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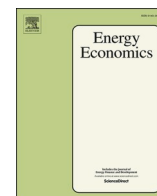
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Chinese ties and low carbon industrialization in Africa

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ABSTRACT

This paper examines the impact of Chinese foreign direct investment (FDI) on low-carbon industrialization in Africa, within the context of China's growing economic ties with the continent. The analysis relies on a panel dataset comprising Chinese greenfield FDI into the manufacturing sectors of 34 African countries from 2003 to 2014, employing the Lewbel Instrumental Variable approach to address potential endogeneity issues. The results show that these Chinese FDI inflows increased industrial carbon emissions in Africa. This adverse effect is particularly pronounced when Chinese FDI targets labor and resource-intensive manufacturing sectors. We attribute this finding to two mechanisms: the sector concentration on labor and resource-intensive manufacturing and the manufacturing processes of Chinese FDI characterized by suboptimal de facto implementation of environmental, social and governance (ESG) standards compared to the international best practices. Additional analysis underscores the potential moderating influence of FDI-host countries' environmental regulations, albeit statistically insignificant, highlighting the legacy of ineffective institutional enforcement that is prevalent on the Africa continent.

1. Introduction

Since the establishment of the Forum on China-Africa Cooperation (FOCAC) in 2000 and the China-Africa Development Fund in 2006, China's economic ties with Africa have grown and deepened significantly. China is currently Africa's largest trading partner, and in many African countries, it has become the top export destination and largest supplier of imports (Owusu et al., 2022; Chen et al., 2024a). China's financial involvement with Africa has also steadily increased. For instance, since 2000, China has provided over \$1 trillion in development financing to developing countries, rivaling traditional multilateral development banks and Western countries (Horn et al., 2019; Humphrey and Michaelowa, 2019; Dreher et al., 2022). Moreover, since 2013, China has overtaken the U.S. to become the world's largest Foreign Direct Investment (FDI) investor in Africa (Yu, 2021). However, China's deepening connections with Africa have been the subject of heated

debate and controversy regarding their composition, intentions, and implications for the continent's economic development.

This paper contributes to this debate by examining how Chinese FDI into the manufacturing sector across African countries affects the region's industrial carbon emission. The paper also considers how this relationship is shaped by the prevailing environmental regulation across African countries. Conceptually, FDI plays a significant role in shaping the economic landscape of most developing countries, particularly in the context of industrialization or more broadly, structural transformation (Mühlen and Escobar, 2020; Hoekman et al., 2023). Recent evidence also shows this to be the case for Chinese FDI presence in Africa (Hu et al., 2021; Darko and Xu, 2022; Chen et al., 2024b). More generally, the potential industrialization gains that FDI confers on the host country's economy materialize through arrays of channels such as capital inflow, technology transfer, job creation, and access to international markets (Kutan and Vukšić, 2007; Glass et al., 2008; Blalock and Gertler,

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2008; Harding and Javorcik, 2012). However, the effect of FDI on industrialization can also vary based on the host country's policies, institutional framework, and the nature of the investments (see Gui-Diby and Renard, 2015; Pineli et al., 2021).

Beyond the FDI effects on industrialization that are often captured by changes in an industry's output, jobs, or productivity, FDI has an environmental implication and has been the focus of few studies (Zugravu-Soilita, 2017; Doytch, 2020; Wang and Luo, 2020; Adekoya et al., 2022; Su et al., 2022). These environmental implications can be sector-specific, but can also extend to the aggregate economy.¹ The direction of this relationship can also be negative or positive, as espoused by the "pollution halo hypothesis" and "pollution haven hypothesis". As retrospection, the *pollution halo hypothesis* argues that multinational companies (MNCs) through FDI transfer their greener technology to the host country. MNCs often also introduce higher environmental standards and practices compared to domestic firms, promoting sustainable operations. This view aligns with Bu et al. (2019), who found that FDI firms are more energy-efficient than non-FDI firms. While the preceding suggests that FDI is pro-environment, the "pollution haven hypothesis" suggests that MNCs may relocate or expand operations into countries with lax environmental regulations to reduce costs. In this case, FDI presence in a sector will adversely affect the sector's environmental performance. Amid this conceptually ambiguous relationship, some empirical studies argue and show that the environmental effect of FDI may well depend on the country's idiosyncrasies such as productive capacities and institutional quality (Wang and Chen, 2014; Wang and Luo, 2020; Adekoya et al., 2022).

