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Can Mobile Money Adoption Affect Environmental Sustainability in Energy Transition Context ?

Yacouba COULIBALY

U. of Orléans and U. Clermont Auvergne, France, LÉO

Research Consultant at UNU-WIDER

Helsinki 00160, Finland

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Abstract

Although mobile money has been hailed as a serious innovation in the pursuit of financial inclusion and poverty reduction ; however, its impact on the environment and energy transition is not yet fully understood. This study takes this thorny path by analysing the impact of mobile money adoption on greenhouse gas and CO₂ emissions in 41 African countries over the period 2002-2020. Using the entropy balancing method, I find that the adoption of mobile money contributed to an increase in emissions of 0.41 and 0.51 percentage points of greenhouse gases and CO₂, respectively in African countries. After checking the robustness of these results, I show that the main drivers of the destabilizing and amplifying effect of mobile money on the environment are fossil fuel energy consumption, agricultural value added, and financial development. In addition, the heterogeneity tests performed show the sensitivity of the result to the type of mobile money and some structural and institutional factors, including inflation, renewable energy consumption, rural population growth, remittance inflow, and rule of law. The main conclusions of the paper argue for more stringent environmental policies. This should encourage countries to invest in renewable energy to take advantage of the positive impact of mobile money on the environment and the energy transition.

Keywords : • Greenhouse gas emissions • CO₂ emissions • Energy transition
• Climate change • Environment • Climate Change • Mobile money

JEL Codes : E51, Q43, Q54, Q56

1 Introduction

The mobile money system has emerged in developing countries as an alternative financial inclusion tool to improve people's well-being (Apeti, 2023; Yao et al., 2023; Sekabira and Qaim, 2017). Basically, mobile money is a mobile payment system linked to a phone number that allows its owners to perform most withdrawal-and deposit transactions through a network of agents on a cell phone (Batista and Vicente, 2020; GSMA, 2021). Mobile money, in the countries that have adopted it, has enabled the financial inclusion of a large part of the population excluded from the traditional banking system, while providing them with an easy means of payment (Ahmad et al., 2020; N'dri and Kakinaka, 2020; Donovan, 2012).

Since its introduction in Africa by Kenya in 2007, statistics on the use of the service have increased exponentially (GSMA, 2021). Jack and Suri (2014) found that there were 13 times more active mobile financial services agents than ATMs in Kenya in 2011. According to GSMA (2021), there are over 9.1 million mobile money agents with 4.8 million active agents. It is estimated that there would be 1.21 billion accounts with nearly 740000 active accounts for a daily transaction of \$2.10 billion (Apeti, 2023). In addition, in Africa, more specifically in West Africa, the number of mobile money accounts increased by 20.9%, bringing the total number of accounts to 104.5 million from 2016 to 2017 (GSMA, 2021). In addition, the number of accounts increased by 13%, while the volume and value of transactions increased by 15% and 22%, respectively in 2020, (see for instance Apeti (2023) and GSMA (2021)).

In fact, the statistics and the extent of this new financial technology on the economies of developing countries, especially African countries, have led to much reflection, and very interesting results have been found. For instance, Apeti (2023) evaluates the impact of mobile money adoption on consumption volatility. The results show that countries that use mobile money have lower consumption volatility. The author explains this result by two transmission channels, namely financial inclusion and migrant remittances. These two channels have also been identified by other authors as the main factors behind the stabilizing effect of mobile money (Shaikh et al., 2023; Coffie and Hongjiang, 2023; Aggarwal et al., 2020; Niankara, 2023; Ahmed and Cowan, 2021; Koomson et al., 2021; Seng, 2021; Munyegera and Matsumoto, 2016; Riley, 2018; Okello Candiya Bongomin et al., 2018; Donovan, 2012). Like these authors, others show a positive effect of mobile money adoption on poverty (Djahini-Afawoubo et al., 2023; Yao et al., 2023; Lee et al.,

2021; Suri, 2017; Aker et al., 2016), on household savings (Batista and Vicente, 2020), increases consumer spending (Mohamed and Nor, 2022) and significantly increases tax revenue (Apeti and Edoh, 2023), increases household resilience to climate shocks, natural disasters and idiosyncratic shocks (Koomson et al., 2021; Afawubo et al., 2020; Phadera et al., 2019).

Since mobile money enables easy use of financial services by increasing household consumption through person-to-person, government-to-person, etc., money transfers, it could increase household consumption of fossil fuels. Accordingly, mobile money could affect environmental sustainability in host countries by accelerating the supply of hydrocarbons. In fact, mobile money can increase the number of subscribers to the power grid thanks to the simplified and fast payment of electricity bills. In fact, mobile money can increase the number of subscribers to the Electric circuit breaker thanks to the simplified and fast payment of electricity bills. This increases the capacity of electricity production in the power industry, an activity associated with great environmental risks. Another channel through which mobile money can enter the environment is through migrant remittances. The literature shows that mobile money increases remittances (Riley, 2018; Munyegera and Matsumoto, 2016), part of which is spent on fuel for agriculture, machinery and cars. This could intensify agricultural activity, accelerate deforestation (Combes et al., 2018), and increase greenhouse gas emissions in the country, as fossil fuels are responsible for 73% of global greenhouse gas emissions (Nations, 2021). However, it is possible that mobile money will facilitate financial inclusion (Shaikh et al., 2023) and increase the number of smartphone users in the country (Kabbiri et al., 2018). The increase in users could boost demand and production of smartphones, accelerating the production of minerals, which in turn could increase the supply of minerals important for the production of electric batteries for the energy transition. Conversely, on the other side of the coin, the darkest and most worrisome side of the smartphone manufacturing industry is its heavy reliance on exponentially growing energy consumption (Belkhir and Elmeligi, 2018). In fact, as our dependence on ICT devices and services rapidly increases, so does our need for energy to manufacture and electricity to power these devices, which is associated with significant emissions of carbon dioxide, greenhouse gases (GHGs), and other global warming pollutants (Belkhir and Elmeligi, 2018). Overall, the theoretical impact of the mobile money on environmental is ambiguous, something which should motivate the estimation of the empirical impact of mobile money on greenhouse gas emissions to inform policy responses to the mobile money.

Yet, the emerging literature on the socioeconomic impacts of mobile money ([Apeti, 2023](#); [Djahini-Afawoubo et al., 2023](#); [Apeti and Edoh, 2023](#); [Coffie and Hongjiang, 2023](#); [Niankara, 2023](#); [Shaikh et al., 2023](#); [Yao et al., 2023](#); [Mohamed and Nor, 2022](#); [Seng, 2021](#); [Koomson et al., 2021](#); [Ahmed and Cowan, 2021](#); [Lee et al., 2021](#); [Afawubo et al., 2020](#); [Ahmad et al., 2020](#); [Aggarwal et al., 2020](#); [Kabbiri et al., 2018](#); [Riley, 2018](#); [Munyegera and Matsumoto, 2016](#); [Jack et al., 2013](#), etc.) has so far remained relatively silent about the impact of the mobile money adoption on environmental sustainability, notably on the greenhouse gas emissions and CO₂ emissions for developing countries, including African economies. This is surprising because environmental sustainability is likely to be compromised by mobile money, even if it is a catalyst for financial inclusion and economic growth due to variations in both demand and supply of fossil fuels. To our knowledge, there are studies on the impact of fin-tech development on the environment ([Tao et al., 2022](#); [Liu et al., 2022](#); [Merello et al., 2022](#), etc.). These studies did not examine the important role that mobile money plays in greenhouse gases and CO₂ emissions in African countries. Therefore, this study fills an important gap in both the literature on the socioeconomic impacts of mobile money adoption and the literature on the determinants of environmental sustainability, because, to our knowledge, this is the first paper that estimates the impact of mobile money adoption on greenhouse gas emissions for a panel of African economies.

Basically, the way mobile money affects the environment is different from other fin-tech systems because it is easily accessible, fast, and formal. In fact, mobile money services can increase self-entrepreneurship, the ability of households to obtain well-paying jobs, receive remittances, invest, and improve firm's performance ([Lee et al., 2021](#); [Patnam and Yao, 2020](#); [Aggarwal et al., 2020](#)), this can boost the performance of tax revenue mobilization ([Apeti and Edoh, 2023](#)), and increase the overall capacity of government to finance sustainable development policies ([Okello Candiya Bongomin et al., 2018](#)). In the same vein, it is possible that the financial resources mobilized through mobile money services could be used to finance climate change adaptation and mitigation policies. This could take the form of funding renewable energy sources and green projects, as well as environmental improvement. It is also possible that mobile money can provide financial services such as savings — loans — and transfers to people facing environmental realities and promote resilience to climate change. In addition, mobile money can play an important role in providing — insurance to help smallholder farmers — affected by predictable weather fluctuations access financial protection. Environmental quality and financial development

were studied by [Zafar et al. \(2019\)](#), who found that financial development reduces carbon emissions and promotes environmental quality. However, other authors have noted that financial development increases CO₂ emissions ([Sharma et al., 2019](#)). Based on — this result from ([Sharma et al., 2019](#)), combined with the finding that mobile money promotes financial development ([Apeti, 2023](#); [Umar et al., 2020](#); [Shahbaz et al., 2013](#); [Tamazian et al., 2009](#), etc.), one might expect that mobile money would increase CO₂ emissions from financial development.

Mobile money services can increase the share of intra-African trade in GDP in adopting countries ([Sawadogo and Wandaogo, 2021](#); [Sekabira and Qaim, 2017](#)), an economic activity associated with high CO₂ emissions ([Wu et al., 2021](#)). In addition, [Aron \(2018\)](#) and [Ahmad et al. \(2020\)](#) argue that mobile money transactions can facilitate access to bank markets to obtain loans to finance their investments. [Munyegera and Matsumoto \(2016\)](#) and [Apeti \(2023\)](#) also argue — that mobile money provides access to external finance such as remittances, thereby boosting investment and consumption. Investment and consumption can increase — fossil fuel consumption. According to [Qiu \(2022\)](#), the macroeconomic effect of mobile money is not fully understood, even though the initiative has contributed to poverty — reduction. This author — believes that, with — limited market integration, mobile money increases national — consumer price indexes, triggering inflationary effects. This could lead monetary authorities to adopt restrictive monetary policies to stabilize prices. This would slow down green investment of firm's due to a lack of liquidity. The consequence could be a slowdown in the energy transition due to inflation caused by the increased use of mobile money.

Theoretically the environmental impact of mobile money is somewhat ambiguous. This should motivate future — research on the issue to enrich the current climate — debate. Despite the evolving literature on mobile money and its implications for development, to our knowledge little has been said about environmental sustainability. Most of the previous studies that have examined the impact of financial development, particularly mobile money, on greenhouse gas and carbon emissions — have been conducted in developing countries, primarily in Asia and Latin America (For instance, see [Aker et al. \(2016\)](#) and [Omri et al. \(2015\)](#)). Very little has been said about the case of African countries. Yet, this continent, which for many years has been considered the locomotive of global growth, is massively attracting new economic and financial technologies to eradicate poverty, inequality and climate change. This paper aims to fill this gap by analyzing whether the adoption of digital financial services, particularly mobile money, can be a factor that could

affect environmental sustainability given the large carbon footprint in African countries. In fact, if the use of mobile money transactions requires a cell phone, massive adoption of it could accelerate the production of strategic minerals for phone manufacturing. Indeed, [Cox et al. \(2022\)](#) estimate that mineral exploitation could increase the supply of minerals for battery production for the energy transition and reduce global carbon emissions, this could mitigate or even offset the negative impact of mineral development on the environment as a whole. However, force is to constat that mineral exploitation causes CO2 emissions and destroys forest cover, while forests are essential for carbon sequestration.

To identify the causal effect of mobile money on environmental sustainability, I rely on entropy balancing, a method of impact analysis recently developed by [Hainmueller \(2012\)](#). Using a sample of 41 African countries over the period 2002-2020, I show that mobile money adoption increases worsens environmental performance by increasing greenhouse gas and CO2 emissions in countries with mobile money relative to countries without mobile money. This result is robust to a battery of tests, including a placebo test, changing the definitions of mobile money, adding additional control variables, changing the sample design, and using alternative estimation methods such as propensity score matching, instrumental variable (2SLS), and system GMM. Another aspect treated in this paper shows that mobile money has a negative impact on ecological efficiency. Moreover, the heterogeneity tests performed show that : *i*- the effect of mobile money may depend on the level of renewable energy consumption, institutional quality (rule of law), rural population, inflation rate, and remittances ; and *ii*- the effect of mobile money may depend on the type of mobile money service. Finally, I analyze three transmission channels through which mobile money could affect environmental sustainability. At the end of this analysis, I provide evidence that the range of fossil fuel energy consumption, the increase in agricultural value added through intensification of agricultural activities, and innovations in financial development are channels through which mobile money negatively affects environmental performance in African countries. The remainder of the paper is organised as follows. The following section presents a prior research on environmental effects of Financial technology. Section 3 reports some stylized facts. Then, Section 4 describes the empirical methodology, while Section 5 presents the data and descriptive statistics. The main results are presented in Section 6, while in Section 7 I examine the sensitivity of these results and analyses the possible the transmission channels. Finally, Section 8 concludes the study and presents the main policy recommendations from the results.

