent an ideal situation where GATFP exceeds TFP. At country level growth can be divided into three scenarios: desired growth, where GATFP exceeds TFP; balanced growth with both estimates equivalent; and undesired growth, where TFP exceeds GATFP. Unfortunately, most African nations fall in the last scenario. We conclude that policies must be developed to encourage sustainable agricultural productivity growth in Africa.

Keywords: green agricultural productivity; undesired output; productivity; agriculture; Global Malmquist–Luenberger Index; Africa

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1. Introduction

Agriculture is seen as a mainstay of the African economy, employing approximately 65% of the population [1,2]. This implies that Africa's productivity growth is crucial for poverty alleviation, profit generation and food security on the continent [3]. As a result, the productivity growth of agriculture in Africa has received more attention since the beginning of the twenty-first century and this has led to the establishment of the Comprehensive Africa Agriculture Development Programme (CAADP) [4], an agriculture-growth led initiative for the entire continent where African Union member states spend 10% of their national budget on agriculture to realise annual agricultural growth of 6%. For a long time, the traditional approach adopted by CAADP towards improvement of agricultural productivity growth involved land expansion and intensified use of modern inputs [5]. The drawback of this approach is increased greenhouse gas (hereafter, GHG) emissions, compromising the quality of the environment, threatening sustainable development and also contributing to the current climate change crisis [6]. In simple terms, the traditional (famous) approach for the enhancement of agricultural productivity in the continent fails

to balance increased agricultural productivity with environmental protection and future considerations. As a result, there is now an increased need for an alternative approach to improve agricultural productivity growth in Africa. This is evident from the aspirations of CAADP Malabo.

The GHGs consist of several harmful gasses including carbon dioxide, methane and nitrous oxide. Many of these gasses are vital to support life in the sense that they trap heat which in turn keeps the planet warm [7]. However, excessive emission of these gasses has severe repercussions for the quality of environment [8–10] because they can accumulate beyond threshold levels and cause damage. For instance, carbon dioxide stays in the atmosphere for up to 1000 years, methane for nearly a decade and nitrous oxide for approximately 120 years. If their build-up goes beyond the naturally required amount, the climate warms above its typical temperature, resulting in climate change. According to Tongwane and Moeletsi [11], the annual average emission of GHGs in Africa rose from 2.9% to 3.1% from 1994 until 2014, with variation from one region to the other. This supports claims in the FAO [12] that both farm-gate and land-use-related emissions have shown an upward trend since the turn of twenty-first century. This increase has recently been the cause of a rise in sea levels, which has resulted in floods, a decrease in rainfall and other disasters that have a detrimental impact on the continent's agricultural productivity growth.

"Green growth" is defined as the advancement of economic growth through resilience, efficient and sustainable management of natural resources including increased agricultural output, and encouragement of sustainable infrastructure and urbanisation, while reducing pollution and waste [13]. It has been one of the most common measures adopted by different countries around the world to achieve sustainable development. This is evident from South Korea's proposal to establish low-carbon and energy-independent communities [14], US subsidies towards encouraging the green total factor productivity growth (GATFP) [15], initiative from Malabo Declaration and African Development Bank, seeking to transition Africa towards green growth [4,16,17] and China's growing concern for the reduction of pollution particularly in agriculture. These initiatives originate from the United Nations' initiative of "Changing Our World: The 2030 Agenda for Sustainable Development", which outlines 17 global sustainable development goals (SDGs). This has also led to a shift in scholarly literature towards green total factor productivity growth [18].

The green total factor productivity is computed by incorporating unwanted output such as pollution or emissions alongside traditional inputs such as capital, labour and energy inputs [19]. It stems from Chung [20], whose analysis of a pulp mill in Sweden led to the introduction of a new directional distance function (DDF) and the development of the Malmquist–Luenberger Productivity Index (MLPI). The MLPI evaluates total factor productivity growth while taking into account the undesirable outputs [21]. The MLPI has been used by several researchers to evaluate green productivity growth for different sectors of the economy particularly in China. However, to our knowledge, the method has not been applied within an African context to investigate GATFP growth. This is surprising given the increased demand for strategies to improve agricultural productivity through CAADP in a sustainable manner. However, it implies that available research lacks sufficient policy insights to achieve the balance between resource utilisation, increased productivity and environmental protection.

The aim of the study is to investigate whether agriculture growth is sustainable or not, taking into consideration the effect of emissions. We employ the GML to derive GATFP estimates for 49 African countries from 2000 to 2019. The choice of GML is attributed to the advantage of overcoming the infeasibility problem and its ability to handle both desired and undesired outputs. The paper provides a new perspective that expands current knowledge by shedding new light on green agricultural productivity change and important policy recommendations for its acceleration at various levels of the continent. The next section provides the literature review, followed by the data and methods in Section 3.

The results including policy implications are presented and discussed in Section 4, while Section 5 provides the conclusions.

2. Literature Review

Agricultural productivity growth remains a hot topic in economic research. Currently, the debate on agricultural productivity growth places emphasis on the achievement of agricultural growth while protecting the environment, often referred as to as GTFP [18]. To address this existent literature relies heavily on the MLPI using Data Envelopment Analysis (DEA) method [22]. Some studies [23,24] have modified the conventional MLPI to GML with the aim of addressing the infeasibility problem in the MLPI, while other studies [25] have applied various DEA sub-models in the analysis of GTFP. Several GTFP studies were conducted in the manufacturing sector [26], energy [6,27] economics [22], transport [28] and agricultural sector [29–31]. The evidence increases that implementing sustainable development practices is the only approach to increase resource use efficiency and reduce emissions without harming economic growth [32].

A large volume of studies (e.g., [1,3]) measuring agricultural productivity growth have been published in many parts around the world. Much of this literature focus on partial factor productivity growth or the conventional total factor productivity growth at continental, regional or cross-regional and country or cross-country levels using frontier methodologies. The greatest shortcoming of these studies is their disregard for environmental quality which is frequently jeopardised by unwanted outputs [6]. This suggests that these studies may not be helpful today, given the shift in the territory of literature towards GATFP. Much of the existing literature on GATFP has been produced within the context of the Chinese economy, with limited studies on the topic in other parts of the world.