The preceding discussion brings to the fore the ambivalent environmental effects of FDI. However, an evaluation of China's FDI in Africa reveals a unique pattern that easily evokes interest in its environmental implications in the continent. First, China's FDI into Africa is largely concentrated in the energy and natural resource sectors, raising questions about China's resource-seeking intent (Financial Times, 2013). Second, the rise of Chinese FDI in Africa has coincided with the continent's high commodity exports to China (Zafar, 2007; Garcia-Herrero and Casanova, 2017) and imports of low-cost, low-technology, and labor-intensive manufactures from China (Torreggiani and Andreoni, 2019). The environmental cost of exploiting commodities is well-established in the literature (Li and Yang, 2023; Ghazouani and Maktouf, 2024). Recent evidence also highlights the environmental cost of low-technology and labor-intensive manufacturing (Avenyo and Tregenna, 2022). Extant studies have also highlighted China's relatively lower emphasis on standards and certification in its value chain (Kaplinsky et al., 2011; Ndubuisi and Owusu, 2022). This can further extend to lower environmental standards and practices among Chinese MNCs in Africa and beyond. This argument aligns with Larsen et al. (2023) which note that much of the funding for Chinese outward FDI lacks policies or guidelines on low-carbon, green transformation, or sustainable growth. It also aligns with those of Voituriez et al. (2019) and Springer et al. (2023), which highlighted that Chinese FDI tends to adhere to the minimum environmental, social, and governance (ESG) standards in host countries. While the Chinese government has recently enacted more stringent domestic regulations on the environmental standards of Belt and Road Initiative (BRI) projects, with "green, clean"

¹ For instance, if a significant share of foreign MNCs in a sector adopts best global environmental practices, this contributes positively to the sector's environmental performance both through the direct actions of the MNCs and spillovers to domestic firms through learning, competition, and technology transfer. To the extent that the sector contributes to the economy's total economic activity, it can also cause an economy-wide improvement in environmental performance. In developing countries, however, foreign MNCs could also be resource-seeking leading to overexploitation national resource and biodiversity loss, which are environmental issues and outcomes that are not sector-bound.

objectives (Coenen et al., 2021), it may take some time before these new regulations take full effect. In this case, while Chinese FDI may indeed be contributing to Africa's industrialization, it may be doing so less sustainably.

Africa's need to industrialize remains immutable to its structural transformation goals. However, as the global call to decouple economic activities and transition to a low-carbon economy intensifies, the region needs not just to industrialize but to do so sustainably. Attaining this fit requires that the region reconsider and reevaluate its industrialization strategies which FDI has been a crucial aspect. Along this line, the rising Chinese FDI presence in Africa amid its potential environmental effect, especially as it concerns transitioning to low-carbon industrialization, becomes an empirical question. Hence, the first objective of this paper is to empirically examine how African countries' industrial carbon emission is influenced by Chinese FDI into the manufacturing sector across African countries. As a second objective, we also consider whether the FDI composition leads to varying industry carbon outcomes since underlying economic interest and technology tend to differ across FDI types and can therefore hold different environmental implications. Decoupling economic activities also requires a new regulatory framework that better structures the actions and incentives of economic agents. Consistent with this view, past studies have, among others, examined the role of environmental regulation (Zhang et al., 2020; Neves et al., 2020; Xiao et al., 2023). Drawing inspiration from this literature, therefore, as a third objective, we examine how the prevailing environmental regulation in a country moderates the observed relationship between FDI and low-carbon industrialization.