2 Prior research on environmental effects of Fintech

Despite the evolving literature on mobile money and its macroeconomic impact on economic and social development, there is virtually no literature on its environmental impact. For this reason, I link our article to the handful of studies on financial technology, financial development and environment, given that mobile money constitute an innovation in financial technology and a pillar of financial development. [Shahbaz et al. \(2013\)](#) estimates the impact of financial development on CO₂ emissions in Malaysia using the bounds-testing approach to cointegration for the period 1971-2011. The results show that financial development reduces CO₂ emissions. These results corroborate the findings of [Umar et al. \(2020\)](#) who studied the long-term and causal effects of innovation, financial development, and transportation infrastructure on CO₂ emissions using the combined cointegration and wavelet coherence approach over the period from 1971-2018 in China. The author finds that there are long-term negative correlations between CO₂ emissions and financial development. [Tamazian et al. \(2009\)](#) examined the impact of financial development on carbon emissions in BRICS countries using a random effects model over period 1992–2004. Their results showed that financial development, as measured by stock market value, foreign direct investment, bank deposit-to-GDP ratio, capital account convertibility, financial liberalization, and financial openness, reduces carbon emissions. Similarly, [Tao et al. \(2022\)](#) investigated whether fintech development helps economies make a smooth transition to lower carbon and greenhouse gas emissions. Their findings are very encouraging and confirm that fintech development can indeed help reduce greenhouse gas emissions. These results are confirmed by [Awais et al. \(2023\)](#) who developed a green growth (GG) index to better understand the relationship between fintech and resource sustainability using panel data from 66 countries for the period 2010-2021. Their results show that internet penetration and Findex have a positive impact on green economic activity, while carbon emissions have a negative impact. Population growth and unemployment can also impact green growth. The authors therefore recommend the adoption of financial technology to achieve greener economic growth. Using the Method of Moments Quantile Regression, [Lisha et al. \(2023\)](#) examines the link between sustainability, green innovations, financial technologies (FinTech), financial development, and natural resources. for the BRICS economies between 2000 and 2019. They find that FinTech and natural resources negatively affect environmental sustainability in all three quantile ranges (0.10e-0.30e, 0.40e-0.60, and 0.70e-0.90e). In contrast, green innovation and financial development promote en-

environmental sustainability in the lower to higher quantiles (0.10e-0.90e). However, other studies have found a positive impact of financial development on CO₂ emissions. For instance, [Boutabba \(2014\)](#) estimates the impact of financial development, income, energy, and trade on carbon emissions in India. The results suggest that there is evidence of long-term causal relationships between carbon emissions, financial development, income, energy consumption, and trade openness. Most importantly, financial development has a positive long-term effect on carbon emissions, implying that financial development improves environmental degradation. [Wang et al. \(2020\)](#) are using CS-ARDL econometric techniques to how economic globalization, along with financial development, agriculture value-added, and natural resources affect CO₂ emissions in G7 economies for the period of 1996–2017. They conclude that economic globalization, financial development, and natural resources are leading to an increase in carbon emissions. Also using GMM estimators, [Khan and Ozturk \(2021\)](#) are investigated the direct and indirect effects of financial development on CO₂ emissions for 88 developing countries over period 2000–2014. The results show that financial development has a negative effect on pollution, but this effect disappears when the level of financial development reaches a certain threshold.

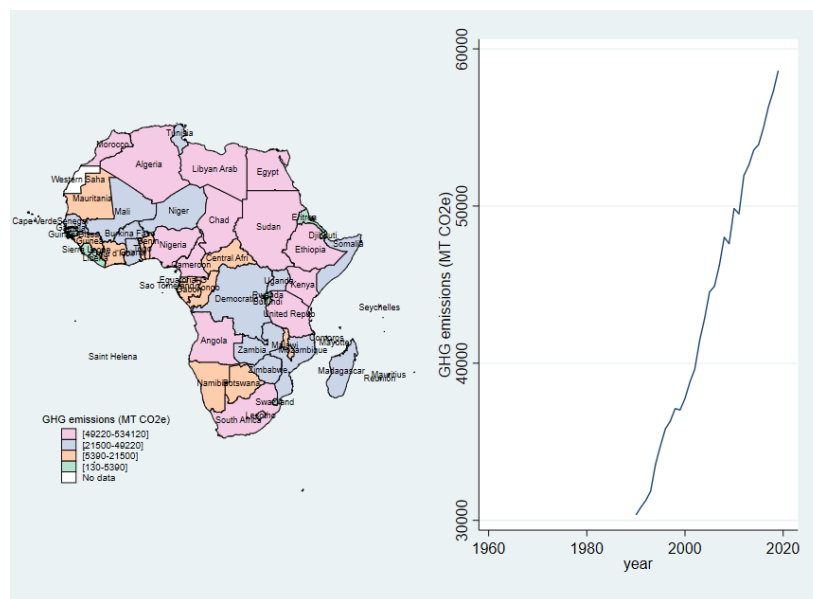
Indeed, commercial openness can serve as a channel for mobile money to destabilize environmental sustainability. In fact, mobile money can promote intraregional trade ([Sawadogo and Wandaogo, 2021](#)), which in turn compromises environmental quality ([Shahbaz et al., 2017](#)). [Dou et al. \(2021\)](#) are assessed the impact of trade openness on CO₂ emissions of China-Japan-ROK FTA from 1970 to 2019. Results show that trade openness has a positive impact on the greenhouse effect. Overall, the impact of fintech in general and mobile money in particular on environmental sustainability is far from a consensus in the literature. Mobile money can drive the emergence of information and communications technology (ICT) by increasing demand for smartphones ([Kabbiri et al., 2018](#)). While ICT does have a significant impact on the global emissions footprint ([Belkhir and Elmeligi, 2018](#)). According to [Belkhir and Elmeligi \(2018\)](#) the relative contribution of ICT-related greenhouse gas emissions could increase from around 1 to 1.6% in 2007 to over 14% of global greenhouse gas emissions in 2016 by 2040.

I proceed with a graphical analysis between mobile money and greenhouse gas emissions to determine if there is a correlation between the two variables in countries that adopt mobile money and countries that do not.

3 Mobile money and environmental sustainability in Africa : Stylized facts

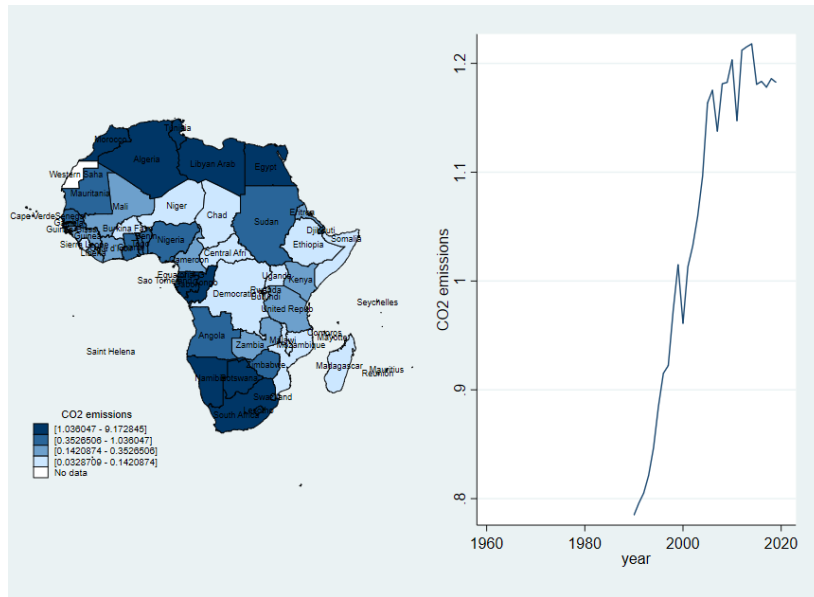
The underlying intuition of the paper is that mobile money, through household consumption, investment, and access to credit for agricultural activities, accelerates fossil fuel production and exacerbates the deterioration of environmental indicators. To this end, I first analyze the evolution of greenhouse gas emissions, then that of CO₂ from the 1960s to the last period under study. Figure 1 provides an overview of the evolution of these environmental indicators in megatons (MT). The figure clearly shows an exponential increase in GHG emissions from the 1990s to 2020, with GHG emissions from African countries reaching 40000 MT in 2008 and peaking at 53120 MT in 2020. Not surprisingly, Kenya, which was the first African country to introduce mobile money in 2007, is one of the largest emitters, with emissions ranging from 49220 to 534120 MT per year.

FIGURE 1 – Trend of GHG emissions in Africa from 1960-2020.



Source : Author's calculation based on WDI data.

FIGURE 2 – Trend of CO2 emissions in Africa from 1960-2020.



Source : Author’s calculation based on WDI data.

FIGURE 3 – Mobile money, GHG and CO2 emissions in Africa.



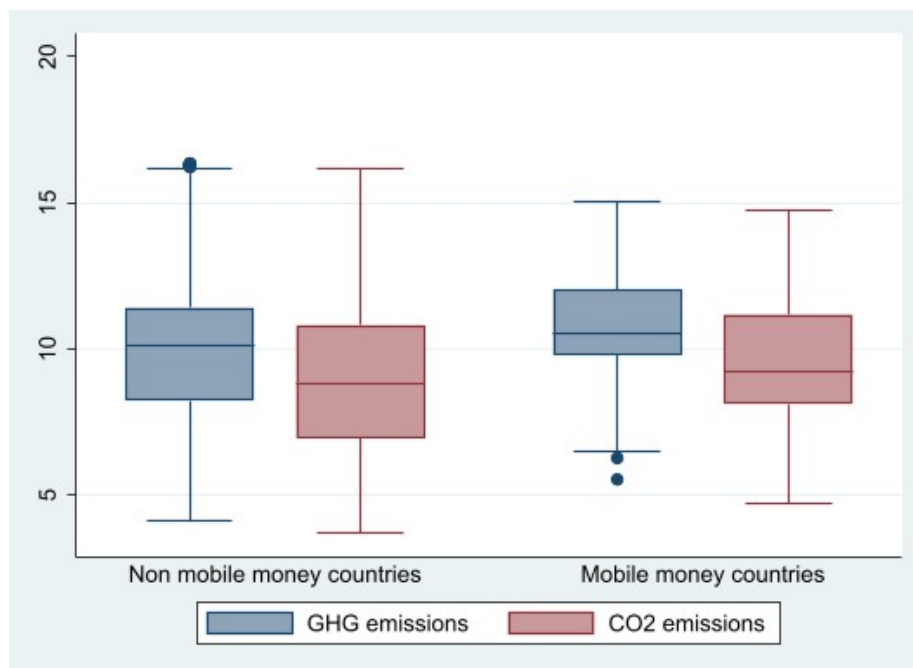
Source : Author’s calculation based on WDI data and GSMA data.

As depicted in figure 4 greenhouse gas emission rates, as well as CO2 emissions, are higher in countries that have adopted mobile money than in countries that have not. A more detailed analysis of the graph shows that cumulative emissions in countries that have adopted mobile money were relatively low before adoption compared to those that have not. However, after the introduction (post-period), these indicators have increased rapidly and continue to evolve. However, the gap in GHG and CO2 emissions is less pronounced in countries that do not have mobile money in both periods (pre-period and post-period).

This observation suggests that mobile money is associated with greenhouse gas emissions and CO2 emissions in Africa.

Even if this observation may serve as an argument or graphical evidence that mobile money is likely to go in pairs with emissions, it would be detrimental to conduct a more in-depth and innovative analysis such as econometric analysis to capture the actual causal effect of mobile money on emissions in African countries. In fact, not all GHG and CO2 emissions during the study period should be attributed to the adoption of mobile money, as other factors such as industrialization, demographics, exploitation of natural resources, etc. may also have contributed to emissions. This is the example of South Africa, which is one of Africa's biggest polluters because its state-owned energy company, Eskom, relies heavily on coal to generate electricity. Overall, I observe an upward trend in GHG and CO2 emissions for the countries in the sample. This gives me an inconclusive indication of the causal effect of mobile money on GHG emissions. Therefore, econometric analysis is crucial to capture the causal effect of mobile money on emissions in African countries.

FIGURE 4 – Mobile money, GHG and CO2 emissions in Africa.



Source : Author's calculation based on WDI data and GSMA data.

4 Methodology

Our objective is to analyze whether mobile money adoption improves environmental sustainability in African countries. Environmental sustainability is considered in this paper through two alternative variables : Greenhouse gas emissions and CO2 emissions. The main challenge of our empirical investigation is to establish a causal relationship between the adoption of mobile money and environmental performance indicators in African countries. The reasons why African countries adopt mobile money could be related to a country's macroeconomic conditions, economic performance, level of development, access to cell phones, commercial partners, and access to traditional financial services. While these factors may affect greenhouse gas emissions and CO2 emissions — making adoption endogenous. I address this endogeneity using a matching approach.

Indeed, in our analysis the countries which have adopted mobile money are the treated group. The units of analysis are country-year observations, observations — with mobile money in place constitute the treatment group while observations without mobile money represent the control group. The average — treatment effect on the treated (ATT) is given by :

$$ATT = E[Y_{(1)}|T=1] - E[Y_0|T=1] \quad (1)$$

where $Y_{(.)}$ is the outcome variable measuring the environmental sustainability. T indicates whether the observation unit is subject to mobile money adoption ($T = 1$) or not ($T = 0$). $E[(Y_{(1)}|T=1)]$ is the environmental sustainability level during the mobile money period, $E[(Y_0|T=1)]$ is the counterfactual result for countries that had adopted mobile money, i.e. the environmental sustainability in countries that had adopted mobile money if they had not. Equation 4 implies that comparing emissions observed in countries without mobile money with emissions that would be observed in the same countries if mobile money were introduced would yield an unbiased estimate of ATT. The main difficulty, however, is that the second term on the right-hand side of this equation is unobservable. I cannot observe the GHG and CO2 emissions of a country without mobile money if it had adopted mobile money. In this case, given a random selection of non-mobile money countries, I can simply compare the sample average of the non-mobile money countries and the mobile money countries to avoid this problem. However, the choice to adopt mobile money may be driven by certain observable factors (economic performance, level of

development, access to cell phones and financial development, etc.) that also determine greenhouse gas and CO2 emissions. This can lead to self-selection. Comparing the average value of GHG and CO2 emissions between the two samples may lead to a problem of "*selection on observables*" and bias the linear regression method (see for instance [Apeti \(2023\)](#); [Afawubo et al. \(2020\)](#) and [Apeti and Edoh \(2023\)](#)). In this case, the estimate of the ATT under unconfoundedness (or conditional independence), meaning that systematic differences in outcomes between treated and comparison individuals with the same covariate values are attributable to treatment, I can replace the unobservable term $E[Y(0)|T = 1]$ in Equation 4 with the observable term $E[Y(0)|T = 1, X = x]$. Considering these various elements and proofs, I can rewrite Equation 4 as follows :

$$ATT = E[(Y_{(1)}|T=1, X = x)] - E[Y_0|T=1, X = x] \quad (2)$$

where $X = x$ is a vector of observable covariates that may affect both the decision to adopt mobile money and the environmental sustainability, $E[Y(1)|T = 1, X = x]$ is the environmental sustainability of fiscal rule units, and $E[Y(0)|T = 0, X = x]$ is the expected environmental sustainability for the synthetic control units.

Following a handful of recent impact assessment studies, I use entropy balancing developed by [Hainmueller \(2012\)](#) and implemented by [Neuenkirch and Neumeier \(2016\)](#) and [Balima and Sy \(2021\)](#). This method consists of two principal steps : First, the weights assigned to the control units (in this case, the non-mobile money countries) are calculated in the entropy balancing. In the second step, the weights obtained in the first step are used in a regression analysis with the treatment variable (mobile money countries) as the explanatory variable. I then weight the countries with and without mobile money based on observable characteristics. Thus, the average difference in GHG and CO2 emissions between countries with mobile money and the "*closest*" non-mobile money countries should be explained by the introduction of mobile money adoption.