The DEA-based models, which include the radial, additive and slack-based measure (SBM) models, are most frequently employed to analyse GATFP [25]. The standard DEA approaches such as the Charnes, Cooper, and Rhodes (CCR) [33] and Banker, Chames, and Cooper (BCC) models are known as radial models. While the CCR model assumes constant returns to scale, the BCC model allows for varied returns to scale [34]. These models are used separately or in conjunction with MLPI to consider a wide range of undesirable outputs such as methane, carbon dioxide and nitrous oxide. For instance, Falavigna and Manello [35] employed the Directional Output Distance Function (DODF)-DEA in Italy to derive MLP indices while considering emission of methane as an undesirable outputs, and found growth in GATFP due to technological progress. Thus supporting the role of technology in the achievement of sustainable agricultural production. Using a balanced panel data from 30 provinces covering the years 2003 to 2017, Liu et al. [36] examined the GATFP of China based on the application of the Super-SBM model. Their results show a fluctuating trend both at national and provincial level, but on the overall, the growth rate revealed a gradual declining trend. However, they propose the promotion of clean agricultural production, investment in R&D for agricultural science and technology as policy interventions to improve the GATFP.

A study conducted by Zhong et al. [37] during the years 1997 to 2019 using Metafrontier Malmquist–Luenberger for 30 provinces in China found an average GATFP of 1.73% per annum. The results show that the average GATFP is driven by technological change. However, the results at provincial level showed a declining trend due to deficiencies in optimal production and technological gaps. Overall, their results imply that GATFP can be further improved by strengthening efficiency change through investment in education and training in the agricultural sector. On the other hand, the application of DEA–Luenberger in Chinese agriculture by Liang and Long [38] shows that efficiency change underpins the GATFP for the country. This is contrary to an earlier study by Wang et al. [39], who found no difference between the results of conventional agricultural TFP growth and GATFP while using the SFA method in China. From 1985 to 1998, Yörük and Zaim [40] estimated the MLPI and its constituents in OECD countries and found that Ireland and Norway were the most productive countries. They further reveal that the overall productivity of these

countries was driven by technical change. Overall, there is very little consensus in the current empirical literature. To the authors' knowledge, no single GATFP study has been conducted in Africa.

3. Materials and Methods

3.1. Data and Variable Information

The sample used in this study consists of panel data for 49 countries in Africa covering the period 2000 to 2019. The data was obtained from the United States Department of Agriculture and Economic Research Services (USDA ERS) and the World Bank (WB). The countries are grouped into five regions, which include: North Africa (5 countries), Southern Africa (13 countries), East Africa (7 countries), West Africa (16 countries) and Central Africa (8 countries). Due to incompleteness of the data, eight African countries were excluded from the analysis. The study considers two outputs and seven traditional inputs as shown in Table 1:

Desirable output represents a gross value of agricultural output from crops, livestock and aquaculture measured in USD 1000 at constant 2015 prices. Undesirable output is a combination of: (i) agricultural methane emissions from animals, animal waste, rice production, agricultural waste burning (non-energy, on-site) and savanna burning, measured in thousand metric tons of CO_2 equivalent, and (ii) agricultural nitrous oxide emissions are emissions produced through fertilizer use (synthetic and animal manure), animal waste management, agricultural waste burning (non-energy, on-site) and savanna burning, measured in thousand metric tons of CO_2 equivalent. Both variables were obtained from the World Bank. The traditional inputs considered for this analysis are:

Land is described as quality-adjusted agricultural area measured in 1000 hectares of "rainfed-equivalent cropland". Labour is measured by the number of economically active adults (male and female) primarily employed in agriculture measured in 1000 persons. While capital is defined as the value of net capital stock measured in USD 1000 at constant 2015 prices. Machinery is measured as total stock of farm machinery in "40-CV tractor equivalents" (CV = metric horsepower). The number of 2-wheel tractors, 4-wheel tractors, and combine-harvesters and threshers in use were aggregated. Material is measured as an index of crop and animal intermediate inputs, 2015 = 100. Temperature is the average annual temperature measured in degrees Celsius, and Rainfall is measured as an average precipitation in depth in millimeters per year.

Table 1. Descriptive summary of input and output variables, 2000–2019.

Variable	Mean	Std	Maximum	Minimum	Source
Desired output ($)	5,274,339	8,676,909	30,024	59,306 332	USDA ERS
Undesired output (CO_2)	13,592	15,066	10	83,410	WB
Land (ha)	5805	8741	37	62,460	USDA ERS
Labour (n)	3242	4273	11	21,298	USDA ERS
Temperature (°C)	24	3	11	30	WB
Rainfall (mm)	1007	664	23	3146	WB
Capital ($)	5971	17,604	5	188,491	USDA ERS
Material ($)	87	39	8	444	USDA ERS
Machinery (40-CV)	96	19	49	249	USDA ERS

The choice of output and input indicators for our study corresponds with that used in previous studies. For instance, several researchers [22,41,42] consider carbon dioxide as a major undesirable output in agriculture. We follow the steps of these researchers because their consideration of carbon dioxide is limited to the agricultural sector as opposed to the entire economy, thus providing the most accurate measure of undesirable output relevant for our analysis. Zhang et al. [43] use capital and labor, and Adom and Adams [44] incorporate rainfall temperature, whereas Nkamleu [45] employs land as one of the input variables. It should also be noted that current data from the World Bank does not provide

data of CO_2 exclusive to agriculture sector; hence, we opted for nitrous oxides and methane as the undesired output for our study. However, these are measured in thousand metric tons of CO_2 as indicated in Table 1.

3.2. Estimation Procedure

Since its introduction by Caves et al. [46], the Malmquist Productivity Index (MPI) remains the most extensively used techniques for performance over time for decision making units (DMUs). Using aggregate output Y(y) and input X(x) via the distance function approach (D_o), MPI measures productivity changes between two points in time t technology (observation) and the other period t+1 technology. The y and x represent output and input, respectively. Nonetheless, this productivity change is described as a product of "Catch-up" and "Frontier shift" terms, the former often called efficiency change and the latter, technical change. Taken together, this can be expressed as:

$$M_0^{t+1}\left(x^{t+1}, y^{t+1}, x^t, y^t\right) = \frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)} \left[\frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^{t+1}, y^{t+1})} \frac{D_0^t(x^t, y^t)}{D_0^{t+1}(x^t, y^t)} \right]^{1/2} \quad (1)$$