To address our research objectives, we compile a panel dataset comprising Chinese FDI into the manufacturing sectors of 34 African countries from 2003 and 2014. We constructed the FDI data using the FDI deal-level data from the Financial Times FDI Intelligence Database. Our FDI data comprises only greenfield investments and excludes merger and acquisition (M&A) FDI that only accounts for about 1 % of China's FDI in Africa between 2000 and 2022. As per the industrial carbon intensity, we directly source the data from the World Bank World Development Indicators. Employing both conventional panel model estimator and an instrumental variable method to address potential endogeneity, the study offers four sets of results. First, manufacturing FDI from China increases Africa's industrial carbon emission level. This result holds irrespective of controlling for FDI from other regions. Second, this effect increases if the manufacturing FDI from China is channeled into the labor and resource-intensive manufacturing sectors. However, we find no significant effect when the FDI is channeled into knowledge-intensive manufacturing sectors. Third, the results, albeit statistically insignificant, show the potential role of the FDI host country's environmental regulations in moderating the adverse industrial carbon emission effect of Chinese FDI to Africa.

The study offers empirical evidence and practical recommendations that contribute to our understanding of the complex relationship between FDI and sustainable industrial development. First, it contributes to the growing body of literature on the impact of FDI on inclusive green growth (Borga, 2021; Ofori et al., 2023). While previous literature generally examines FDI and its impacts on carbon emissions at the aggregate level, this paper focuses specifically on the manufacturing FDI and carbon emissions within the same sector, controlling for different sources of FDI, thereby overcoming potential issues with aggregation bias. Consequently, this study represents the first attempt to quantify how FDI affects the carbon intensity of manufacturing production in Africa, offering insights into the prospects of low-carbon industrialization in the world's least industrialized continent.

Second, this paper contributes to the understanding of the mechanisms behind the environmental impacts of China's FDI by demonstrating that the adverse environmental effects may stem from two channels: the sectoral composition as well as the implementation of environmental, social, and governance (ESG) standards that guides the actual operational processes of these manufacturing investment projects

in FDI recipient countries. While some studies have analyzed the impacts of China's FDI along the Belt and Road Initiative (BRI) countries, revealing its adverse impacts on energy consumption and green development (Yang and Ni, 2022; Shinwari et al., 2024), it could potentially benefit the environment through technological transfer and the sharing of global best practices (Shi et al., 2022). However, it remains unclear how Chinese FDI might have a more adverse impact on the host country's manufacturing carbon emissions compared to other sources of FDI. Our findings suggest two mechanisms: the sector concentration of FDI and the actual operational processes of these manufacturing investment projects. The results show that Chinese manufacturing FDI in labor and resource-intensive sectors increases carbon emissions, whereas FDI in technology-intensive sectors does not. These empirical findings indicate that both the source of FDI, which generally determines the level of adherence to clean production processes, and the sector of the FDI are important factors in determining the environmental impact.

The remainder of the paper is organized as follows. Section 2 first discusses the theoretical perspectives of FDI and low-carbon industrialization. Section 3 discusses the datasets and method. Section 4 discusses the results. Section 5 concludes.

2. Literature review

2.1. Low carbon manufacturing and Africa's industrialization future

The success of Africa's industrialization prospects hinges on adeptly managing the climate transition. The global imperative to shift towards a greener economy carries profound implications for manufacturing production and trade in Africa. Despite contributing less than 4 % to total global emissions, the region grapples with a disproportionately high level of climate risks. The interlinkage between climate change and Africa's productive capacity is underscored by its substantial reliance on commodities, rendering it economically vulnerable to climatic fluctuations. Notably, a staggering 95 % of agriculture in Africa depends on rainfall, accentuating vulnerability due to the sector's substantial contribution to regional employment and gross domestic product (GDP) (African Development Bank Group, 2019). Furthermore, evolving consumer preferences in key export markets towards sustainable products present a formidable challenge.