Unlike other methods for estimating effects and treatment effects, such as propensity score matching, entropy balancing has several advantages because of its ability to combine both matching and regression analysis (see for instance [Hainmueller \(2012\)](#); [Balima and Sy \(2021\)](#); [Sawadogo \(2020\)](#) and [Apeti \(2023\)](#)). In fact, this method outperforms the classical approach based on regression and matching based on propensity score methods because it is non-parametric — which allows to avoid the problem of mis-specification of the functional form of the model that could bias the results. Moreover, it is a method that

also eliminates multicollinearity problems, since the mechanism of re-weighting makes the treatment variable orthogonal to the covariates ([Hainmueller, 2012](#)).

This method has been used by several authors in their studies because of its advantages. For instance, [Apeti and Edoh \(2023\)](#) uses it to assess the impact of mobile money on tax revenue mobilization. [Apeti \(2023\)](#) to assess the effect of mobile money adoption on household consumption volatility. [Balima and Sy \(2021\)](#) to examine the role of IMF-supported programs in reducing the likelihood of subsequent sovereign defaults in borrowing countries. [Jacolin et al. \(2021\)](#) examine the impact of mobile financial services in particular, mobile money, mobile credit, and savings on the informal sector. All of these studies explain the advantages of entropy balancing in impact studies over other methods, which reinforces my belief that the method is robust. In addition, an advantage is that entropy balancing uses more flexible reweighting schemes compared to conventional balancing, where control units are either discarded or balanced. Here, units are reweighted with the goal of achieving a balance between processed and unprocessed units, keeping the weights as close as possible to the base weights to avoid information loss. Its most attractive feature is to allow a high degree of covariate balance between mobile money countries and non mobile money countries—even in small samples—by creating a synthetic control group that is as close as possible to the program group. Finally, classical matching methods and pooled probit models rely on the assumption of conditional independence, i.e., based on a vector of observable covariates, the treatment is independent of unobservable factors.

However, the use of entropy balancing allows us to account for the panel dimension of the data by controlling for country- and time-specific factors in the second stage of the regression analysis. It is necessary to include country-specific effects to account for potential unobserved heterogeneity between countries that have never adopted mobile money and those that have. Indeed, the macroeconomic environment of these two groups may differ beyond the covariates used in the entropy balancing approach. Country effects also control for time-invariant, country-specific conditions that may lead to differences in GHG and CO₂ emissions across countries. However, entropy balancing may fail to control for potential endogeneity biases due to unobserved time-varying factors that may affect both mobile money and environmental sustainability, as well as the reverse causality problem that may exist between the treatment variable and the outcome variable, and cannot successfully address the inertia of environmental sustainability. This can lead to potentially biased results. For this reason, I complement entropy balancing with alternative estima-

tion methods such as Propensity Score Matching (PSM), Instrumental Variable (2SLS) and two-step system-GMM dynamic panel estimator (GMM).

5 Data and descriptive statistics

Treatment variable : I'm collecting information on the existence of a transaction or transfer type of mobile money for African countries from GSMA Mobile Money Metrics database. GSMA Mobile Money Metrics assemble information on mobile money deployment and implementation in developing countries using a wide range of data sources that the program has been collecting, analyzing, and making publicly available since 2009, including : global metrics, mobile money prevalence index, mobile money deployment tracker, and mobile money regulatory index. Of the four sources mentioned above, I rely on refined data and information from two main sources : Global Metrics and Mobile Money Deployment Tracker. The former provides a comprehensive set of global metrics on accounts, agents, and usage that allow me to easily identify the existence of mobile money in that country. The second source provides the number of live mobile money services worldwide, collected from primary and secondary sources on a monthly basis. Based on these sources and the existing literature ([Apeti, 2023](#); [Apeti and Edoh, 2023](#); [Jacolin et al., 2021](#); [Riley, 2018](#); [Munyegera and Matsumoto, 2016](#)), I measure the adoption of mobile money by a dummy variable that takes the value 1 if country i adopted mobile money in period t and 0 otherwise.

The dataset compiled by GSMA Mobile Money Metrics on mobile money adoption may not be comprehensive due to the time lag between the first year of adoption, widespread deployment and surveys conducted by the GSMA. However, this is the most comprehensive dataset on mobile money services for development countries in particular African countries. Indeed, GSMA Mobile Money Metrics has identified a dozen mobile money services in developing countries. I use eight of them in this study including : *Person-to-person (P2P) transfer*, *Person-to-government (P2G) transfer*, *Government-to-person (G2P) transfer*, *Bill payment*, *Other bulk payment*, *Airtime top up*, *Merchant payment*, and *International remittances*.

Dependent variable : In this study, I use two variables to measure environmental sustainability as dependent variable, namely greenhouse gas and CO2 emissions. Greenhouse gas and carbon dioxide emissions are widely used measures of pollution or indicators of environmental performance in the literature ([Oppon et al., 2023](#); [Huang and Zhang,](#)

2023; Zhang et al., 2023; Romero and Gramkow, 2021; Dong et al., 2019; Cai et al., 2016; Douglas and Nishioka, 2012; Farzin and Bond, 2006; Han and Chatterjee, 1997, etc.) and are at the center of all debates on climate change. Data are from the World Bank's development indicators (WDI). It should be noted that data on greenhouse gas and CO2 emissions are available not only globally, but also for many countries and over relatively long time periods compared to other pollution measurements.

Control variables : Following the literature on the determinants of mobile money adoption and greenhouse gas and CO2 emissions, I choose the following variables : lag final consumption expenditure, log natural resources rents, lag public debt, log GDP per capita, log households consumption, general government revenue, and log trade openness. Indeed, these variables are chosen so that the control group of units without mobile money is, on average, as similar as possible to the treatment group of units with mobile money in terms of relevant pre-treatment characteristics. In other words, the selection was based on a set of similar characteristics of the treated and untreated units. I expect a negative correlation between natural resource rents and the adoption of mobile money, as heavy reliance on natural resources weakens the manufacturing value chain in favour of the extractive sector. This could slow down the willingness of governments to adopt new financial technologies. Countries with a resource-rich subsoil may try to focus exclusively on the extractive sector at the expense of other sectors and ignore the benefits of innovative reforms. Moreover, I expect a negative relationship between public debt, GDP per capita and mobile money adoption. In fact, unsustainable debt reduces fiscal space and the government's ability to implement serious reforms. As for GDP per capita, it is often considered an indicator of economic development and may correlate negatively with mobile money adoption, as a country with a high level of economic development has access to a variety of payment methods. A circumstance that would discourage it from adopting mobile money services.

However, I expect a positive correlation between the other four variables and mobile money adoption namely : final consumption expenditure, households consumption, general government revenue, and trade openness. Indeed, it can be assumed that in order to increase household consumption, a government adopts mobile money services to make transfers to the most vulnerable households in the event of a climate shock or natural disaster (see for instance, Apeti (2023) on household consumption volatility). Similarly, the government — can try to adopt mobile money in order to improve — internal — resource mobilization; avoid tax fraud, tax evasion and the hassles of making standard tax payments (see, Apeti and Edoh, 2023). The positive sign between trade openness

and mobile money can be justified by the fact that a country that has the most modern, innovative, and reliable means of transaction is likely to see an increase in trade flows. It is possible that a country adopts the reform because its trading partner has adopted mobile money services and requires it in its transactions and payments to merchants.

Finally, I test the performance of entropy balancing for my covariates. To this end, I present in tables 1 some descriptive statistics obtained before and after weighting to estimate the treatment effect of mobile money adoption. Columns [1] and [2] of Panel A show the sample means before weighting for the country-year observations for the treatment — group (with mobile money) and the control group (without mobile money), respectively. Column [3] of this table shows the difference in means between the two groups. The results reveal a difference — between these two — groups. Indeed, mobile money countries are characterized by high consumption expenditure, high natural resources rents, low public debt, low GDP per capita, high household consumption, low government revenue, and low trade openness. These results are mostly consistent with the expected relationship between the probability of adopting mobile money and the various reliable control variables discussed above. Columns [1] and [2] of Panel B show the sample mean after weighting between the treatment group and the synthetic group obtained by entropy balancing, and column [3] shows the difference between the first two. The analysis of the two groups in this table reveals the effectiveness of entropy balancing, as the difference shown in the previous table seems to disappear. Thus, using entropy balancing, I can construct a perfect control group that is very similar to the mobile money countries in terms of the means of the prepossessed covariates. My sample includes 100 country-year observations with mobile money in place (units of analysis or treated units) and 679 country-year observations without mobile money in place (units of control). The potential control group without mobile money is six times larger than the treatment group with mobile money, which allows us to obtain a weighted control group for the treatment group.

TABLE 1 – Descriptive statistics and covariate balancing

Panel A : Descriptive statistics before weighting	[1]	[2]	[3]=[2]-[1]
	Mobile money	Non mobile money	Difference
Lag Final consumption expenditure	81.6	79.29	-2.31
Log Natural resources rents	1.3	0.858	-0.442
Lag Public debt	41.05	51.6	10.55
Log GDP per capita	8.549	9.061	0.512
Log Households consumption	4.182	4.107	-0.075
General government revenue	20.21	25.1	4.89
Log Trade	4.096	4.238	0.142
Observations	93	549	
Panel B : Descriptive statistics After weighting	[1]	[2]	[3]=[2]-[1]
	Mobile money	Non mobile money	Difference
Lag Final consumption expenditure	81.6	81.6	0
Log Natural resources rents	1.3	1.3	0
Lag Public debt	41.05	41.05	0
Log GDP per capita	8.549	8.549	0
Log Households consumption	4.182	4.182	0
General government revenue	20.21	20.21	0
Log Trade	4.096	4.096	0
Observations	93	549	
Observations of weights	93	549	

This table presents the pre-weighting sample means of the matching covariates for country-year observations where mobile money were in place (the treatment group) in column [1] and country- year observations where no mobile money were in place (the potential control group) in column [2]. Column [3] reports the differences in means between treated and control group.

6 Results

6.1 Mobile money and CO2 emissions

To analyze the causal impact of mobile money adoption on environmental sustainability, I begin by discussing the impact of mobile money adoption on CO2 emissions in this sub-section. Indeed, my intention is to study the magnitude of the impact of mobile money adoption on the issue variables separately. The intuition behind this maneuver is simple, I'm trying to separate the effect of the adoption of this new technology on the CO2 emissions from the greenhouse gas emissions (GHG). This seems both necessary and important given the current pollution levels in Africa. Indeed, by promoting financial development, mobile money contributes to carbon emissions by increasing fossil fuel consumption and accelerating industrialization. At the same time, mobile money can be used to combat

pollution by providing access to clean and affordable energy sources that reduce carbon emissions. Thus, the impact on CO2 emissions is ambiguous than greenhouse gas. Therefore, it is important to separate the two variables and capture the impact of both. The results presented in the Table 2 show that mobile money has a positive impact on CO2 emissions in adopting countries as opposed to non-adopting countries (see Table 2). This result can be explained by the fact that mobile money influences consumption, savings, and investment decisions in the non-renewable energy sector in African countries. Since energy transition is not a reality in most African countries, users channel the money flows received through mobile money into the consumption of fossil fuels such as oil, gasoline, gas, electricity, etc.

TABLE 2 – Mobile money and CO2 emissions

CO2 emissins (log)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
Mobile money dummy	0.6709*** (0.1828)	0.1801*** (0.0296)	0.6824*** (0.1931)	-0.0132 (0.0178)	0.5123*** (0.1241)	0.0442** (0.0190)	0.5459*** (0.1303)	0.0300* (0.0160)
Constant	7.9366*** (0.0738)	10.0554*** (0.0463)	7.1904*** (0.2630)	9.5485*** (0.0708)	-6.8087*** (2.7876)	-6.5855*** (1.166)	-8.2306*** (2.6278)	7.7972*** (1.1986)
Mains Covariates in the second step	No	No	No	No	Yes	Yes	Yes	Yes
Year fixed effects in the second step	No	No	Yes	Yes	No	No	Yes	Yes
Country fixed effects in the second step	No	Yes	No	Yes	No	Yes	No	Yes
R-squared	0.0443	0.9657	0.1176	0.9898	0.4969	0.9830	0.5327	0.9916
Observations	607	607	607	607	607	607	607	607

Standard errors in brackets. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Estimation method : Entropy balancing

6.2 Mobile money and Greenhouse gas emissions

To estimate the impact of mobile money on greenhouse gas emissions in African countries, I also use the entropy balancing method as a sub-section 6.1. The results are presented in Table 3. First, I exclude country and time fixed effects in column [1]. Then, in Columns ([1]-[4]), I present the second-stage results without adding the covariates that were used to form the synthetic group in the first stage. In Columns ([2]-[3]), I include the country and time fixed effects respectively, while in column [4] I include these two effects together. Finally, in Columns ([5]-[8]), I repeat the exercise in Columns ([1]-[4]) except that in each second-stage regression I add the covariates¹ used in the first stage, na-

1. The idea of including matching covariates in the second stage of entropy balancing increases the quality of matching as in a randomized experiment, and controlling for country/FE and time/FE eliminates any country or year specific effects (see for instance [Apeti \(2023\)](#); [Apeti and Edoh \(2023\)](#); [Balima and Sy \(2021\)](#) and [Sawadogo \(2020\)](#)).

mely final consumption expenditure, natural resource rents, public debt, GDP per capita, household consumption, general government revenue, and trade openness. The impact of mobile money on greenhouse gas (GHG) emissions is positive and statistically significant at the 1% level (Table 3, Column [1]). Mobile money increases GHG emissions by 0.44 percentage points in the adopting countries. This result could be explained by the fact that mobile money facilitates access to credit through financial development, which allows households to purchase energy-consuming appliances and cars. While easy access to credit helps businesses invest in new equipment, machinery, and factories, which further increases greenhouse gas emissions. It should be noted that financial development also plays a crucial role in industrial restructuring and the urgency of energy-intensive manufacturing. This may help amplify the effect of mobile money on greenhouse gas emissions. In the same vein, mobile money, by increasing the number of phone users, creates additional demand for minerals to make phones, which will tend to accelerate the rate of fossil fuel production. Since fossil fuels production and consumption are associated with significant GHG emissions, mobile money end up having a positive impact on GHG emissions. The digital business-to-farmer (B2P) may also be a possible explanation for this result. According to [GSMA \(2022\)](#), 39% of mobile money providers offering bulk payments made payments to farmers in the agricultural value chain, and 120 agricultural organizations had digitized mobile payments in the value chain, 75% of which were in sub-Saharan Africa (e.g., Kenya and Uganda). Mobile money is becoming a vital service not only for farmers, but also for agribusinesses, cooperatives, and farmer groups, which will intensify agricultural activities and destroy forest cover. This will ultimately lead to an increase in GHG.