The first term out of the square brackets in Equation (1) indicates the efficiency change between two periods, t and t+1, while the geometric mean of the second term in the square brackets captures technical progress in period t+1 and t, with output distance function described as:

$$D_o(x, y) = \min\{\theta : (y/\theta) \in P(x)\} \quad (2)$$

where D_o refers to the distance functions which permit for description of a multiple-input multiple-output production technology without the need to describe the behaviour objective of the firm [3], while P(x) represents the set of all output vectors with y produced using the input vectors x. Over the years, this index has been modified in several ways. This includes, among other things, the quasi-Malmquist productivity index established by Grifell-Tatjé et al. [47], non-radial Malmquist index [48], generalised Malmquist index [49] and the global Malmquist index [50], referred in this study as GM. For a DMU that uses input x to produce output y, the global benchmark technology can be described as $T_c^G = \text{conv}\left\{T_c^1 \cup \ldots \cup T_c^T\right\}$, where subscript "c" indicates that the global benchmark technologies satisfy constant returns to scale. As a result, the GM is describe on T_c^G as:

$$M_c^G\left(x^t, y^t, x^{t+1}, y^{t+1}\right) = \frac{D_c^G(x^{t+1}, y^{t+1})}{D_c^G(x^t, y^t)} \quad (3)$$

Equation (2), (x^{t+1}, y^{t+1}) and (x^t, y^t) are compared using different benchmarks. However, given the single global benchmark technology, the geometric mean convention is not needed when defining the global index, where the output distance functions is:

$$D_c^G(x, y) = \min\left\{\phi > 0 \mid (x, y/\phi) \in T_c^G\right\} \quad (4)$$

This leads to the following expression for GM:

$$\begin{aligned} M_c^G\left(x^t, y^t, x^{t+1}, y^{t+1}\right) &= \frac{D_c^{t+1}(x^{t+1}, y^{t+1})}{D_c^t(x^t, y^t)} \times \left\{ \frac{D_c^G(x^{t+1}, y^{t+1})}{D_c^{t+1}(x^{t+1}, y^t + 1)} \times \frac{D_c^t(x^t, y^t)}{D_c^G(x^t, y^t)} \right\} \\ &= \frac{TE_c^{t+1}(x^{t+1}, y^{t+1})}{TE_c^t(x^t, y^t)} \times \left\{ \frac{D_c^G(x^{t+1}, y^t)/D_c^t)/D_c^{t+1}(x^{t+1}, y^{t+1})}{D_c^G(x^t, y^t)/D_c^t(x^t, y^t)} \right\} \\ &= EC_c \times \left\{ \frac{BPG_c^{G,t+1}(x^{t+1}, y^{t+1})}{BPG_c^{G+t}(x^t, y^t)} \right\} = EC_c \times BPC_c \end{aligned} \quad (5)$$

where EC_c is the technical efficiency change index and BPC_c is the technical change index. However, the seminal work of Chung et al. [20] was another game changer in the evolution of MPI. This work led to the establishment the MPLI which was later modified by Oh [24] with the purpose of overcoming the infeasibility problem, thus yielding to the GML. Against this background, the study employs the GML proposed by Oh [24], expressed as follows:

$$\begin{aligned} &\text{GML}^{\,t,t+1}\left(x^t, y^t, b^t, x^{t+1}, y^{t+1}, b^{t+1}\right) \\ &= \frac{1 + D^G\left(x^t, y^t, b^t\right)}{1 + D^G\left(x^{t+1}, y^{t+1}, b^{t+1}\right)} \end{aligned} \tag{6}$$

where the directional distance function $D^G(x, y, b) = \max\{\beta \mid (y + \beta y, b - \beta b) \in P^G(x)\}$ is described on the global technology set.

The $\text{GML}^{\,t,t+1}$ can be decomposed as follows:

$$\begin{aligned} &\text{GML}^{t,t+1}\left(x^t, y^t, b^t, x^{t+1}, y^{t+1}, b^{t+1}\right) \\ &= \frac{1 + D^G\left(x^t, y^t, b^t\right)}{1 + D^G\left(x^{t+1}, y^{t+1}, b^{t+1}\right)} = \frac{1 + D^t\left(x^t, y^t, b^t\right)}{1 + D^{t+1}\left(x^{t+1}, y^{t+1}, b^{t+1}\right)} \\ &\times \left[\frac{\left(1 + D^G\left(x^t, y^t, b^t\right)\right) / \left(1 + D^t\left(x^t, y^t, b^t\right)\right)}{\left(1 + D^G\left(x^{t+1}, y^{t+1}, b^{t+1}\right)\right) / \left(1 + D^{t+1}\left(x^{t+1}, y^{t+1}, b^{t+1}\right)\right)}\right] \\ &= \frac{\text{TE}^{t+1}}{\text{TE}^t} \times \left[\frac{\text{BPG}_{t+1}^{t,t+1}}{\text{BPG}_t^{t,t+1}}\right] \\ &= \text{EC}^{t,t+1} \times \text{BPC}^{t,t+1} \end{aligned} \tag{7}$$

where $BPG^{t,t+1}$ is the best practice gap between a contemporaneous technology frontier and global technology frontier along the ray from observation at time period s in direction (y^s, b^s). Thus, $BPC^{t,t+1}$ represents the technical change between the two periods. It then follows that $BPC^{t,t+1} > (<)1$ signifies that the production technology in period t+1 is closer to (or further away from) the global production technology than that of production technology in period t. Therefore, $BPC^{t,t+1} > 1$ indicates technical advancement between t and t+1, whereas $BPC^{(t,t+1)} < 1$ indicates technical regression.

Changes in efficiency are measured by $EC^{t,t+1}$, which represents a movement of countries towards the best practice frontier. If $EC^{t,t+1} > 1$, then there has been a shift towards the frontier in period t+1, and the country is more efficient. However, if $EC^{t,t+1} < 1$, it indicates that the country is further away from the border in t+1 than in t, and hence inefficient. However, if there has been no change in inputs and outputs over the two periods, then $GML^{t,t+1} = 1$. If there has been an increase in productivity then $GML^{t,t+1} > 1$, and for a decrease $GML^{t,t+1} < 1$. This model takes into consideration both the desired and undesirable outputs, and yield to GATFP estimates. We used STATA version 17 to implement Equations (4)–(6). The following stata code of estimation shows how the bad output enters the GML estimation:

gtfpch land labor capital machinery material temp rain = output: CO_2, global.

In this estimation procedure, we assume constant returns to scale, which overcomes the non-convexity problem.