In terms of concerns, the pushback on low-carbon industrialization policies hinges on the premise that these policies could potentially stymie Africa's industrialization aspirations. This risk arises from the constraints on export opportunities, the erection of entry barriers, and the stifling of rents from value chain trade. Given that a considerable portion of Africa's exports is resource-based, predominantly derived from extractive resources like minerals and fossil fuels, policies such as the European Union's carbon border adjustment measure (CBAM) could potentially undo the gains achieved from these carbon-intensive exports (He et al., 2022; Ndubuisi and Owusu, 2022). Moreover, the transition to low-carbon industrialization is a costly endeavor, characterized by labor-saving practices and necessitating substantial investments in capabilities to ensure competitiveness. Many African nations find themselves grappling with a transition lag, both in terms of infrastructure, capabilities, and fiscal constraints hindering the financing of this transformative process. In this context, FDI from China assumes significant relevance, given China's ascension as the world's largest FDI investor. Amidst these challenges, the shift to low-carbon manufacturing presents a unique opportunity for Africa to invest in climate-smart manufacturing. This strategic pivot away from commodity dependence could pave the way for enhanced competitiveness, efficiency, and the creation of higher-value-added exports from the region.

2.2. Theoretical perspectives: FDI and low-carbon industrialization

The implications of FDI on low-carbon industrialization are less straightforward. On the one hand, FDI is often associated with the

deployment of advanced technologies that are inherently cleaner than those employed by domestic producers, particularly in developing recipient countries. MNCs possess sophisticated production, cleaner, and pollution-control technologies and practices which they transfer to their affiliates in developing countries. This infusion of cleaner technologies can act as a catalyst for improvements in industrial processes in the host country, as it enables the development and implementation of cleaner production methods, energy-efficient technologies, and industrial waste reduction strategies, resulting in the reduction of emissions throughout the production lifecycle "Pollution Halo" effect (Gallagher and Zarsky, 2007; Demena and Afesorgbor, 2020).

While this knowledge and technology transfer often takes place involuntarily through MNCs' interaction with domestic firms in recipient countries, it can also occur through voluntary actions, where MNCs voluntarily share new knowledge with their domestic input suppliers to ensure more efficient production of the outsourced tasks. However, for domestic firms wanting to participate and benefit from the global production network, MNCs require these firms to have certain productive capabilities to enter and remain competitive. To satisfy these requirements, domestic firms (suppliers) are compelled to make investments to build specific capabilities for the specific activities they perform in the production network. Such investment could involve introducing new environmentally friendly production technologies, adopting a mix of innovations, engaging in skill upgrades for workers to utilize equipment and information efficiently, or even changing organizational structure, which could lead to improvements in cleaner production methods resulting in reduced emissions from industrial production.

On the other hand, challenges arise in low-income countries where fierce competition among developing nations for foreign investors (attraction of resource-seeking and pollution-intensive FDI) may result in the lowering of environmental standards for foreign investors, potentially resulting in heightened emissions and increasing pollution in weakly regulated developing countries (Zugravu-Soilita, 2017). In essence, the impact of FDI on low-carbon industrialization is an empirical question and is conditioned on the type of FDI and the regulatory quality of the recipient country, calling for a nuanced approach that takes into account the complexities in the FDI-low-carbon industrialization nexus.