TABLE 3 – Mobile money and Greenhouse gas emissions

Greenhouse gas emissions (log)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
Mobile money dummy	0.4388*** (0.1161)	0.0945*** (0.0149)	0.4619*** (0.1793)	0.0016 (0.0120)	0.4069*** (0.1232)	0.0250** (0.0124)	0.4676*** (0.1317)	0.0064 (0.0120)
Constant	9.7850*** (0.0731)	11.2305*** (0.0163)	9.2467*** (0.2696)	10.9365*** (0.0328)	4.8261*** (2.8062)	2.8889*** (0.6036)	3.0220 (2.6748)	9.7459*** (0.6864)
Mains Covariates in the second step	No	No	No	No	Yes	Yes	Yes	Yes
Year fixed effects in the second step	No	No	Yes	Yes	No	No	Yes	Yes
Country fixed effects in the second step	No	Yes	No	Yes	No	Yes	No	Yes
R-squared	0.0233	0.9889	0.0649	0.9957	0.3389	0.9937	0.3787	0.9961
Observations	607	607	607	607	607	607	607	607

Standard errors in brackets. *** p<0.01, ** p<0.05, * p<0.1. Estimation method : Entropy balancing

7 Robustness checks

Estimates show that mobile money adoption significantly increases greenhouse gas and CO₂ emissions in African countries. In this section, I test the robustness of these results and the identified heterogeneous potentials.

7.1 Change of treatment variable : continuous variable.

Our baseline results are based on the use of a binary processing variable. However, the literature points out two major problems with using binary variables in a cross-national study. The first problem is that the binary variable is not able to capture the intensity of mobile money adoption in different countries, and the second problem is how mobile money is deployed in host countries. [Apeti \(2023\)](#)'s study used mobile money accounts per population as an alternative measure of the treatment variable to get around this problem. I follow [Apeti \(2023\)](#) in this approach, but go beyond it and add a second variable, namely registered mobile phone accounts per population. This consideration is explained by the fact that there could be a significant gap between active and registered mobile money accounts. By using both variables, I try to avoid this potential bias that could affect my results. Data for both variables are from the IMF Financial Access Survey database. This is not the most comprehensive database, but it provides broader temporal coverage than other databases such as FINDEX and GSMA data. The overall results are shown in Table 3. [Panel A](#) reports the results using mobile accounts as the variable of interest, while [Panel B](#) reports the results using registered mobile accounts. The main result of the paper remains unchanged when this consideration is included in the regressions.

7.2 Mobile money adoption, environmental sustainable and trend

In recent years, there has been a trend toward increasing mobile money penetration in African countries (see [Figure 4](#) and [GSMA \(2021\)](#)). Beside this, it is possible that the environment is damaged by other factors such as the development process of a country resulting in high greenhouse gas and CO₂ emissions in recent years (see above [Figure 1](#) and [Figure 2](#)). Indeed, according to the conventional Environmental Kuznets Curve (EKC) hypothesis, the initial phase of a country's economic development is likely to be associated with environmental degradation, but environmental degradation will decrease after a cer-

TABLE 4 – Robustness results with using continuous mobile money variables

VARIABLES	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
	Greenhouse gas emissions (log)				CO2 emissions (log)			
Panel A								
Mobile money accounts (FAS)	0.0842** (0.0325)	0.0305*** (0.0107)	0.0149 (0.0285)	0.0287** (0.0125)	0.1593*** (0.0297)	-0.0141 (0.0089)	0.1184*** (0.0237)	0.0184* (0.0103)
Constant	8.9980*** (0.4260)	10.9994*** (0.2569)	9.0319*** (3.0020)	6.4905*** (2.4254)	6.3229*** (0.3889)	9.3466*** (0.2141)	-1.1521 (2.4943)	9.6805*** (1.9891)
Country /FE	No	Yes	No	Yes	No	Yes	No	Yes
Time/FE	No	Yes	No	Yes	No	Yes	No	Yes
Controls	No	No	Yes	Yes	No	No	Yes	Yes
R-squared	0.0420	0.9924	0.4240	0.9942	0.1582	0.9944	0.5806	0.9959
Panel B								
Mobile money accounts registered (FAS)	0.2418*** (0.0350)	-0.0082 (0.0119)	0.1768*** (0.0303)	-0.0152 (0.0120)	0.2541*** (0.0384)	-0.0102 (0.0119)	0.2778*** (0.0284)	0.0143 (0.0109)
Constant	6.8616*** (0.5127)	11.2221*** (0.1269)	0.0098 (2.7729)	6.2328*** (2.1486)	5.0444*** (0.5633)	9.5921*** (0.1270)	-12.8897*** (2.5955)	5.0271** (1.9536)
Country /FE	No	Yes	No	Yes	No	Yes	No	Yes
Time /FE	No	Yes	No	Yes	No	Yes	No	Yes
Controls	No	No	Yes	Yes	No	No	Yes	Yes
R-squared	0.1896	0.9954	0.5418	0.9960	0.1763	0.9961	0.6621	0.9972

Standard errors in brackets. *** p<0.01, ** p<0.05, * p<0.1. Estimation method : Entropy balancing

tain level of economic growth due to efforts to promote green growth policies. Therefore, the development process can be expected to lead to an upward trend in greenhouse gas and CO2 emissions over time, although this cannot be fully explained by mobile money. To account for pollution over time and the upward trend in the number of countries adopting mobile money over the study period, I repeat the regressions of the baseline model by introducing a trend. Despite this new specification, the new estimates remain similar to those of the baseline model (see Table A12, in Appendix).

7.3 Adding control variables

I test the robustness of the results by extending the specification of the base model. To this end, I control for several additional variables that are likely to be positively or negatively correlated with both mobile money and GHG emissions. Based on the economic literature of mobile money adoption and GHG emissions, I control for the effects of seven additional variables, namely : household consumption volatility, domestic investment ², net ODA (% of GDP), rural population growth, urban population growth, democratic institutions and autocratic institutions.

2. Domestic investment is measured as the ratio of gross capital formation to GDP.

According to [Apeti \(2023\)](#), countries that have adopted mobile money have experienced low volatility in consumption as a percentage of GDP. Given that greenhouse gas emissions and CO₂ are largely due to household consumption, it is possible that mobile money affects the environment through consumption volatility³. The effect of consumption volatility on environmental sustainability can be mediated by GDP per capita volatility, since according to [Combes and Ebeke \(2011\)](#), GDP per capita volatility positively influences consumption volatility, which is usually caused by episodes of negative food price shocks ([Combes et al., 2014](#)). I take these observations into account controlling the effect of consumption volatility.

The economics literature has shown that domestic investment has a positive impact on environmental sustainability. For instance, [Brock and Taylor \(2010\)](#) found that high investment rates increase carbon dioxide emissions. I therefore control this effect of domestic investments. Donors and development partners are actively engaged in helping developing countries promote environmentally sound development. I take this consideration by including ODA as a percentage of GDP in the baseline specification. Their impact on environmental sustainability depends on their nature and final destination⁴, i.e. *Dirty ODA* and/or *Environmental ODA*.

In recent years, the massive adoption of mobile money has enabled populations in recipient countries to lift themselves out of poverty through financial inclusion. This has been observed through the increasing of mobile money transaction use by the population in rural and urban areas. It can also be assumed that the increase in population increases environmental degradation and ecological footprint. In fact, the increase in population could lead to an increased demand for fuel, food, energy, industry and transportation. In the same vein of ideas, population growth could lead to increased demand for fuel, food, energy, industry, and transportation. Similarly, rapid population growth could also lead to increased deforestation, land use change, and fossil fuel burning ([Cropper and Griffiths, 1994](#)). So I control the effects of rural population growth and urban population growth.

Finally, I use polity V 's political regime data to control for the effects of a democratic regime and those of an autocratic regime. In fact, according to [You et al. \(2015\)](#); [Bernauer](#)

3. Household consumption volatility is measured standard deviation of the real household consumption per capita growth rate estimated over a 5-year moving window (For construction, see [Apeti, 2023](#))

4. A number of other authors share the conclusion that the effect of ODA depends on its final destination (see [Hadjiyiannis et al., 2013](#); [Faye and Niehaus, 2012](#); [Tierney et al., 2011](#); [Michaelowa and Michaelowa, 2011](#); [Castro and Hammond, 2009](#); [Mak Arvin and Lew, 2009](#); [Alesina and Dollar, 2000](#)).

and Koubi (2009) and Farzin and Bond (2006), countries with democratic institutions emit fewer pollutants and harm the environment less than under an autocratic regime. For this I control the effect of democratic and autocratic institutions. Columns ([1]-[7]) in Table A2 in Appendix, reflecting the results of these specifications, show that they are consistent with our baseline results. In other words, the addition of these extra covariates does not change our results.

7.4 Alternative samples

In Table A3 in Appendix, I perform — some additional tests by re-estimating the main — model from alternative samples. First, I start from the conventional Environmental Kuznets Curve (EKC) hypothesis suggesting that the initial phase of economic development is likely to be accompanied by environmental degradation, but that environmental degradation declines after a certain level of economic growth due to green growth policy efforts. Therefore, I exclude from the sample those countries whose economic growth, as measured by GDP per capita, is higher than the average of the overall sample. Still in the same context, given that at a certain level of economic growth, pollution and environmental degradation will reduce after a certain level of economic growth, I exclude for this purpose countries whose squared GDP — is higher than the average of the total sample. Second, some African countries have demonstrated — strong participation in international — environmental forums. Researchers from the **Notre Dame Global Adaptation Initiative** team have developed an indicator of engagement in international — environmental conventions that captures a country’s ability to participate in — multilateral negotiations and agree internally on appropriate actions. It is possible that a country’s strong participation in these forums and treaties is associated with a decrease in pollution and environmental degradation. Keeping these countries in the regressions could bias the conclusions, so I exclude⁵ them all from the sample to resume the regressions. Finally, I follow Apeti (2023) in excluding mobile money in the first year of the policy’s adoption and bringing forward (lagging) the introduction of mobile money by one year. Tables A3 to A6 in Appendix contain the results of these estimates. In these tables, I report the results of greenhouse gas emissions in Panel A and CO2 emissions in Panel B. New results, reported in Tables A3 to A6, respectively, remain positive and significant, with a magnitude comparable to our benchmark estimates.

5. These African countries are : Guinea-Bissau, Mali, Chad, Togo, and Tanzania.

7.5 Placebo test

Despite all the tests performed, the baseline — results remained unchanged. I now examine whether there are confounding factors that could affect my basic results, which have remained stable so far. The empirical literature shows that the adoption of an economic policy is generally associated with parallel reforms, making the adoption of mobile money a non-random factor (Apeti, 2023). One could therefore imagine that unobservable variables correlated with policy adoption and potentially with the outcome variable could affect the baseline results. While I'm aware that the empirical — method used in this study aims to address these types of concerns, I still — strengthen my results by conducting a placebo test on mobile money adoption. To do this, I follow Apeti (2023) in setting placebo or arbitrary dates for mobile money, computed by randomly assigning mobile money episodes to countries in our sample after removing the actual adoption years, i.e., those provided by the GSMA database. The main idea behind this test is that if my results are biased by unobservable variables, the placebo — test might also show significant effects. In fact, random treatments within the sample have no effect on GHG and CO2 emissions (Table A7, in Appendix). Therefore, I can rule out the possibility of confounding — factors influencing my results.

7.6 Alternative estimation methods

I use three methods to test the robustness of my baseline results, namely propensity score matching (PSM), the two-stage panel least squares (2SLS) method, and the two-stage dynamic system GMM panel estimator. The purpose of this exercise is to test whether my results are affected or biased by the choice of estimation method. First, I start the verification with the propensity score matching method. This method — aims to minimize selection bias by comparing each — country that — adopts mobile money with — a — counterfactual country that does not adopt mobile money and is assumed to be fairly similar on some observable characteristics. Indeed, the propensity score matching method proposed by Rosenbaum and Rubin (1983) is a two-step process : first, a probit model is used to generate a propensity score $p(x)$ for each country, which — estimates — the probability of that country adopting mobile money with its feature vector. The second step is to use the propensity scores obtained to match treated and untreated observations, and then the ATTs are — calculated to estimate the treatment effect. However, a shortcoming of this method is that it assumes that treatment assignment is random. This reduces the

chances that a treated individual will be well matched with an untreated — individual on the basis of a similar characteristic. To be sure that the matches worked well, I refer to the assumption of conditional independence (common support). To avoid self-selection bias in matching, I choose my matching algorithms by following the literature (Dehejia and Wahba, 2002), which allows choosing a good neighborhood threshold ($N=1$, $N=2$, and $N=3$); the radius method (with $r = 0.005$; $r=0.01$; and $r=0.05$, respectively); the *kernel method*; and *local linear regression*. The new ATTs for GHG emissions and CO2 emissions are reported in Tables A8 and A9 in Appendix, respectively. First, the results are stable. Second, all Pseudo-R2 of our estimates are below 10%, indicating that the matching produces balanced results. In other words, our results are robust to the common support hypothesis. Finally, our results are also robust to the conditional independence assumption, as the cutoff values of Rosenbaum’s sensitivity tests at 10% significance range from 1.65 to 2.85 and 1.75 to 2.35, respectively, which is comparable to existing studies (see for instance, Simone and Bazilian (2019) and/or Rosenbaum and Rubin (1983)). Before matching, common support appears to be quite large, but the plot shows that treated units with a high propensity score may not be matched due to the small — number of nearby control units. After matching, the distribution of propensity score is similar in the treated and untreated groups, showing that treated — units — were indeed matched with untreated units with similar propensity score (see Figure 5 below). Therefore, new findings strengthen my main results.