4. Results

Table 2 presents the average geometric means, standard deviations, minimum, maximum and difference for African agriculture over the period 2000 to 2019. The GML index results show a moderate yearly average GATFP of 0.6%, which is mostly explained by the efficiency change component (0.6%). This shows that agricultural productivity in Africa was modestly sustainable over the study period. However, it falls short of the CAADP aim of allocating 10% of national budget to agriculture to achieve 6% yearly growth. Nonetheless, green technology had a negligible impact (0.1%) on GATFP, indicating that increased

investment in research and innovation should be prioritised. We also found discrepancies between GML and GM index estimates due to the inclusion of undesirable output in the GML index as a result of negative externalities. For instance, the GM index reveals an annual average productivity of 0.9%. This finding shows that the GM index overstated the annual average productivity growth rate by 0.3%, indicating that this approach yields to bias estimates void of effect of environmental pollution. In simple terms, the GM index estimates are nearly twice those of the GML index, thus presenting an upwardly biased estimate of productivity. This suggest that the GML index comes closest to characterising true total factor productivity growth. This also implies that future research on agricultural productivity in Africa should focus on green productivity rather than conventional productivity, which does not account for environmental impact. The first 19 years into the twenty-first century show mixed findings on green agriculture productivity growth rate with GML index estimates ranging from 0.985% to 1.021%. Over the study period, 12 years record positive GATFP growth and these include 2000–2001 (1.33%), 2004–2005 (1.27%), 2006–2007 (0.49%), 2007–2008 (1.90%), 2009–2010 (2.80%), 2011–2012 (1.61%), 2012–2013 (0.22%), 2014–2015 (0.29%), 2015–2016 (1.55%), 2017–2018 (1.10%) and 2018–2019 (2.12%). We observe significant decline of green productivity ranging from −1.53% to −0.14% over a period of seven years (2001–2002, 2005–2006, 2003–2004, 2008–2009, 2010–2011, 2013–2014 and 2016–2017). On the other hand, for a period of four years (2012–2013, 2014–2015, 2002–2003 and 2006–2007), growth remains positive but less than 1.00%, where the rates ranged from 0.22% to 0.65%. Six years (2000–2001, 2004–2005, 2007–2008, 2011–2012, 2015–2016 and 2017–2018) also exhibit positive growth with rates ranging from 1.10% to 1.90%. Only two years (2009–2010 and 2018–2019) recorded growth rates of above 2%.

Figure 1 presents the GML and GM index estimates for different African regions over the study period, with a purpose of assessing regional integration in terms of agricultural productivity growth. Recall that index values greater (less) than unity signify improvements (deterioration) in growth. As such, each region is assessed based on four quadrants where the quadrant on the bottom right presents the ideal situation, that is, high GATFP and low traditional TFP. It is clear from Figure 1 that agricultural growth for African regions fall under two quadrants: the bottom left (quadrant), where both GATFP and traditional TFP are low, and the top right (quadrant), where both categories of agricultural productivity growth are high. This suggests that, while growth rates remain positive at regional level, signifying better integration, more effort is required to ensure that such growth is increasingly sustainable going forward. This implies that regions should invest on green technology to minimise harmful effects on the environment. More details regarding productivity estimates for the different regions are provided in Tables A1–A6 in Appendix A. The Southern Africa region had the highest annual average GATFP at 0.8%, ranging from 0.97% in 2016–2017 to 1.06% in 2018–2019 (as indicated by GML in Table A1 in Appendix A). With the exception of four years (2001–2002, 2005–2006, 2013–2014 and 2016–2017), the growth rates for GATFP improved significantly. West Africa came second with GATFP growth rate of 0.7% driven by efficiency change, ranging from 0.96% in 2003–2004 to 1.01% in 2018–2019 (see Table A2 in Appendix A). For a period of six years, this region exhibits positive growth rates which are but slightly less than one, while the rest of the years show greater improvement of growth of GATFP.

Table 2. Productivity growth estimates, 2000–2019.

Estimates	GML	BPC	EC	GM	BPC	EC	Difference		
Column	[1]	[2]	[3]	[4]	[5]	[6]	[1]–[4]	[2]–[5]	[3]–[6]
Mean	1.006	1.001	1.006	1.009	1.000	1.010	−1.3%	0.1%	−1.3%
Std	0.062	0.063	0.058	0.084	0.081	0.050	−1.2%	−1.8%	0.8%
Min	0.580	0.590	0.610	0.555	0.592	0.767	2.5%	−1.2%	−15.7%
Max	1.690	1.710	1.640	1.866	1.880	1.262	−17.6%	−17.0%	37.8%
2000∼2001	1.013	0.994	1.021	1.014	0.980	1.035	0.0%	1.4%	−1.4%
2001∼2002	0.993	1.011	0.989	0.989	0.995	0.996	0.3%	1.7%	−1.7%
2002∼2003	1.005	0.995	1.017	1.017	1.017	1.000	−1.2%	−1.2%	1.6%
2003∼2004	0.997	1.000	0.998	0.992	0.996	0.998	0.5%	0.5%	0.0%
2004∼2005	1.013	1.006	1.008	1.017	0.993	1.024	−1.4%	1.2%	−1.6%
2005∼2006	0.985	0.995	0.992	0.990	1.005	0.986	−1.5%	−1.0%	0.6%
2006∼2007	1.007	0.978	1.035	1.002	0.964	1.040	0.4%	1.4%	−1.5%
2007∼2008	1.019	1.026	0.995	1.032	1.023	1.010	−1.3%	0.3%	−1.5%
2008∼2009	0.999	0.990	1.009	1.017	1.004	1.015	−1.8%	−1.4%	−1.5%
2009∼2010	1.028	1.026	1.003	1.036	1.031	1.007	−1.8%	−1.5%	−1.4%
2010∼2011	0.994	0.987	1.008	0.996	0.985	1.012	−1.2%	0.2%	−1.4%
2011∼2012	1.016	1.003	1.014	1.022	1.006	1.017	−1.6%	−1.3%	−1.3%
2012∼2013	1.002	1.002	1.003	1.013	1.012	1.001	−1.0%	−1.0%	0.2%
2013∼2014	0.990	0.992	0.997	0.979	0.982	0.997	1.1%	1.1%	0.1%
2014∼2015	1.003	1.011	0.992	1.008	1.021	0.988	−1.5%	−1.9%	0.4%
2015∼2016	1.016	1.005	1.010	1.005	0.992	1.012	1.1%	1.3%	−1.2%
2016∼2017	0.997	0.977	1.022	1.002	0.974	1.030	−1.5%	0.3%	−1.8%
2017∼2018	1.011	1.012	0.999	1.013	1.005	1.008	−1.2%	0.7%	−1.9%
2018∼2019	1.021	1.016	1.006	1.030	1.025	1.008	−1.9%	−1.9%	−1.2%

Note: GML measures green productivity, BPC in column 2 measures green technical change and EC in column 3 is green efficiency change. GM measure traditional agriculture productivity which ignores emissions; BPC and EC in column 5 and 6 are measures of traditional technical change and efficiency change.