2.3. The role of Chinese FDI in low-carbon industrialization in Africa

Some literature has started to examine the goals and impacts of Chinese FDI in Africa. Empirical analysis of transaction-level data on registered small- and medium-sized Chinese private firms investing in Africa between 1998 and 2012 suggests Chinese investment is more prevalent in skill-intensive sectors in more skill-abundant countries and more concentrated in capital-intensive sectors in more capital-scarce countries, indicating an aim to leverage local comparative advantages (Chen et al., 2018). However, data on Chinese economic engagement across 50 African countries shows China's construction activities and exports negatively impact the environment and carbon dioxide emissions in host nations (Tawiah et al., 2021). Large infrastructure projects like roads, railways and airports generate pollution from dust, water contamination and fossil fuel use, while investments in the resource extraction industry degrade local environments. Similarly, Chen et al. (2023) find that Chinese FDI and exports to Africa had a negative relationship with green growth indicators, suggesting that China's resource extraction focus undermines sustainable development goals.

A review article by Calabrese and Tang (2023) finds that Chinese firms' major investments in African manufacturing and construction sectors have prompted views that Africa could become "the next factory of the world" (Sun, 2017). They argue that Chinese FDI into productive sectors broadly promotes structural economic transformation in Africa through industrialization and diversification. However, they raise concerns about the environmental impacts of Chinese FDI. More broadly,

Chinese FDI tends to concentrate on resource extraction, especially in countries with weak regulations. Extant studies have emphasized China's relatively lower focus on standards and certifications in its value chains (Kaplinsky et al., 2011; Ndubuisi and Owusu, 2022), a trend which can extend to weaker environmental standards and practices by Chinese MNCs in Africa and beyond. This view aligns with Larsen et al., (2023), who suggest that much of China's outward FDI lacks policies focused on low-carbon development, green transformation, or sustainable growth. Consequently, while Chinese FDI may contribute to Africa's economic transformation, it may do so in a way that is less environmentally sustainable. This adverse effect on Africa's prospect of low-carbon industrialization is further exacerbated by the region's pre-existing poor technological capability and weak environmentally regulated environment. Ultimately, the first hypothesis that guides our analysis is as follows:

Hypothesis 1. Other things being equal, Chinese FDI into Africa's manufacturing sector undermines the region's prospect of low-carbon industrialization.

The hypothesis above is, among others, predicated on the notion of lax environmental regulation and is silent about the composition of FDI. Yet, as argued in the previous section, the impact of FDI on low-carbon industrialization is conditioned on the type of FDI and the regulatory quality of the host country. Beginning with the former, although we expect that, on average, Chinese FDI into Africa's manufacturing sector undermines the region's prospect of low-carbon industrialization, available evidence indicates a negative relationship between stringent environmental regulation and environmental quality (Zhang et al., 2020; Neves et al., 2020; Xiao et al., 2023). Accordingly, one would expect that the low-carbon industrialization of African countries with better and more stringent environmental regulations may not be adversely affected by Chinese FDI for at least two reasons. First, the stringent environmental regulation serves as a strong signal for a country's readiness and interest in only eco-friendly FDI. In this case, countries with stringent environmental regulations end up attracting environmentally friendly FDI. Second, stringent environmental regulation ensures that the activities of incumbent firms, including those of foreign MNCs are eco-friendly. Ultimately, the second hypothesis that guides our analysis is as follows:

Hypothesis 2. Other things being equal, stringent environmental regulation across African countries attenuates the adverse effect of Chinese FDI on Africa's low-carbon industrialization.

The manufacturing sector is highly heterogeneous, covering sub-sectors with varying technology, labor and resource intensity that have a strong environmental implication. Consistently, Chinese FDI into Africa's manufacturing sector is heterogeneous (see Figs. 3 and 4 in section 3.1), with the net environmental effect depending on the composition of FDI. Other things equal, resource- and labor-intensive manufacturing is generally more carbon-unfriendly than knowledge or technology-intensive manufacturing. For instance, resource-intensive manufacturing is reliant on heavy energy consumption, resource extraction, and inefficient processes that produce large amounts of emissions and other greenhouse gases. Conversely, knowledge or technology-intensive manufacturing is more environmentally friendly because it focuses on innovation, advanced technologies, and efficiency, which tend to have a smaller carbon footprint and lower environmental impact. This view aligns with recent evidence by Avenyo and Tregenna (2022) that found that medium- and high-technology manufacturing is associated with lower carbon emissions than low-technology manufacturing. Ultimately, the third hypothesis that guides our analysis is as follows:

Hypothesis 3. Other things being equal, the adverse effect of Chinese FDI on Africa's low-carbon industrialization varies with the composition of Chinese FDI, with the adverse effect being more pronounced for

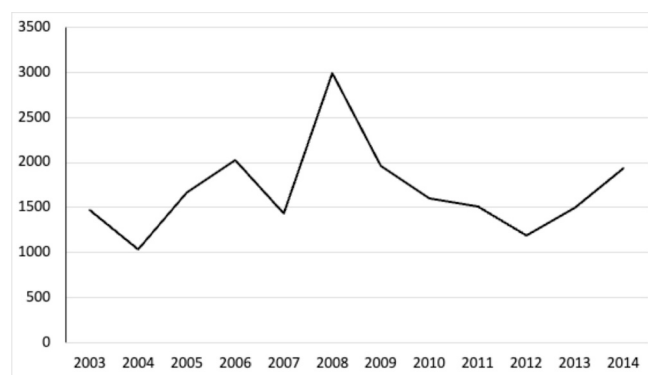


Fig. 1. Annual total FDI inflow to Africa's manufacturing industry, million USD.

Source: Author's based on data from FDI Intelligence.

manufacturing resources and labor-intensive FDI.

3. Research design

3.1. Variables and data sources

It is challenging to estimate the true scale of China's FDI in Africa, given that nearly 60 % of China's outbound FDI is commissioned through offshore financial centers like Hong Kong, the British Virgin Islands and the Cayman Islands (Johns Hopkins University SAIS China-Africa Research Initiative, 2022). The most official records of China's investment in Africa can be found in MOFCOM's yearly statistical bulletin of China's FDI flows and stocks by region and sector, and this dataset has also been used by the previous literature on Chinese overseas FDI (Chen et al., 2018; Stone et al., 2022).

While the MOFCOM data on overseas FDI provides valuable insights, there are two caveats worth noting. First, the MOFCOM FDI data only lists the existence of a firm investing in a targeted country, but not the total value of the investment, thereby making it hard to measure the scale of FDI. Second, it lacks information on FDI from other sources to a targeted country on a yearly basis. Fortunately, the FDI Intelligence Dataset developed by the Financial Times allows us to break down the FDI capital investment amount by source, year, and sector. The FDI Intelligence Data tracks daily greenfield investment announcements from all sources to all sectors in target countries. The reason we focus solely on greenfield FDI and exclude merger and acquisition (M&A) FDI is that only 1 % of China's M&A FDI in Africa between 2000 and 2022 was directed to the manufacturing sector (Moses et al., 2024). Instead, Chinese M&A FDI in Africa has concentrated heavily on the mining and energy sectors, making it less relevant to our primary focus on

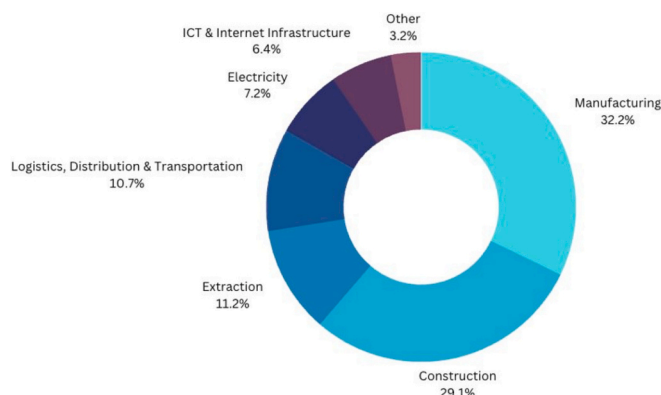


Fig. 2. Chinese FDI to Africa, by sector, share, 2003–2022.