Second, always with the alternative estimates, I use the two-step dynamic system GMM panel estimator to test the robustness of my results. While the above results suggest that mobile money adoption has led to an increase in greenhouse gases and CO2 emissions, causality may also run in the opposite direction. Indeed, the need to combat environmental degradation, pollution, and climate change may drive demand for innovative technological solutions, thus influencing the adoption of mobile money. Another potential source of endogeneity in the analysis could arise from the simultaneity of mobile money adoption with other environmental and climate policy reforms. To circumvent this endogeneity problem, I use the two-step GMM panel estimator for dynamical systems proposed by Blundell and Bond (1998). Indeed, one of the main advantages of the systemic GMM estimator is that this estimation technique can instrument for other explanatory variables that could potentially be endogenous, in addition to the main — endogenous regressor (in this case, the mobile money adoption). Moreover, in the system-GMM estimation, I need to ensure that the total number of instruments does not exceed the number of countries to

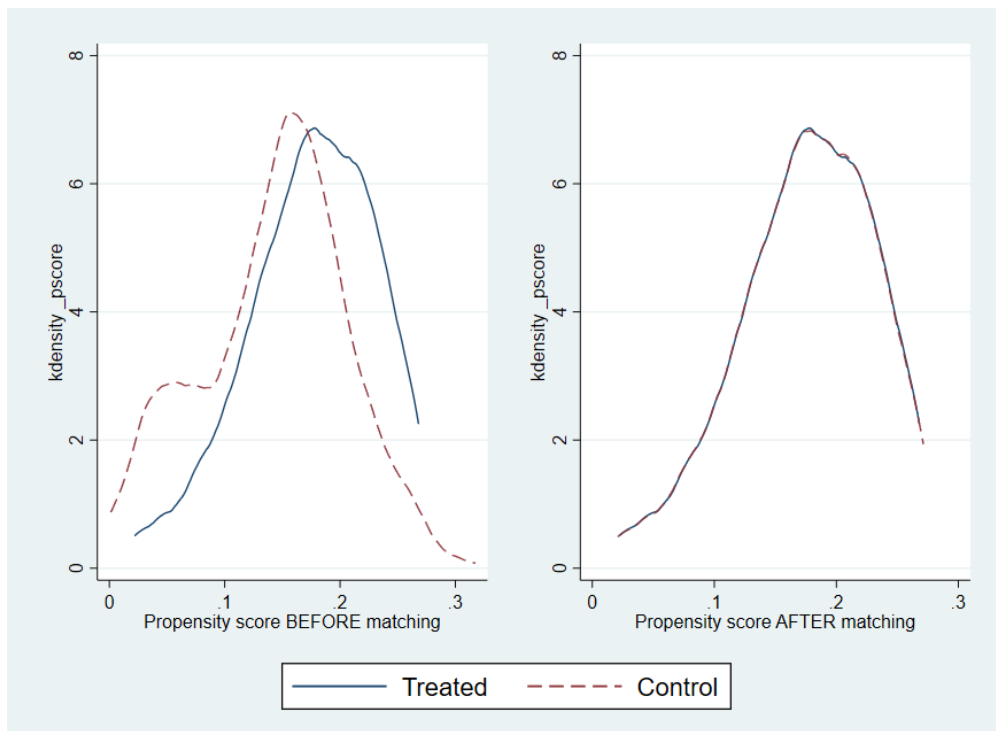
avoid the problem of "*instrument proliferation*" in the estimates (Roodman, 2009). I therefore reduce the number of instruments to avoid proliferation. The two-step GMM estimation with the internal instruments is presented in Column [2] and [4] of Table 4. the AR (1) test for lack of autocorrelation of the first-order error term and the AR (2) test for lack of autocorrelation of the second-order error term do not raise concerns about the validity of our estimates. Finally, the Hansen test does not reject the hypothesis of instrument validity.

Finally, in addition to the above robustness checks, it would also be reassuring to display the results of the GMM estimation of the system with external instruments alongside the internal instruments to mitigate the endogeneity problem of mobile money. It is expected that the proportion of neighboring countries adopting mobile money and the mobile penetration rate should affect the adoption of mobile money, but should not have a direct effect on the level of GHGs and CO2 emissions. The first instrument, the proportion of neighboring countries adopting mobile money, is the inverse of the geographic distance weighting matrix. In fact, the adoption of mobile money in several neighboring countries is likely to increase the likelihood of adopting the same service, e.g., due to the imitation effect of adopting policies that are common in developing countries (Klemm and Van Parys, 2012), without having a direct impact on GHGs and CO2 emissions in the host country. In addition, some studies of tax competition also use a geographic distance weighting matrix as an instrument (see, e.g., Chen et al. (2014) or Overesch and Rincke (2011)). There are three reasons for using the geographic distance weight matrix as opposed to the contiguity matrix. The first reason is that geographically close countries (neighbors) are more relevant trading partners because goods and services are highly mobile due to relatively lower transportation and information costs between geographically close countries. This is in line with **Waldo Tobler's** law of geography : "*everything is related to everything else, but near things are more related than distant things*". The second reason is that in the contiguity matrix the islands would have no neighbors. Finally, as our dataset is not complete, some countries may not have neighbors, which may lead to inconsistencies since it would appear that the two spatial entities do not have a common border. Algebraically, after normalization, the weights w_{ij} of the geographic distance weighting matrix are given as follows :

$$W_{ij} = \begin{cases} \frac{1/d_{ij}}{\sum_j 1/d_{ij}}, & \text{for } i \neq j \\ 0, & \text{for } i = j \end{cases}$$

Where d_{ij} is the Euclidian distance between the capital of country i and country j for $i \neq j$. For the second instrument (mobile penetration rate), I follow [GSMA \(2021\)](#) and [Jacolin et al. \(2019\)](#), who argue that the adoption of mobile financial services such as mobile money is closely linked to the development of the domestic cell phone market. The data for this variable comes from the International Telecommunication Union (ITU). In light of the above, I believe that the proportion of neighboring countries adopting mobile money and the mobile penetration rate might be a good (but not perfect) candidate as instrumental variables for mobile money adoption.

FIGURE 5 – **Common support before and after matching of GHGs**



Source : Author’s elaboration.

Table [A1](#) in Appendix shows the first-stage regressions. In the first column I include all covariates, in contrast to the second column where I include only the instrument. This instrument has no statistical weakness, as the associated coefficients are highly significant and the F-test statistics for the null effect of IV reject this hypothesis. It is also above 10, the threshold — recommended by [Staiger and Stock \(1994\)](#). Not — surprisingly, the coefficients for my instrument (proportion of neighboring countries adopting mobile money) are positive. This confirms the hypothesis that the adoption of mobile money in several neighboring countries increases the probability of adopting same service in the host country. Columns ([1]-[5]) of Table [A10](#) in Appendix, which report the results of these specifications, show their consistency with our basic results. In other words, the

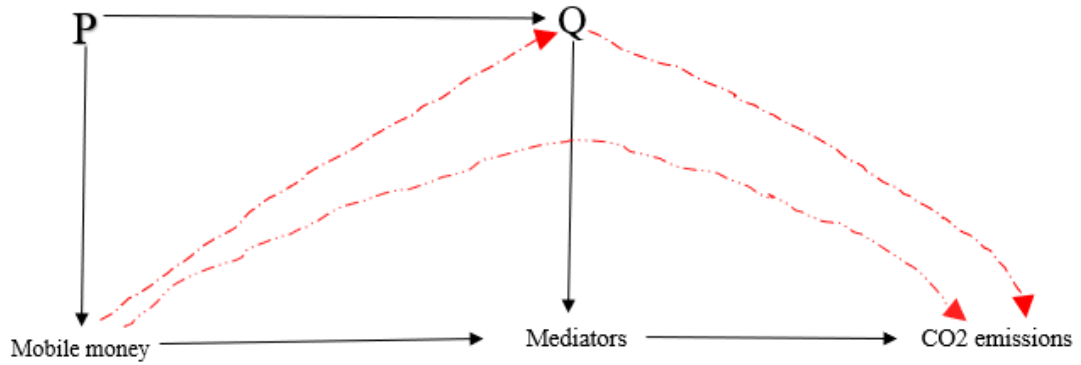
results remain robust even after the endogeneity treatment.

7.7 Transmission channels

Previous findings have shown that mobile money has a negative impact on environmental sustainability through increased greenhouse gas and CO2 emissions. It is imperative to try to identify the channels through which this negative effect of mobile money is transmitted to environmental sustainability. The objective of this subsection is to identify and evaluate these transmission mechanisms in the link between mobile money and environmental sustainability. To accomplish this, I proceed in two more ample and concise ways. First, for the mobile money variable, I go beyond simple adoption of mobile money by using IMF mobile money (FAS). Second, for the environmental sustainability variable, I retain CO2 emissions, taking into account the higher share of mobile money on this variable (see Table 2). Finally, I use a methodology proposed by [Ang \(2013\)](#) based on simultaneous equation modeling. This methodology was used by [Ekoula et al. \(2023\)](#) to identify the transmission channels through which women’s political empowerment affects financial development. In this study, three main — channels were identified — after the regressions : Fossil fuel energy consumption, agricultural value added, and financial development. Figure 6 and 7 summarize these transmission channels. In fact, a traditional way of testing channels would be to add the median variable as an additional regressor in a linear model⁶. In this case, the coefficient of the mediator variable is interpreted as the direct effect. However, this interpretation is only correct if I assume that there are no intermediate confounders, which is an unrealistic assumption according to [Imai et al. \(2010\)](#). I represent these intermediate confounders in Figure 6 by Q, while the pretreatment confounders are represented by P. In fact, the inclusion of X_{i_t} in equation (2’) would lead to β_1 not being equal to the direct effect of mobile money, since according to [Acharya et al. \(2016\)](#) conditioning on a variable after treatment can lead to spurious relationships between treatment and outcome. In addition, assuming no intervening confounders and including our mediator without adding X_{i_t} introduces selection bias unless I include them all equally in the regression. To solve this dilemma, I extend the model following [Ang \(2013\)](#) and [Ekoula et al. \(2023\)](#). The modeling is shown in Figure 7 below.

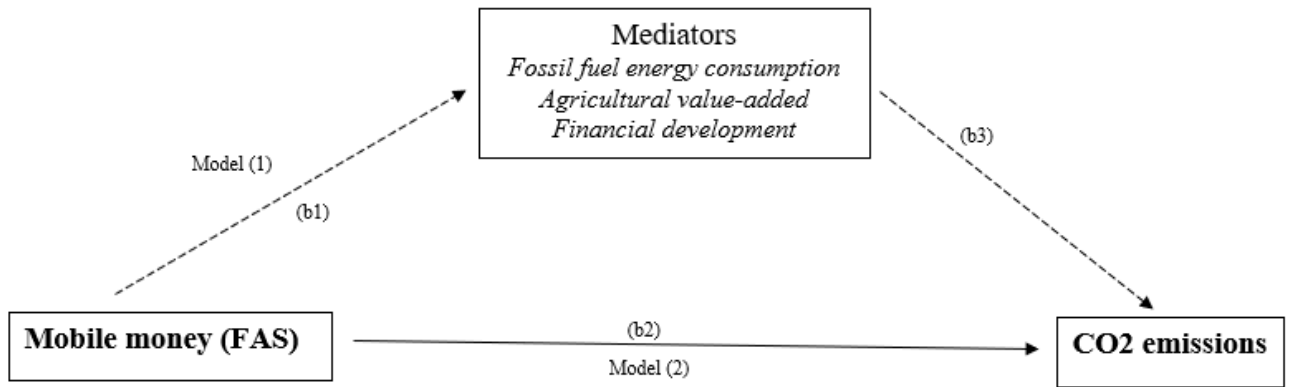
6. This model may take the following form : $Y_{i_t} = \alpha_i + \beta_1 MM_{i_t} + \beta_2 Med_{i_t} + X'_{i_t} \beta_3 + \tau_t + \epsilon_{i_t}$ (2’), where MM_{i_t} is mobile money adoption ; Med_{i_t} are the mediator variables and X'_{i_t} are the covariates.

FIGURE 6 – Channel with intermediate confounders



Source : Author's elaboration.

FIGURE 7 – Modelling the transmission channel mechanisms



Source : Author's elaboration.

The estimation is done in two steps. First, I estimate the following equations :

$$Model(1) : Med_{it} = \alpha_1 + b_1 MM_{it} + c_1' X_{it} + u_{it}, \quad (3)$$

$$Model(2) : CO2_{it} = \alpha_2 + b_2 MM_{it} + b_3 Med_{it} + c_1' X_{it} + u_{it} \quad (4)$$

With Med_{it} the mediation variable (Fossil fuel energy consumption, agricultural value added, and financial development.) and MM_{it} the mobile money. After estimation, I obtain three effects, namely a direct effect due to b_2 , an indirect effect due to $(b_1 * b_3)$, and a total effect due to $(b_1 * b_3) + b_2$. In simple terms, in the first step I estimate model (1) corresponding to the effect of mobile money on environmental sustainability through CO2 emissions and b_1 is the parameter describing this effect. In a second step, I estimate model (2) in which I regress CO2 emissions on mobile money and control for mediators.

The magnitude of this effect is determined by the coefficient (b2) of mobile money. The indirect effect is thus the product of b1 and b3, where b3 measures the strength of the correlation between mobile money and the mediators in model (2). The results of the regressions are reported in Table 5. Columns ([1a]-[3a]) show the estimates of model (1) using fossil fuel energy consumption, agricultural value added, and financial development as mediators, respectively. I then estimate model (2) using the three mediators as controls and report the results in Columns ([1b]-[3b]). Finally, for simplicity, I also report the results of the baseline model in the last Column of Table 5 . Results show that : *i*- the mobile money affects all three mediators, and the effects are statistically significant at the 1% level (Columns [1a],[2a], and [3a] in Table 5). *ii*- All three mediators have a statistically significant impact on CO2 emissions (Columns [1b], [2b], and [3b] in Table 5). *iii*- The mobile money has a significant effect on CO2 emissions in the absence of mediators (Column [4] in Table 5). *iv*- The estimated coefficient of the mobile money on CO2 emissions decreases once a mediator is included in the model (Columns [1b], [2b], and [3b] in Table 5, compared with Column [4]). Finally, I present statistics on mediation effects to confirm the validity of my tests (Table 5 below). To this end, I conduct several mediation tests to analyze whether the indirect effect of mobile money on CO2 emissions is statistically different from zero due to the heavy reliance and influence of agriculture and fossil fuel energy consumption. For instance, considering the mediation effect of fossil fuel energy consumption, Sobel test statistic is estimated to be 0.020 . The P-value is less than 5%, indicating that the null hypothesis of no mediation is rejected. Results are similar when alternative mediation tests (Delta and Monte Carlo)⁷ are used. Indeed, the evidence presented suggests that the effect of mediating fossil fuel energy consumption is substantial, accounting for about 31% of total effect of mobile money on the CO2 emissions.