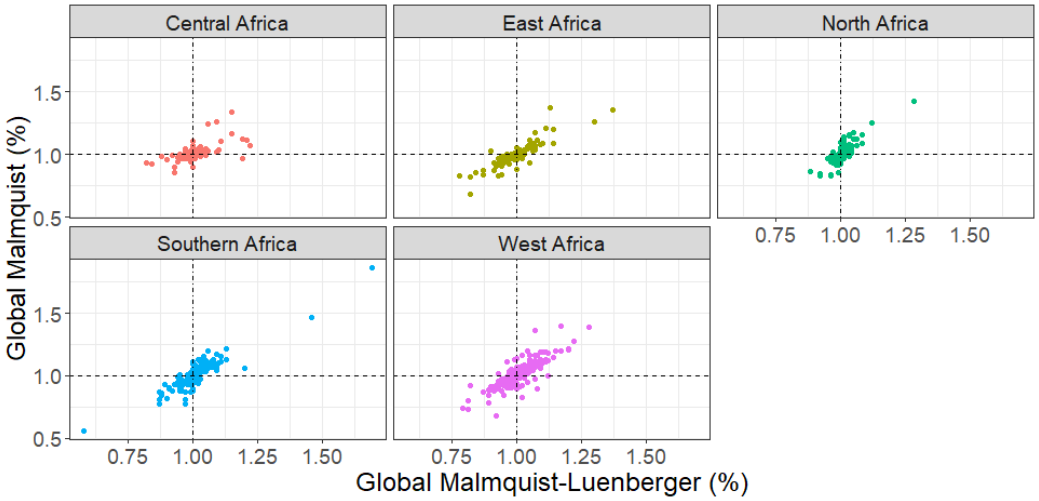


Figure 1. GML and GM index estimates for different regions in Africa, 2000–2019.

North Africa had an average GATFP of 0.7% also driven by efficiency change. This growth rate ranged from 0.01% in 2001–2002, 2010–2011, 2016–2017, 2017–2018, and 2018–2019 to 1.06% in 2007–2008 (see Table A3). This growth can also be classified into: less than one percent, covering the years 2000–2001, 2003–2004, 2006–2007 and 2015–2016; and above one percent for the rest of the sampled periods. In fourth position was Central Africa with an annual average GATFP of 0.5% driven by efficiency change (see Table A4) This ranged from 0.99% in 2000–2001 to 1.05% in 2011–2012. Over a period of four years (2007–2008, 2013–2014, 2014–2015 and 2018–2019), the region was productive, and great improvement was observed for six years (2004–2005, 2006–2007, 2009–2010, 2011–2012,

2015–2016 and 2017–2018), ranging from 1.01% to 1.05%. The least GATFP growth was recorded in East Africa (see Table A5). The region had an annual average growth rate of 0.99%, also explained by efficiency change (1.003%) component. Over the period 2008–2009 and 2010–2011, the region had a productivity at 1.00% and growth showed further improvement in a space of ten years. The overall findings for productivity growth at regional level reveal that GATFP estimates are lower than those of traditional TFP. Regardless of region, efficiency change emerged as a consistent driver of growth while there remains a scope for enhancement of technical change for further improvement of growth. Additionally, the continent has been on the right track towards improved regional integration over the study period. Similar to the discussion of the results in Table 2 for the continental level, great strides should be made towards improvement of green or sustainable agriculture productivity growth even at regional level. For better achievement of the aspirations of CAADP Malabo, this finding implies that customisation of agricultural policies to regional level is required.

The productivity growth rates for individual African countries varies greatly. An ideal growth performance (that is, GML estimates exceeding traditional those of GM) was attained by 20% of the sampled countries. These included South Africa, Tunisia, Djibouti, Madagascar, Côte d'Ivoire, Equatorial Guinea, Comoros, Mozambique, Carbo Verde and Gambia. We also found that Botswana, Central African Republic, Egypt, Eswatini, Mauritius, Nigeria, Tanzania and Uganda had a balanced performance where GATFP was equivalent to traditional TFP. However, sixty-three percent (63%) of the sampled countries exhibited unsustainable agriculture growth, where traditional TFP exceeds GATFP. At a glance, Figure 2 clearly shows that countries such as Niger, Burkina Faso, Senegal and Zambia achieved sustainable agriculture growth over the study period. More specific details for other countries are presented in Table A6.

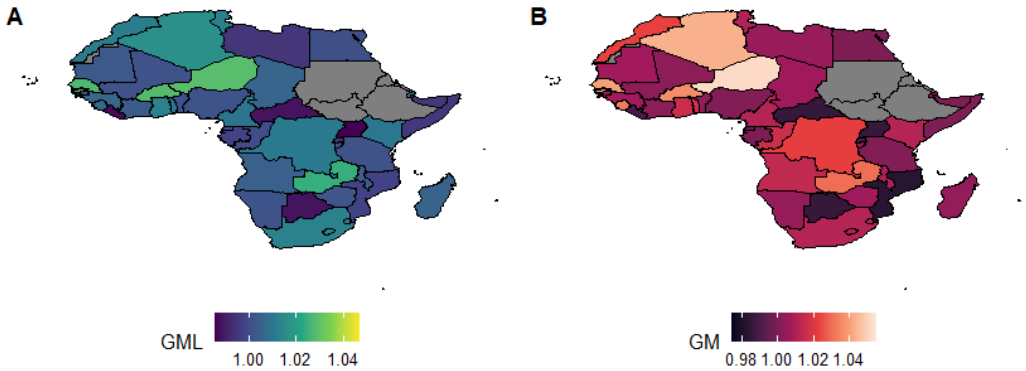


Figure 2. Panel (**A**) shows Green agriculture productivity for each African country measured by GML index, 2000–2019. Panel (**B**) shows traditional agriculture productivity which ignores emission measured by GM index, 2000–2019. Countries in gray colour were not included in our analysis.