7. The results remain unchanged when I change the bootstrap confidence interval to 500 for the Table 5 regressions.

TABLE 5 – Validity of transmission channels mechanisms.

Variables	(i) Mediator :Fossil energy consumption		(ii) Mediator : Agricultural value-added		(iii) Mediator : Financial development		(iv) Baseline regression		
	(1a)	(1b)	(2a)	(2b)	(3a)	(3b)	[4]		
	Fossil energy consumption	Mobile money	Agricultural value-added	Mobile money	Financial development	Mobile money	Mobile money		
Mobile money (FAS)	-0.1151*** (0.0391)	0.2991*** (0.0574)	0.1101*** (0.0237)	0.2591*** (0.0355)	-0.0435*** (0.0157)	0.2510*** (0.0329)	0.0287** (0.0125)		
Fossil fuel energy consumption		0.6199*** (0.1949)							
Agricultural value-added				-0.4365*** (0.0962)					
Financial development						0.9176*** (0.1384)			
Constant	4.8858*** (0.5547)	2.9198** (1.2115)	1.1167*** (0.3412)	5.9469*** (0.4984)	-1.3371*** (0.2263)	6.6864*** (0.5001)	6.4905*** (2.4254)		
Mains contrôls	Yes	Yes	Yes	Yes	Yes	Yes	Yes		
Bootstrap replications	500	500	500	500	500	500			
Log likelihood	-227.0215	-227.0215	-1122.693	-1022.2134	-1022.2134	-227.0215			
	Mediating the effect of Fossil energy consumption			Mediating the effect of Agricultural value-added			Mediating the effect of Financial development		
	Coeff.	Std. error	P-value	Coeff.	Std. Error	P-value	Coeff.	Std. error	P-value
(A) Mediation tests									
Delta	-0.071	0.033	0.031	-0.048	0.015	0.001	-0.040	0.016	0.011
Sobel	-0.071	0.033	0.031	-0.048	0.015	0.001	-0.040	0.016	0.011
Monte Carlo	-0.071	0.033	0.037	-0.048	0.015	0.001	-0.040	0.016	0.011
(A) Composition of the effect									
Indirect effect (Sobel)	0.154			0.048			0.040		
Direct effect	0.646			0.259			0.251		
Total effect	0.49			0.211			0.211		
% of the total effect mediated rowhead	31%			23%			19%		

Standard errors in parentheses *** p <0.01, ** p <0.05, * p <0.1. Bootstrap confidence=500.

7.8 Heterogeneity

7.8.1 Mobile money disaggregated

The accelerating effect of mobile money on environmental sustainability could differ depending on the type of mobile service considered. Indeed, not all mobile money services carry the same weight in transaction use in Africa. According to a recent GSMA survey on global mobile money adoption survey in 2021, person-to-person transfers (P2P) are the most commonly used transactions compared to services (GSMA, 2022). P2P transfers totaled \$387 billion, merchant payments totaled \$66 billion, and bill payments totaled \$61 billion (GSMA, 2022). These three major services have enabled smallholder farmers to access financial services, increase their savings, and obtain agricultural insurance. This has helped improve agricultural returns. In this sense, agriculture in most of these African countries is not modern and does not respect enough environmental standards, its intensification would be more harmful and polluting to the environment because of these financial services, unlike other mobile money services. I take into account these considerations by testing whether the impact of mobile money on environmental sustainability is heterogeneous over the type of transactions used as financial services. The results are reported in Table 6. With the exception of P2G transfer, G2P transfer, and international remittances, I find that mobile money adoption increases GHG and CO2 emissions regardless of the type of service.

TABLE 6 – Heterogeneous impacts of mobile money on GHG and CO2 emissions

VARIABLES	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
Panel A : Greenhouse gas emissions (log)								
Person-to-person (P2P) dummy	0.0898*** (0.0150)							
Person-to-government (P2G) dummy		0.0171 (0.0216)						
Government-to-person (G2P) dummy			0.0010 (0.0235)					
Bill payment dummy				0.0928*** (0.0154)				
Other bulk payment dummy					0.0460*** (0.0166)			
Airtime top up dummy						0.0929*** (0.0150)		
Merchant payment dummy							0.0645*** (0.0159)	
International remittances dummy								0.0191 (0.0229)
Constant	11.2326*** (0.0161)	11.2720*** (0.0260)	11.2720*** (0.0260)	11.2720*** (0.0260)	11.2720*** (0.0260)	11.2313*** (0.0162)	11.2437*** (0.0168)	11.2720*** (0.0260)
Covariates in the second step	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country&Time/FE in the second step	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	607	607	607	607	607	607	607	607
R-squared	0.9888	0.9879	0.9879	0.9888	0.9881	0.9888	0.9884	0.9879
Panel B : CO2 emissions (log)								
Person-to-person (P2P) dummy	0.1738*** (0.0301)							
Person-to-government (P2G) dummy		-0.0294 (0.0368)						
Government-to-person (G2P) dummy			-0.0304 (0.0488)					
Bill payment dummy				0.1847*** (0.0310)				
Other bulk payment dummy					0.0809** (0.0327)			
Airtime top up dummy						0.1680*** (0.0305)		
Merchant payment dummy							0.1060*** (0.0323)	
International remittances dummy								-0.0412 (0.0347)
Constant	10.0582*** (0.0473)	10.1344*** (0.0825)	10.1344*** (0.0825)	10.1344*** (0.0825)	10.1344*** (0.0825)	10.0607*** (0.0483)	10.0879*** (0.0598)	10.1344*** (0.0825)
Covariates in the second step	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country&Time/FE in the second step	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	607	607	607	607	607	607	607	607
R-squared	0.9655	0.9629	0.9629	0.9657	0.9634	0.9653	0.9639	0.9630

Notes : This table presents the results of the causal impact of mobile money on environmental sustainability by mobile transaction type using the baseline model. The equation is estimated from the baseline model, using entropy balancing. I consider eight mobile transactions from the GSMA database : Person-to-person (P2P), Person-to-government (P2G), Government-to-person (G2P), Bill payment, Other bulk payment, Airtime top up, Merchant payment, and International remittances. Robust standard errors in parentheses. * p < 0.1, ** p < 0.05, *** p < 0.01

These results confirm my assumptions and call for vigilance on the part of policymakers regarding the environmental impact of mobile money.

7.8.2 What does mobile money say about ecological efficiency?

Literature on mobile money adoption indicates that this innovation was praised for its ability to financially include the unbanked (Ahmad et al., 2020; N'dri and Kakinaka, 2020). By increasing household consumption through consumption smoothing and saving, providing substantial income to farmers, etc., it has undoubtedly contributed to the improvement of some human development indicators such as gross domestic product and wealth. However, the increase in the human development index is often not in harmony with ecological sustainability (Hickel, 2020). Several innovative technologies have been adopted in African countries in an ad hoc manner to improve the well-being of the population without taking into account the carbon footprint of these technologies. It is therefore necessary to examine what mobile money as a technological innovation says about ecological efficiency. To accomplish this, I use the sustainable development index (SDI)⁸ developed by Hickel (2020) for two main reasons. First, this index combines both human development and environmental sustainability. It is composed of five indicators : education, life expectancy, income, CO2 emissions, and material footprint (Hickel, 2020). This makes it possible to discuss both the principles of strong and weak sustainability. The second reason is that this index is a strong sustainability indicator, in the sense that countries cannot use a low ecological impact to compensate for a low human development performance. Conversely, a strong development performance cannot compensate for a high ecological impact (Hickel, 2020). For reasons of planetary limits, the SDI⁹ was calculated so that the maximum score is equal to 1. Indeed, the calculation of the overshoot is based on a limit of 6.8 tons per person/year for the material footprint (Bringezu, 2015) and a limit of 1.74 tons per person/year for CO2 emissions (IPCC, 2018). Furthermore, the SDI shows that no country with a score above 0.9 is truly successful in sustainable deve-

8. The formula is described as follows : $SDI = \frac{Development\ Index}{Ecological\ Impact\ Index}$ (see, Hickel (2020) for details on development index and ecological impact index)

9. However, this index may suffer from some interpretation bias. One criticism might be that countries score well on human development indicators because they intentionally adopt good policies, such as investing in public health and education. These are policies that other countries may be able to emulate. However, it is not so simple when it comes to ecological indicators. Some of the countries that have a low ecological impact use intentional policies to do so, such as Costa Rica's investment in renewable energy infrastructure and Cuba's emphasis on reusing materials (for instance, see Hickel (2020))

lopment. There is no country that achieves the highest human development score while staying within or even close to ecological limits. The results in Table 7 suggest that mobile money reduces ecological efficiency through the decrease of sustainable development index in countries that adopt it compared to those that do not. These observations suggest that African countries adopting mobile money, in particular, need to invest heavily in renewable energy, circular economy principles, and post-growth strategies to accelerate progress toward a green transition.

TABLE 7 – Mobile money and ecological efficiency

VARIABLES	SDI
Mobile money dummy	-0.0035* (0.0020)
Lag Final consumption expenditure	0.0000 (0.0001)
Log Natural resources rents	0.0066* (0.0040)
Lag Public Debt	-0.0000 (0.0001)
Log GDP per capita	0.0480*** (0.0143)
Log Households consumption expenditure	-0.0167 (0.0142)
General government revenue	0.0001 (0.0002)
Log Trade openness	0.0048 (0.0046)
Constant	0.1108 (0.1442)
Time/FE	Yes
country/FE	Yes
Observations	539
R-squared	0.9674

Standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

7.8.3 Macroeconomic and institutional factors are matter ?

In this subsection, I conclude the heterogeneity tests by examining the role of some macroeconomic and institutional aggregates. Indeed, I am interested in factors such as inflation, remittances flows, trade openness, rural population growth, financial openness, and renewable energy consumption. The intuition is that mobile money can have an amplifying effect in situations characterized by strong commercial openness, strong inflation, strong remittances flows, strong rural populations, and strong financial openness. Conversely, the effect may be weakened in situations with high renewable energy consumption and institutional factors. To achieve this, I proceed through the interactions between mobile money and macroeconomic and institutional variables. The results of the regressions are reported in Table 8. Panel A shows the results of greenhouse gas emissions, while panel B shows the results of the interactions with mobile money on CO₂ emissions. Column [2] of Table 8, Panel A reveals that the positive effect of mobile money on GHG emissions is by renewable energy consumption, potentially due to the positive effect of green and renewable energy sources on the environment, especially on GHG emissions. Similarly, mobile money appears to be effective in countries with high rural population growth (Column [4], Panel A). In column [5], I assess mobile money and remittances inflows. The coefficient is positive and statistically significant. This suggests that remittances received by recipients via mobile money increase GHG emissions. This result is consistent with the findings of Riley (2018) and Munyegera and Matsumoto (2016). In column [6], I investigate whether the effect of mobile money is conditioned by institutional quality, more precisely on the implementation of rules of law. The results obtained are surprising because the positive and highly significant coefficient indicates that mobile money associated with rule of law increases greenhouse gas emissions. This could be due to the fact that in most of these African countries, the rule of law is not a reality and environmental regulations are not strictly and fully respected.

Finally, in Panel B, column [1], I examine heterogeneity as a function of countries' inflation levels. Surprising as it may be, the coefficient is negative and significant. Mobile money adoption is effective when adopted by countries with poor control over national consumer price indices. As with greenhouse gas emissions, column [2] of Panel B shows that the interaction between mobile money and remittances inflows increases CO₂ emissions.

TABLE 8 – Mobile money, GHG and CO2 emissions : structural factors

Panel A : Greenhouse gas emissions (log)	[1]	[2]	[3]	[4]	[5]	[6]
Mobile money (MM) dummy	0.1040*** (0.0182)	0.1960*** (0.0437)	0.0760*** (0.0190)	0.1407*** (0.0196)	0.0831*** (0.0151)	-0.0595 (0.0539)
MM*Inflation	-0.0023 (0.0019)					
MM*Renewable energy consumption		-0.0015** (0.0006)				
MM*financial openness			0.0608 (0.0434)			
MM*Rural population growth				-0.0774*** (0.0238)		
MM*Remittances inflows					0.0256** (0.0103)	
MM*Rule of law						0.3965*** (0.1342)
Constant	11.2338*** (0.0544)	11.2173*** (0.0558)	11.2387*** (0.0560)	11.2292*** (0.0550)	11.3125*** (0.0667)	11.2474*** (0.0557)
Country & Time/FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	589	607	606	535	527	607
R-squared	0.9890	0.9890	0.9889	0.9891	0.9890	0.9890
Panel B : CO2 emissions (log)	[1]	[2]	[3]	[4]	[5]	[6]
Mobile money (MM) dummy	0.2150*** (0.0360)	0.3115*** (0.0853)	0.1928*** (0.0370)	0.1999*** (0.0407)	0.1535*** (0.0282)	0.0916 (0.1056)
MM*Inflation	-0.0068* (0.0038)					
MM*Renewable energy consumption		-0.0019 (0.0012)				
MM*financial openness			-0.0421 (0.0847)			
MM*Rural population growth				-0.0147 (0.0494)		
MM*Remittances inflows					0.0408** (0.0191)	
MM*Rule of law						0.2278 (0.2630)
Constant	10.0619*** (0.1076)	10.0382*** (0.1088)	10.0498*** (0.1092)	10.0503*** (0.1141)	10.2219*** (0.1242)	10.0651*** (0.1091)
Country & Time/FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	589	607	606	535	527	607
R-squared	0.9662	0.9658	0.9657	0.9574	0.9699	0.9657

Notes : This table reports the results of the heterogeneity effects of mobile money. The equation is estimated by considering the main model augmented by the interactive term. Controls are included but not reported for space purpose. Robust standard errors in parentheses. * p < 0.1, ** p < 0.05, *** p < 0.01.

8 Conclusion

The biggest threat of the 21st century is global warming and climate change due to carbon emissions. Numerous studies have identified the sources of carbon emissions, and carbon taxes have been implemented in some countries. However, very little has been said about the impact of new financial technologies (fintech) on environmental sustainability.