5. Discussion

The initial aim of the study was to assess whether agriculture productivity in Africa is sustainable in the first 19 years of the twenty-first century. The results indicated an average GATFP of 1.006% for agriculture in Africa over the study period. This indicates an annual average growth rate of 0.6% if emissions are taken into consideration. However, it falls short by 5.4% from the desired annual target of 6% [51,52] by CAADP. If emissions are discarded, the annual average growth rate was 0.9%, which still remains low compared to the aspirations of the aforementioned programme. Nonetheless, both findings confirm Bruntrup [53] and Benin [54], who claim that agricultural growth rates in Africa are still far from combating poverty and food insecurity.

A recent biennial review report which assesses progress towards achievement of Malabo Declaration show that Rwanda is the only country on track towards achieving the

CAADP Malabo commitments by 2025 [55]. This corroborates our finding of 63% African nations lagging behind in attaining sustainable agriculture growth. This suggests that more effort is required to transform African economies towards green growth which ensures better high-quality development and better management of natural resources [56]. One way to achieve this is through strengthening the research and development of green science and technology, and encouraging strong integration of industrialisation and agriculture development [36]. This should also include improved regulation and climate-smart agricultural practices [57,58].

Similar to Boussemart et al. [59], we found that traditional TFP estimates exceed those of green agriculture productivity growth and the difference was (0.3%), indicating that the GM index approach tends to overestimate the productivity growth rates. For better policy formulation, future studies on productivity growth of agriculture in Africa should place more emphasis on green productivity applying the appropriate measures such as the GML index approach. According to AFDB [56], such kind of approaches will yield to policies that promote better climate-resilient and climate-compatible growth that ensures sustainable consumption and production patterns. This is also a solution to the current situation, as evidenced from our findings, which reveal that Africa's regional productivity growth pattern is characterised by either both low GATFP and traditional TFP estimates, or higher estimates for both.

Despite the high emission of SO_2 and NO_x due to high presence of industrial and thermal power plants [60], Southern Africa and Northern Africa showed GATFP growth. A possible explanation for this result is that these two regions have relatively developed economies compared to other regions, thus making great strides towards better management of emissions. West Africa also showed positive green agriculture growth despite higher levels of agricultural emissions coupled by huge population density [11,60]. On the other hand, the lowest GATFP in Central Africa can be attributed to political instability evident from rebel insurgency particularly in countries such as the Democratic Republic of Congo [61]. This is harming the country's and neighboring countries' economies, significantly impacting Africa's regional integration ambitions, particularly in this region. Another key finding is that East Africa and Southern Africa were the only regions achieving the desired outcome of GATFP exceeding traditional TFP estimates. Other regions can emulates these two by implementing programmes and strategies aimed at encouraging green productive efficiency.

The sampled countries showed mixed findings on productivity estimates with Lesotho, Niger, Burkina Faso, Senegal, Zambia, Benin, South Africa, Ghana and Tunisia leading in terms of GATFP. These differences in regional and country estimates of both GATFP and conventional TFP can be ascribed to a number of factors such as variations in climate, level of development and political environment [45]. However, role models should be taken from nations with high GATFP and low traditional TFP to better understand appropriate performance and derive policy insights. Countries with balanced performance should work harder to reach the level of the aforementioned nations. Overall, this suggests that country- or region-specific policies for improved green productivity are also crucial [62].

6. Conclusions

The study is motivated by the urgent need to ensure that agriculture productivity growth in Africa is sustainable in order to feed the rapidly expanding population and foster economic growth. Additionally, it addresses the gap in the literature by balancing resource utilisation, increased productivity growth and environmental protection in accordance with sustainable development objectives. We used the GML index method, which considers emissions as an undesirable output in agricultural productivity analysis, hence the term GATFP. This was accomplished in conjunction with the GM index method, which disregards the impact of undesirable outputs yielding to traditional TFP estimates. Using panel data from 49 African nations from 2000 to 2019, we focused on the continent, region and national levels.

Based on the analysis, we conclude that Africa's green agriculture productivity growth (GATFP) is slightly sustainable with a fluctuating trend. In addition, there are differences in productivity estimates both at the region and national level. This growth is consistently explained by green productive efficiency while green technical change had very minimal contribution. However, the results from GM suggest that ignoring emissions leads to unreliable estimates of true agriculture productivity growth. This implies that emissions have a serious effect on agricultural productivity in Africa; hence, climate-smart agricultural practices are non-negotiable. Henceforth, the GML provides a true reflection of agriculture productivity growth (GATFP) in the continent. Regionally, the growth is mostly characterised by high (low) GATFP and traditional TFP except for Southern Africa and East Africa. Another important finding is that growth can be viewed into three scenarios: desired growth, where GATFP exceeds traditional TFP; balanced growth , where both estimates are equivalent; and undesired growth, where traditional TFP exceeds GATFP. Unfortunately, most African nation fall in the last scenario.

Our findings have several implications for practice and policy. The green technical change should be strengthened through investment in research and development of green science and technology, and by encouraging strong integration of industrialisation and agriculture development. This should be matched by improved environmental regulation and greater compliance to climate-smart agricultural practices. Moreover, policy options should also include agroforestry, integrated nutrient management, advanced seeds, conservation tillage, water resource management and improved livestock and crop breeds. Prior to our study, no single research was found on GATFP in Africa. In this way, the study has shed new light that expands the current understanding on agricultural productivity at different levels of the continent by shifting from the traditional analytical approach. Notwithstanding data limitations due to delayed updates arising from COVID-19 disruption, the study has successfully laid the foundation for future studies while providing indirect evaluation of Africa's compliance to CAADP and the sustainable development agenda. Therefore, future studies should focus on GATFP instead of conventional TFP for better policy formulation aligned to the green growth in Africa's agricultural sector.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Estimates of GML and GM index for Southern Africa, 2000–2019.

Southern Africa	GML	BPC	EC	GM	BPC	EC
2000∼2001	1.03	0.98	1.05	1.02	0.98	1.04
2001∼2002	0.99	1.04	0.97	0.95	0.98	0.97
2002∼2003	1.01	0.98	1.05	1.02	1.01	1.01
2003∼2004	1.01	1.00	1.01	0.99	0.99	1.01
2004∼2005	1.00	1.00	1.00	1.00	0.98	1.02
2005∼2006	0.99	0.98	1.01	0.98	0.98	1.00
2006∼2007	1.01	1.00	1.01	1.03	0.99	1.05
2007∼2008	1.01	1.00	1.01	1.01	1.00	1.01
2008∼2009	1.01	1.00	1.01	1.03	1.01	1.02
2009∼2010	1.01	1.01	1.00	1.02	1.02	1.01
2010∼2011	1.02	1.02	1.00	1.02	1.01	1.01
2011∼2012	1.00	1.00	1.00	1.01	1.00	1.01
2012∼2013	1.01	0.99	1.02	1.01	0.99	1.02
2013∼2014	0.98	1.00	0.98	0.96	0.98	0.98
2014∼2015	1.02	1.02	1.01	1.02	1.02	1.00
2015∼2016	1.02	1.01	1.01	1.01	1.00	1.01
2016∼2017	0.97	0.96	1.01	0.98	0.95	1.03
2017∼2018	1.01	1.01	1.00	1.01	1.01	1.00
2018∼2019	1.06	1.06	1.01	1.08	1.06	1.02
Mean	1.008	1.002	1.008	1.009	0.998	1.011

Note: GML measures green productivity, BPC in column 3 measures green technical change and EC in column 4 is green efficiency change. GM measure traditional agriculture productivity which ignores emissions; BPC and EC in column 6 and 7 are measures of traditional technical change and efficiency change.

Table A2. Estimates of GML and GM index for West Africa, 2000–2019.

West Africa	GML	BPC	EC	GM	BPC	EC
2000∼2001	1.02	1.01	1.01	1.03	0.99	1.04
2001∼2002	0.98	1.00	0.98	0.98	1.00	0.98
2002∼2003	1.00	1.00	1.00	1.02	1.02	1.01
2003∼2004	1.02	1.01	1.01	1.01	1.00	1.00
2004∼2005	0.99	1.01	0.98	1.02	1.00	1.02
2005∼2006	0.99	1.00	0.99	0.99	1.01	0.98
2006∼2007	0.99	0.96	1.04	0.97	0.94	1.04
2007∼2008	1.06	1.07	0.99	1.09	1.07	1.01
2008∼2009	0.99	0.98	1.01	1.01	1.00	1.01
2009∼2010	1.05	1.05	0.99	1.05	1.06	1.00
2010∼2011	0.97	0.96	1.02	0.97	0.95	1.02
2011∼2012	1.03	1.02	1.01	1.04	1.02	1.02
2012∼2013	1.00	1.00	1.01	1.01	1.02	0.99
2013∼2014	1.02	0.99	1.02	1.02	1.00	1.02
2014∼2015	1.00	1.02	0.98	1.01	1.04	0.97
2015∼2016	1.00	1.01	1.00	0.99	0.96	1.03
2016∼2017	1.01	0.98	1.04	1.01	0.99	1.02
2017∼2018	1.01	1.01	1.00	1.01	1.00	1.01
2018∼2019	1.01	1.01	1.00	1.01	1.01	1.00
Mean	1.007	1.004	1.005	1.011	1.004	1.008

Note: GML measures green productivity, BPC in column 3 measures green technical change and EC in column 4 is green efficiency change. GM measure traditional agriculture productivity which ignores emissions; BPC and EC in column 6 and 7 are measures of traditional technical change and efficiency change.

Table A3. Estimates of GML and GM index for North Africa, 2000–2019.

Noth Africa	GML	BPC	EC	GM	BPC	EC
2000∼2001	0.99	1.01	0.98	0.95	0.98	0.97
2001∼2002	1.01	1.01	1.00	1.03	0.97	1.07
2002∼2003	1.07	1.00	1.07	1.11	1.09	1.02
2003∼2004	0.96	1.00	0.96	0.98	1.06	0.93
2004∼2005	1.02	0.99	1.03	1.02	0.96	1.06
2005∼2006	1.00	1.00	1.00	1.03	1.06	0.97
2006∼2007	0.98	0.99	1.00	0.99	0.95	1.03
2007∼2008	1.02	1.00	1.02	1.04	0.98	1.06
2008∼2009	1.02	1.02	1.00	1.06	1.06	1.00
2009∼2010	1.00	1.00	1.00	1.00	0.99	1.02
2010∼2011	1.01	1.00	1.01	1.02	0.97	1.06
2011∼2012	1.02	0.99	1.03	1.03	0.98	1.05
2012∼2013	1.00	1.00	1.00	1.01	1.00	1.01
2013∼2014	1.00	0.99	1.00	0.98	0.96	1.03
2014∼2015	1.03	1.00	1.03	1.07	1.07	1.00
2015∼2016	0.97	1.00	0.97	0.95	0.97	0.98
2016∼2017	1.00	0.99	1.01	1.00	0.98	1.03
2017∼2018	1.01	1.00	1.01	1.02	1.03	0.99
2018∼2019	1.01	1.01	1.00	1.02	0.99	1.03
Mean	1.007	1.000	1.007	1.016	1.002	1.016

Note: GML measures green productivity, BPC in column 3 measures green technical change and EC in column 4 is green efficiency change. GM measure traditional agriculture productivity which ignores emissions; BPC and EC in column 6 and 7 are measures of traditional technical change and efficiency change.

Table A4. Estimates of GML and GM index for Central Africa, 2000–2019.

Central Africa	GML	BPC	EC	GM	BPC	EC
2000∼2001	0.99	0.98	1.01	1.01	0.95	1.07
2001∼2002	0.98	0.99	0.99	1.01	1.02	0.99
2002∼2003	0.99	0.99	0.99	0.99	0.99	0.99
2003∼2004	0.98	0.99	1.00	0.97	0.95	1.02
2004∼2005	1.05	1.01	1.04	1.04	1.01	1.03
2005∼2006	0.98	0.99	0.99	1.00	1.01	0.99
2006∼2007	1.03	0.97	1.07	0.99	0.97	1.03
2007∼2008	1.00	1.00	0.99	1.01	0.99	1.03
2008∼2009	0.99	1.00	0.99	0.99	0.99	1.00
2009∼2010	1.04	1.03	1.02	1.05	1.04	1.01
2010∼2011	0.98	0.99	0.99	0.99	1.01	0.99
2011∼2012	1.05	1.01	1.04	1.05	1.03	1.02
2012∼2013	0.99	1.02	0.98	1.00	1.02	0.99
2013∼2014	1.00	1.01	0.99	0.98	1.00	0.99
2014∼2015	1.00	1.02	0.98	0.99	1.01	0.98
2015∼2016	1.03	1.01	1.03	1.05	1.03	1.02
2016∼2017	0.99	0.99	1.00	1.01	1.00	1.01
2017∼2018	1.01	1.01	1.00	1.00	0.98	1.02
2018∼2019	1.00	0.98	1.02	1.03	1.06	0.99
Mean	1.005	1.000	1.006	1.009	1.003	1.009

Note: GML measures green productivity, BPC in column 3 measures green technical change and EC in column 4 is green efficiency change. GM measure traditional agriculture productivity which ignores emissions; BPC and EC in column 6 and 7 are measures of traditional technical change and efficiency change.