This paper analyzes the causal effect of mobile money adoption on environmental sustainability. Using a large sample of 41 African countries over the period 2002-2020 and employing entropy balancing, I show that countries using mobile money have higher GHG and CO₂ emissions, which appears to be novel in the existing literature on this topic. This result is robust to various tests, including alternative specifications and alternative estimation methods. The transmission channel analysis indicates that fossil fuel energy consumption, agricultural value added, and financial development drive the amplifying effect of mobile money on environmental indicators. However, the results reveal some heterogeneity between the nature of mobile money and structural factors such as inflation, renewable energy consumption, rural population growth, remittances inflows, and rule of law. Other results highlighted in this paper show that mobile money not only undermines the environment in African countries, but is also a barrier to environmental transition through the channel of ecological efficiency, carbon footprint and material footprint in African countries.

In parallel, the estimation results corroborate the existence of an environmental Kuznets curve inverted U-shaped relationship between economic development and environmental performance for African economies. Based on a cross-country analysis, this study contributes to the debate on the role of financial innovations (such as mobile money) on the environment and risk management in African countries. By demonstrating that mobile money weakens environmental performance, this article could enable policymakers mindful with environmental issues, inclusive and green growth to consider implementing policies aimed at mitigating negative environmental impacts of this financial technology through investments in renewable energy, the green economy and biodiversity conservation. This should not only promote environmental sustainability, but also accelerate the energy and ecological transition in African countries.

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Appendix

Table A1 – First stage results with instrument, linear probability model.

VARIABLES	[1]	[2]
	Mobile money	Mobile money
Instrument	0.295*** (0.105)	0.410*** (0.0954)
Lag Final consumption expenditure	0.00149 (0.00173)	
Log Natural resources rents	0.00884 (0.0112)	
Lag Public Debt	-0.00140*** (0.000419)	
Log GDP per capita	0.00677 (0.0266)	
Log Households consumption expenditure	-0.0396 (0.116)	
General government revenue	0.000114 (0.00206)	
Log Trade openness	-0.0431 (0.0272)	
Constant	0.333 (0.555)	0.0958*** (0.0141)
F-test	3.42	18.46
Observations	642	779
R-squared	0.041	0.023

Note : Dependent variables : Mobile money adoption. OLS regressions. Instrument = proportion of neighboring countries adopting mobile money. Standard errors are in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01

Table A2 – Mobile money and Greenhouse gas emissions : additional controls

	[1]	[2]	[3]	[4]	[5]	[6]	[7]
VARIABLES	Household Consumption Volatility	Investment	ODA	Rural population growth	Urban population growth	Democratic Institutions	Autocratic Institutions
Mobile money	0.0362** (0.0173)	0.0301*** (0.0102)	0.0406** (0.0174)	0.0517*** (0.0179)	0.0362** (0.0175)	0.0278* (0.0162)	0.0427** (0.0174)
Constant	8.7298*** (0.1599)	10.9503*** (0.0374)	8.8847*** (0.1323)	8.8670*** (0.1615)	9.3924*** (0.2703)	9.2809*** (0.1218)	8.9630*** (0.1078)
Covariates in the first step	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Covariates in the second step	No	No	No	No	No	No	No
Country/FE in the second step	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time/FE in the second step	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.9981	0.9970	0.9980	0.9984	0.9980	0.9983	0.9980

Notes : This Table presents the effect of mobile money adoption on Greenhouse gas emissions obtained by weighted least squares regressions. The treatment variable is mobile money dummy. The outcome variable is GHGs emissions. The control variables include the lag final consumption expenditure log natural resources rents, lag public Debt, log GDP per capita, log Households consumption, government revenue and log Trade openness. Standard errors are in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01

Table A3 – Mobile money, Greenhouse gas and CO2 emissions : alternative sample (1/4)

Panel A	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
VARIABLES	Greenhouse gas emissions (log)							
Mobile money	0.4388*** (0.1155)	0.0945*** (0.0136)	0.4619*** (0.1328)	0.0016 (0.0102)	0.4070*** (0.0977)	0.0250** (0.0110)	0.4676*** (0.1099)	0.0065 (0.0099)
Constant	9.7850*** (0.0828)	11.2306*** (0.0557)	9.2468*** (0.3435)	10.9365*** (0.0434)	4.8261** (1.9874)	2.8889*** (0.6016)	3.0220 (2.0376)	9.7460*** (0.6262)
Mains Covariates in the second step	No	No	No	No	Yes	Yes	Yes	Yes
Year fixed effects in the second step	No	No	Yes	Yes	No	No	Yes	Yes
Country fixed effects in the second step	No	Yes	No	Yes	No	Yes	No	Yes
Observations	607	607	607	607	607	607	607	607
R-squared	0.0233	0.9889	0.0649	0.9957	0.3389	0.9937	0.3787	0.9961
Panel B	CO2 emissions (log)							
Mobile money	0.6709*** (0.1267)	0.1801*** (0.0264)	0.6824*** (0.1430)	-0.0133 (0.0173)	0.5123*** (0.0945)	0.0442** (0.0200)	0.5459*** (0.1057)	0.0300* (0.0160)
Constant	7.9366*** (0.0908)	10.0554*** (0.1085)	7.1904*** (0.3700)	9.5486*** (0.0739)	-6.8087*** (1.9225)	-6.5855*** (1.0951)	-8.2307*** (1.9597)	7.7972*** (1.0125)
Mains Covariates in the second step	No	No	No	No	Yes	Yes	Yes	Yes
Year fixed effects in the second step	No	No	Yes	Yes	No	No	Yes	Yes
Country fixed effects in the second step	No	Yes	No	Yes	No	Yes	No	Yes
Observations	607	607	607	607	607	607	607	607
R-squared	0.0443	0.9657	0.1176	0.9898	0.4969	0.9830	0.5327	0.9916

Notes : This Table presents the effect of mobile money adoption on Greenhouse gas emissions obtained by weighted least squares regressions. The treatment variable is mobile money dummy. The outcome variable is GHGs emissions. The control variables include the lag final consumption expenditure log natural resources rents, lag public Debt, log GDP per capita, log Households consumption, government revenue and log Trade openness. Excludes countries with GDP above the sample average. Standard errors are in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01

Table A4 – Mobile money, Greenhouse gas and CO2 emissions : alternative sample (2/4)

Panel A	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
VARIABLES	Greenhouse gas emissions (log)							
Mobile money	0.4447*** (0.1224)	0.0945*** (0.0149)	0.5084*** (0.1426)	0.0033 (0.0081)	0.3084*** (0.0991)	0.0245** (0.0109)	0.4007*** (0.1123)	0.0002 (0.0079)
Constant	9.7691*** (0.0867)	11.2301*** (0.0787)	9.2778*** (0.3519)	10.9258*** (0.0409)	10.2552*** (2.0887)	2.2345*** (0.6173)	8.2100*** (2.1609)	9.8376*** (0.5126)
Mains Covariates in the second step	No	No	No	No	Yes	Yes	Yes	Yes
Year fixed effects in the second step	No	No	Yes	Yes	No	No	Yes	Yes
Country fixed effects in the second step	No	Yes	No	Yes	No	Yes	No	Yes
Observations	491	491	491	491	491	491	491	491
R-squared	0.0263	0.9882	0.0662	0.9976	0.4107	0.9946	0.4442	0.9978
Panel B	CO2 emissions (log)							
Mobile money	0.6605*** (0.1290)	0.1902*** (0.0308)	0.7195*** (0.1467)	-0.0041 (0.0184)	0.4244*** (0.0908)	0.0477** (0.0230)	0.4738*** (0.1028)	0.0209 (0.0176)
Constant	7.8009*** (0.0914)	9.9932*** (0.1628)	7.1622*** (0.3620)	9.4774*** (0.0926)	-0.6323 (1.9141)	-7.1147*** (1.3028)	-2.1462 (1.9774)	8.4444*** (1.1378)
Mains Covariates in the second step	No	No	No	No	Yes	Yes	Yes	Yes
Year fixed effects in the second step	No	No	Yes	Yes	No	No	Yes	Yes
Country fixed effects in the second step	No	Yes	No	Yes	No	Yes	No	Yes
Observations	491	491	491	491	491	491	491	491
R-squared	0.0508	0.9559	0.1326	0.9893	0.5657	0.9790	0.5916	0.9906

Notes : This Table presents the effect of mobile money adoption on Greenhouse gas emissions obtained by weighted least squares regressions. The treatment variable is mobile money dummy. The outcome variable is GHGs emissions. The control variables include the lag final consumption expenditure log natural resources rents, lag public Debt, log GDP per capita, log Households consumption, government revenue and log Trade openness. Excludes countries with GDP squared above the sample average. Standard errors are in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01

Table A5 – Mobile money, Greenhouse gas and CO2 emissions : alternative sample (3/4)

Panel A	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
VARIABLES	Greenhouse gas (log)							
Money money	0.4887*** (0.1268)	0.1023*** (0.0146)	0.4890*** (0.1462)	0.0089 (0.0117)	0.4763*** (0.1065)	0.0309** (0.0121)	0.4865*** (0.1207)	0.0003 (0.0112)
Constant	9.7488*** (0.0914)	11.2272*** (0.0550)	9.3643*** (0.3824)	10.9322*** (0.0473)	0.3861 (2.1384)	3.5630*** (0.6576)	-0.4321 (2.2074)	9.6226*** (0.6935)
Mains Covariates in the second step	No	No	No	No	Yes	Yes	Yes	Yes
Year fixed effects in the second step	No	No	Yes	Yes	No	No	Yes	Yes
Country fixed effects in the second step	No	Yes	No	Yes	No	Yes	No	Yes
Observations	521	521	521	521	521	521	521	521
R-squared	0.0278	0.9894	0.0763	0.9953	0.3576	0.9938	0.3891	0.9959
Panel B	CO2 emissions (log)							
Money money	0.6726*** (0.1404)	0.1871*** (0.0266)	0.6776*** (0.1591)	0.0069 (0.0176)	0.5428*** (0.1021)	0.0520*** (0.0200)	0.5410*** (0.1144)	0.0117 (0.0153)
Constant	8.0369*** (0.1012)	10.0523*** (0.1005)	7.3943*** (0.4162)	9.5545*** (0.0709)	-12.2989*** (2.0497)	-4.5076*** (1.0835)	-12.9671*** (2.0929)	8.0146*** (0.9494)
Mains Covariates in the second step	No	No	No	No	Yes	Yes	Yes	Yes
Year fixed effects in the second step	No	No	Yes	Yes	No	No	Yes	Yes
Country fixed effects in the second step	No	Yes	No	Yes	No	Yes	No	Yes
Observations	521	521	521	521	521	521	521	521
R-squared	0.0423	0.9715	0.1208	0.9915	0.5257	0.9866	0.5587	0.9938

Notes : This Table presents the effect of mobile money adoption on Greenhouse gas emissions obtained by weighted least squares regressions. The treatment variable is mobile money dummy. The outcome variable is GHGs emissions. The control variables include the lag final consumption expenditure log natural resources rents, lag public Debt, log GDP per capita, log Households consumption, government revenue and log Trade openness. Excludes countries with an indicator of engagement in international environmental conventions greater than or equal to 1. Standard errors are in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01

Table A6 – Mobile money, Greenhouse gas and CO2 emissions : alternative sample (4/4)

Panel A	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
VARIABLES	Greenhouse gas emissions (log)							
Mobile money	0.4388*** (0.1155)	0.0945*** (0.0136)	0.4619*** (0.1328)	0.0016 (0.0102)	0.4070*** (0.0977)	0.0250** (0.0110)	0.4676*** (0.1099)	0.0065 (0.0099)
Constant	9.7850*** (0.0828)	11.2306*** (0.0557)	9.2468*** (0.3435)	10.9365*** (0.0434)	4.8261** (1.9874)	2.8889*** (0.6016)	3.0220 (2.0376)	9.7460*** (0.6262)
Mains Covariates in the second step	No	No	No	No	Yes	Yes	Yes	Yes
Year fixed effects in the second step	No	No	Yes	Yes	No	No	Yes	Yes
Country fixed effects in the second step	No	Yes	No	Yes	No	Yes	No	Yes
Observations	607	607	607	607	607	607	607	607
R-squared	0.0233	0.9889	0.0649	0.9957	0.3389	0.9937	0.3787	0.9961
Panel B	CO2 emissions (log)							
Mobile money	0.6709*** (0.1267)	0.1801*** (0.0264)	0.6824*** (0.1430)	-0.0133 (0.0173)	0.5123*** (0.0945)	0.0442** (0.0200)	0.5459*** (0.1057)	0.0300* (0.0160)
Constant	7.9366*** (0.0908)	10.0554*** (0.1085)	7.1904*** (0.3700)	9.5486*** (0.0739)	-6.8087*** (1.9225)	-6.5855*** (1.0951)	-8.2307*** (1.9597)	7.7972*** (1.0125)
Mains Covariates in the second step	No	No	No	No	Yes	Yes	Yes	Yes
Year fixed effects in the second step	No	No	Yes	Yes	No	No	Yes	Yes
Country fixed effects in the second step	No	Yes	No	Yes	No	Yes	No	Yes
Observations	607	607	607	607	607	607	607	607
R-squared	0.0443	0.9657	0.1176	0.9898	0.4969	0.9830	0.5327	0.9916

Notes : This Table presents the effect of mobile money adoption on Greenhouse gas emissions obtained by weighted least squares regressions. The treatment variable is mobile money dummy. The outcome variable is GHGs emissions. The control variables include the lag final consumption expenditure log natural resources rents, lag public Debt, log GDP per capita, log Households consumption, government revenue and log Trade openness. Exclusion of new adopters and lagged mobile money adoption of one year. Standard errors are in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01