Table A5. Estimates of GML and GM index for East Africa, 2000–2019.

East Africa	GML	BPC	EC	GM	BPC	EC
2000∼2001	1.02	1.00	1.02	1.01	1.00	1.01
2001∼2002	1.02	1.00	1.02	1.03	1.00	1.03
2002∼2003	0.98	1.00	0.98	0.97	1.00	0.97
2003∼2004	0.98	1.00	0.98	0.99	1.00	0.99
2004∼2005	1.03	1.00	1.03	1.02	1.00	1.01
2005∼2006	0.96	1.00	0.96	0.97	1.00	0.97
2006∼2007	1.03	0.99	1.04	1.03	0.98	1.06
2007∼2008	0.97	1.01	0.96	0.97	1.02	0.95
2008∼2009	1.00	0.98	1.02	1.02	0.98	1.04
2009∼2010	1.03	1.00	1.02	1.03	1.01	1.02
2010∼2011	1.00	0.99	1.01	0.99	0.99	1.00
2011∼2012	0.98	0.98	1.00	0.97	0.97	1.00
2012∼2013	1.01	1.02	0.99	1.04	1.03	1.01
2013∼2014	0.94	0.97	0.97	0.91	0.95	0.96
2014∼2015	0.96	0.99	0.97	0.96	0.97	0.99
2015∼2016	1.04	1.00	1.04	1.02	1.02	1.00
2016∼2017	1.01	0.98	1.03	1.01	0.94	1.07
2017∼2018	1.03	1.03	1.00	1.04	1.02	1.02
2018∼2019	1.01	1.00	1.01	0.99	0.98	1.02
Mean	0.999	0.997	1.003	0.999	0.993	1.007

Note: GML measures green productivity, BPC in column 3 measures green technical change and EC in column 4 is green efficiency change. GM measure traditional agriculture productivity which ignores emissions; BPC and EC in column 6 and 7 are measures of traditional technical change and efficiency change

Table A6. Estimates of GML and GM for individual countries in Africa, 2000–2019.

Country	GML	BPC	EC	GM	BPC	EC
Algeria	1.016	1.007	1.008	1.043	1.018	1.026
Angola	1.004	1.001	1.004	1.014	0.999	1.015
Benin	1.015	1.002	1.013	1.016	1.005	1.010
Botswana	0.988	1.000	0.988	0.985	0.990	0.994
Burkina Faso	1.028	1.030	1.000	1.036	1.032	1.005
Burundi	1.000	0.998	1.004	1.003	0.983	1.022
Cabo Verde	0.997	0.994	1.003	0.974	0.974	1.002
Cameroon	1.009	1.000	1.009	1.011	1.001	1.011
Central African Republic	1.007	1.003	1.011	1.007	0.994	1.014
Chad	1.005	1.000	1.005	1.007	1.001	1.007
Comoros	0.998	0.997	1.001	0.995	0.996	1.001
Congo DR	1.010	1.010	1.001	1.022	1.009	1.015
Congo Republic	0.999	0.997	1.003	1.016	1.002	1.014
Côte d'Ivoire	1.003	1.000	1.003	1.002	0.999	1.005
Djibouti	1.009	1.000	1.009	1.006	1.001	1.003
Egypt	1.000	1.000	1.000	1.000	1.000	1.000
Equatorial Guinea	1.000	1.000	1.000	0.996	0.996	1.003
Eswatini	1.011	1.000	1.011	1.011	1.001	1.010
Gabon	0.997	0.989	1.009	1.000	0.986	1.015
Gambia	0.991	0.985	1.012	0.982	0.977	1.008
Ghana	1.012	1.000	1.012	1.016	1.001	1.015
Guinea	1.005	0.998	1.008	1.007	0.998	1.010
Guinea-Bissau	1.001	0.994	1.008	1.006	0.997	1.011
Kenya	1.009	1.000	1.009	1.011	1.000	1.011
Lesotho	1.047	1.024	1.025	1.055	1.031	1.022
Liberia	0.986	0.989	1.000	0.990	0.975	1.016
Libya	0.994	0.986	1.008	1.005	0.971	1.039

Table A6. *Cont.*

Country	GML	BPC	EC	GM	BPC	EC
Madagascar	1.005	0.997	1.012	1.004	0.997	1.009
Malawi	1.004	1.000	1.004	1.009	1.000	1.009
Mali	1.001	1.000	1.001	1.003	1.000	1.003
Mauritania	1.002	1.002	1.002	1.007	1.001	1.007
Mauritius	1.007	1.000	1.007	1.007	1.000	1.007
Morocco	1.011	1.005	1.006	1.023	1.022	1.002
Mozambique	0.997	0.978	1.021	0.982	0.964	1.020
Namibia	1.001	0.996	1.005	1.004	0.986	1.019
Niger	1.028	1.026	1.010	1.052	1.033	1.022
Nigeria	1.001	1.000	1.001	1.001	1.000	1.001
Rwanda	0.994	0.995	0.999	0.989	0.988	1.000
Sao Tome and Principe	1.010	1.000	1.010	1.014	1.034	0.992
Senegal	1.027	1.030	1.001	1.040	1.039	1.001
Sierra Leone	1.006	1.006	1.001	1.033	1.017	1.018
Somalia	0.995	1.000	0.995	1.000	0.993	1.008
South Africa	1.012	1.000	1.012	1.011	1.000	1.011
Tanzania	1.001	1.000	1.001	1.001	1.000	1.001
Togo	1.010	1.006	1.005	1.017	1.015	1.003
Tunisia	1.012	1.000	1.012	1.010	0.999	1.011
Uganda	0.985	0.985	1.000	0.985	0.984	1.002
Zambia	1.024	1.043	1.009	1.030	1.019	1.012
Zimbabwe	1.002	0.993	1.010	1.007	0.996	1.011

Note: GML measures green productivity, BPC in column 3 measures green technical change and EC in column 4 is green efficiency change. GM measure traditional agriculture productivity which ignores emissions, BPC and EC in column 6 and 7 are measures of traditional technical change and efficiency change.

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