Table A7 – Mobile money, Greenhouse gas and CO2 emissions : Placebo test

VARIABLES	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
	Greenhouse gas emissions (log)							
Placebo mobile money (random dates)	0.2176 (0.2633)	-0.0194 (0.0328)	0.2660 (0.2725)	-0.0045 (0.0210)	0.0997 (0.2219)	0.0244 (0.0244)	0.1421 (0.2292)	0.0120 (0.0204)
Constant	9.9989*** (0.0600)	11.2720*** (0.0577)	9.2468*** (0.3467)	10.9363*** (0.0434)	5.0078** (2.0153)	2.5970*** (0.5932)	2.9432 (2.0683)	9.7281*** (0.6276)
Mains Covariates in the second step	No	No	No	No	Yes	Yes	Yes	Yes
Year fixed effects in the second step	No	No	Yes	Yes	No	No	Yes	Yes
Country fixed effects in the second step	No	Yes	No	Yes	No	Yes	No	Yes
Observations	607	607	607	607	607	607	607	607
R-squared	0.0011	0.9879	0.0472	0.9957	0.3200	0.9937	0.3598	0.9961
VARIABLES	CO2 emissions (log)							
Placebo mobile money (random dates)	-0.0471 (0.2921)	-0.0907 (0.0636)	0.0949 (0.2963)	-0.0537 (0.0357)	-0.0886 (0.2168)	0.0145 (0.0445)	-0.0226 (0.2220)	-0.0191 (0.0331)
Constant	8.2833*** (0.0665)	10.1344*** (0.1120)	7.1904*** (0.3771)	9.5471*** (0.0738)	-6.5576*** (1.9685)	-7.0680*** (1.0804)	-8.3275*** (2.0040)	7.8653*** (1.0175)
Mains Covariates in the second step	No	No	No	No	Yes	Yes	Yes	Yes
Year fixed effects in the second step	No	No	Yes	Yes	No	No	Yes	Yes
Country fixed effects in the second step	No	Yes	No	Yes	No	Yes	No	Yes
Observations	607	607	607	607	607	607	607	607
R-squared	0.0000	0.9630	0.0836	0.9898	0.4724	0.9829	0.5113	0.9916

Notes : This Table presents the effect of mobile money adoption on Greenhouse gas emissions obtained by weighted least squares regressions. The treatment variable is mobile money dummy. The outcome variable is GHGs emissions. The control variables include the lag final consumption expenditure log natural resources rents, lag public Debt, log GDP per capita, log Households consumption, government revenue and log Trade openness. Standard errors are in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01

Table A8 – Mobile money and Greenhouse gas emissions : using PSM

Dependent Variable :	1-Nearest Neighbor	2-Nearest Neighbor	3-Nearest Neighbor	Radius Matching		Local linear regression		Kernel
		Matching	r=0.005	r=0.05	r=0.01	Matching	Matching	Matching
Greenhouse gas emissions (log)								
Baseline								
ATT	0.3334 (0.2362)	0.4343 (0.2817)	1.4443** (0.2257)	0.4592** (0.6206)	0.4500*** (0.1388)	0.4695*** (0.1491)	0.5935*** (0.1388)	0.4443*** (0.1360)
Observations	607	607	607	607	607	607	607	607
Treated	89	89	89	89	89	89	89	89
Untreated	518	518	518	518	518	518	518	518
Matching Quality								
Pseudo-R2	0.009	0.004	0.003	0.001	0.002	0.003	0.009	0.001
Rosenbaum bounds sensitivity test	1.65	2.0	2.1	2.3	2.15	2.1	2.85	2.15
Standardized bias (p-value)	0.942	0.993	0.997	1.000	1.000	0.997	0.942	1.000

Bootstrapped standard errors based on 50 replications reported in brackets. *** p<0.01, ** p<0.05, * p<0.1. Note : No difference with observations in Table 2.

Table A9 – Mobile money and CO2 emissions : using PSM

Dependent Variable :	1-Nearest Neighbor	2-Nearest Neighbor	3-Nearest Neighbor	Radius Matching		Local linear regression		Kernel
		Matching	r=0.005	r=0.05	r=0.01	Matching	Matching	Matching
Greenhouse gas emissions (log)								
Baseline								
ATT	0.4248 (0.2810)	0.5252** (0.2100)	0.5037** (0.2345)	0.5424*** (0.1557)	0.5235*** (0.1441)	0.5659*** (0.1469)	0.6538*** (0.1694)	0.5204*** (0.1633)
Observations	607	607	607	607	607	607	607	607
Treated	89	89	89	89	89	89	89	89
Untreated	518	518	518	518	518	518	518	518
Matching Quality								
Pseudo-R2	0.009	0.004	0.003	0.001	0.002	0.000	0.009	0.001
Rosenbaum bounds sensitivity test	1.75	2.25	2.15	2.35	2.1	2.25	2.6	2.1
Standardized bias (p-value)	0.942	0.993	0.997	1.000	1.000	1.000	0.942	1.000

Bootstrapped standard errors based on 50 replications reported in brackets. *** p<0.01, ** p<0.05, * p<0.1. Note : No difference with observations in Table 1.

Table A10 – Mobile money and GHGs and CO2 : using IV-2SLS and System-GMM

VARIABLES	[1]	[2]	[3]	[5]
	Greenhouse gaz emissions (log)		CO2 emissions (log)	
	IV-2SLS	System GMM	IV-2SLS	System GMM
Lagged GHG (log)		0.954*** (0.041)		
Lagged CO2 (log)				0.942*** (0.068)
Mobile money (dummy)	1.196* (0.683)	0.129*** (0.041)	2.330*** (0.712)	0.060* (0.041)
Lag Final consumption expenditure	-0.034*** (0.008)	0.005* (0.003)	-0.029*** (0.007)	0.004 (0.003)
Log Natural resources rents	0.277*** (0.039)	-0.051 (0.032)	0.279*** (0.044)	-0.081* (0.042)
Lag Public Debt	-0.009*** (0.002)	-0.000 (0.001)	-0.006*** (0.002)	-0.006*** (0.002)
Log GDP per capita	0.375*** (0.122)	-0.440*** (0.059)	1.194*** (0.139)	-0.224** (0.089)
Log Households consumption expenditure	1.138** (0.538)	-0.881*** (0.152)	1.486*** (0.492)	0.017 (0.249)
General government revenue	-0.012* (0.007)	0.000 (0.003)	-0.011 (0.007)	0.001 (0.007)
Log Trade openness	-0.598*** (0.107)	0.106 (0.086)	-0.562*** (0.127)	-0.198 (0.142)
Constant	7.232*** (2.439)	7.011*** (0.986)	-3.377 (2.620)	3.482** (1.390)
Number of instruments	2	30	2	24
Observations	601	490	601	391
R-squared	0.302		0.273	
R2 Centered	0.302		0.273	
R2 Uncentered	0.983		0.972	
AR(1) test, p-value		0.006		0.012
AR(2) test, p-value		0.699		0.154
Hansen, p-value		0.664		0.825
Sargan, p-value		0.000		0.0430
Kleibergen-Paap LM test, p-value	0.000		0.000	
Number of countries	41	36	41	36

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1, GMM-System - Generalized Method of Moments estimator with country fixed effects. The study period is 2002–2020. The lagged GHGs and CO2 are endogenous; mobile money is strictly exogenous while other variables are considered. The two external instruments used are : the proportion of neighboring countries adopting mobile money and the mobile penetration rate.

Table A11 – Mobile money and GHGs and CO2 : using IV-2SLS

VARIABLES	[1]	[2]	[3]	[4]
	Greenhouse gas emissions (log)		CO2 emissions (log)	
	2SLS-1	2SLS-2	2SLS-1	2SLS-2
Mobile money	0.712 (0.600)	1.790* (0.963)	1.815*** (0.667)	3.294*** (1.068)
Lag Final consumption expenditure	-0.051*** (0.010)	-0.064*** (0.008)	-0.044*** (0.008)	-0.050*** (0.009)
Log Natural resources rents	0.250*** (0.038)	0.245*** (0.042)	0.258*** (0.043)	0.255*** (0.052)
Lag Public Debt	-0.009*** (0.002)	-0.007*** (0.002)	-0.007*** (0.002)	-0.004 (0.003)
Log GDP per capita	0.298** (0.121)	0.322** (0.132)	1.114*** (0.137)	1.165*** (0.160)
Log Households consumption expenditure	2.000*** (0.639)	2.760*** (0.527)	2.213*** (0.535)	2.660*** (0.641)
General government revenue	-0.005 (0.008)	0.003 (0.008)	-0.005 (0.007)	-0.000 (0.009)
Log Trade openness	-0.633*** (0.102)	-0.623*** (0.123)	-0.587*** (0.120)	-0.556*** (0.159)
Constant	5.834** (2.569)	3.001 (2.683)	-4.447* (2.596)	-6.833** (3.259)
Number of instruments	2	2	2	2
Number of countries	41	41	41	41
Observations	575	546	575	546
R2 Centered	0.358	0.259	0.359	0.032
R2 Uncentered	0.984	0.982	0.976	0.964
Hansen, p-value	0.373	0.905	0.112	0.910
Kleibergen-Paap LM test, p-value	0.000	0.000	0.000	0.000

Note : *p<0.10, **p<0.05, and ***p<0.01 ; robust standard errors in brackets ; the two retained external instruments are instrumented with its first- and second-order lagged values

Table A12 – Robustness : Combined entropy balancing and trend.

	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
VARIABLES	Greenhouse gas emissions (log)				CO2 emissions (log)			
Mobile money	0.3535*** (0.1141)	0.0016 (0.0102)	0.3057*** (0.0970)	-0.0065 (0.0099)	0.5855*** (0.1257)	-0.0133 (0.0173)	0.3949*** (0.0927)	0.0300* (0.0160)
Constant	9.2631*** (0.1271)	8.6629*** (0.1702)	3.5941* (1.9504)	7.8657*** (0.5850)	7.4146*** (0.1399)	4.9853*** (0.2896)	-8.2371*** (1.8647)	3.9967*** (0.9457)
Country/FE	NO	Yes	No	Yes	NO	Yes	No	Yes
Time/FE	NO	Yes	No	Yes	NO	Yes	No	Yes
Controls	NO	No	Yes	Yes	NO	No	Yes	Yes
Time Trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	607	607	607	607	607	607	607	607
R-squared	0.0671	0.9957	0.3723	0.9961	0.0799	0.9898	0.5335	0.9916

Notes : This Table presents the effect of mobile money adoption on Greenhouse gas and CO2 emissions obtained by introduce the time trend in regressions. The treatment variable is mobile money dummy. The outcome variable is GHGs and CO2 emissions. The control variables include the lag final consumption expenditure log natural resources rents, lag public Debt, log GDP per capita, log Households consumption, government revenue and log Trade openness. Standard errors are in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01

Table A13 – Descriptive statistics

	[1]	[2]	[3]=[2]-[1]	[4]	[5]
	Mobile money	No mobile money	Diff	t-TEST	P-value
Log GHG	10.89	10.39	-0.5	7.9	0.005
Log CO2	9.69	9.44	-0.25	1.6	0.202
lag Final consumption expenditure	81.64	79.25	-2.39	2.5	0.113
Log Natural resources rents	1.32	0.88	-0.44	5.8	0.016
Lag Public debt	40.72	51.05	10.33	13.1	0.000
Log GDP per capita	8.53	9.06	0.53	34.0	0.000
Log Households consumption	4.18	4.11	-0.07	8.3	0.004
General government revenue	20.23	25.16	4.93	22.3	0.000
Log Trade	4.10	4.25	0.15	11.7	0.001

This table presents the pre-weighting sample means of the matching covariates for country-year observations where mobile money were in place (the treatment group) in column [1] and country- year observations where no mobile money were in place (the potential control group) in column [2]. Column [3] reports the differences in means between treated and control group, and the corresponding t-Test statistics in column [4] and p values in column [5].

Table B1 – List of countries.

Country	Country	Country	Country
List of countries		Countries with mobile money	
Angola	Malawi	Angola	Mauritania
Benin	Mali	Benin	Mauritius
Botswana	Mauritania	Botswana	Mozambique
Burkina Faso	Mauritius	Burkina Faso	Namibia
Burundi	Mozambique	Burundi	Niger
Cameroon	Namibia	Cameroon	Nigeria
Chad	Niger	Chad	Rwanda
Comoros	Nigeria	Republic of Congo	Senegal
Republic of Congo	Rwanda	Gabon	Seychelles
Equatorial Guinea	Sao Tome and Principe	Gambia	Sierra Leone
Eritrea	Senegal	Ghana	South Africa
Ethiopia	Seychelles	Guinea	South Sudan
Gabon	Sierra Leone	Guinea-Bissau	Sudan
Gambia	South Africa	Kenya	Tanzania
Ghana	South Sudan	Lesotho	Togo
Guinea	Sudan	Liberia	Uganda
Guinea-Bissau	Tanzania	Madagascar	Zambia
Kenya	Togo	Malawi	
Lesotho	Uganda	Mali	
Liberia	Zambia		
Madagascar			

Table B2 – Sources of variables.

Variables	Nature	Sources
Greenhouse gas emissions	Continuous	WDI
CO2 emissions	Continuous	WDI
Mobile money	Dummy	GSMA Mobile Money Metrics
P2P transfer	Dummy	GSMA Mobile Money Metrics
Bill payment	Dummy	GSMA Mobile Money Metrics
P2G transaction	Dummy	GSMA Mobile Money Metrics
G2P transaction	Dummy	GSMA Mobile Money Metrics
Bulk payment	Dummy	GSMA Mobile Money Metrics
Airtime top-up	Dummy	GSMA Mobile Money Metrics
Merchant payment	Dummy	GSMA Mobile Money Metrics
International remittances	Dummy	GSMA Mobile Money Metrics
Mobile money (FAS)	Continuous	IMF Financial Access Survey (FAS)
Final consumption expenditure (% of GDP)	Continuous	WDI
Household consumption volatility	Continuous	Authors' calculation following Apeti (2023)
Domestic investment (% of GDP)	Continuous	WDI
ODA net (% of GDP)	Continuous	WDI
Rural population growth	Continuous	WDI
Urban population growth	Continuous	WDI
Democratic institutions	Continuous	Polity V
Autocratic institutions	Continuous	Polity V
Environmental convention	Continuous	Yale Environmental Performance Index (EPI)
Trade openness (% of GDP)	Continuous	WDI
Rule of law	Continuous	WGI
Inflation	Continuous	WDI
Financial development	Continuous	IMF Financial Development database
Remittance inflows	Continuous	WDI
Natural resources rents	Continuous	WDI
Public Debt	Continuous	Kose et al. (2017) and Ali Abbas et al. (2011)
GDP per capita	Continuous	WDI
Households consumption	Continuous	WDI
General government revenue	Continuous	WDI
Gross capital formation	Continuous	WDI
Agricultural capacity	Continuous	University Notre Dame Global Adaptation Initiative
Fossil fuel energy consumption (% of total)	Continuous	WDI
Renewable energy consumption (% of total final energy consumption)	Continuous	WDI
Mobile penetration rate	Continuous	International Telecommunication Union (ITU)
Neighbour	Continuous	Authors' construction
Financial openness	Continuous	Chinn and Ito (2006)
Sustainable development index	Continuous	Hickel (2020)