Source: Author's based on data from FDI Intelligence database.

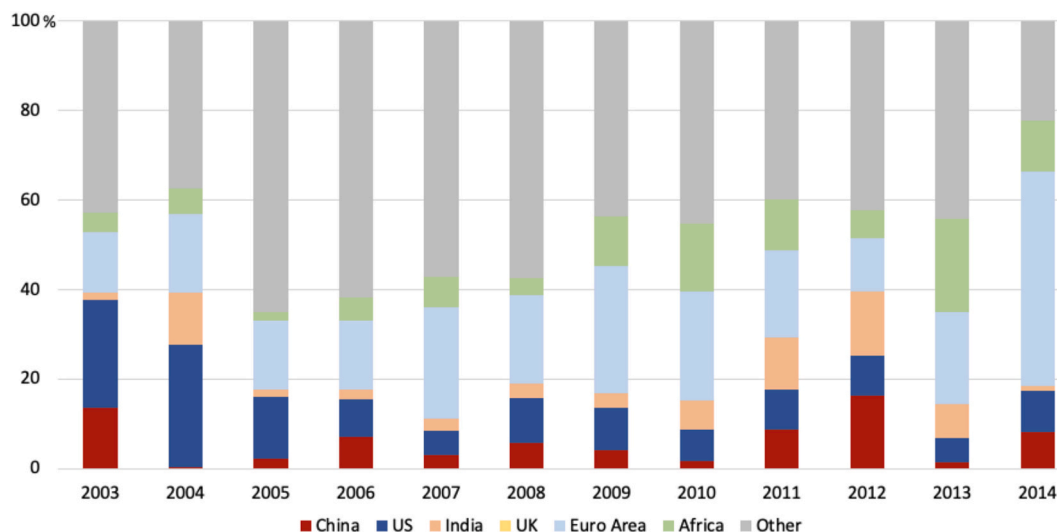


Fig. 3. Annual FDI inflow to Africa's manufacturing industry, by sources, percent. Source: Author's based on data from FDI Intelligence database.

manufacturing FDI. We used the FDI data from 2003 to 2014 and included information on the total amount of capital investment while treating missing observations as zeroes. Given that the FDI Intelligence database tracks investment announcements rather than the actual operation of investments, we took additional steps to confirm the validity of the Chinese FDI information. Specifically, we double-checked the implementation status and total investment value for each of the 665 transactions in the total deal count, on a deal-by-deal basis. However, since our primary dependent variable, carbon emissions from the industrial sector is only available up to 2014, we limit our use of FDI data to the same period. In Appendix A, we provide further details about the steps we followed to aggregate the FDI transactions.

Using this data, we used the total Chinese FDI flows to targeted countries in a given year in Africa. Our empirical measure of carbon emission intensity relies on industry-level carbon emissions data from the World Development Indicator (WDI). Due to missing data points for some countries and the availability of corresponding data series for the Chinese FDI data, we extracted a sample of 34 countries from 2003 to 2014. See Table A.1 in the appendix for the full set of countries that are used in the final analysis. Fig. 1 shows that the world FDI to Africa's manufacturing sector has grown from \$1.4 billion in 2003 to \$3 billion in 2009, declining after 2009 and increasing again since 2012.

Fig. 2 shows that the manufacturing sector attracts the most Chinese investment in Africa. Between 2003 and 2022, on average, 32.2 % of Chinese FDI stock in Africa was concentrated in the manufacturing sector, followed by 29.1 % in construction, 11.2 % in extraction, 10.7 % in logistics, distribution, and transportation, 7.2 % in electricity, and 6.4 % in ICT and internet infrastructure. The significant share of the manufacturing sector in China's FDI to Africa makes it pertinent to study the general environmental impacts of Chinese manufacturing FDI on the continent.

Fig. 3 presents a dynamic landscape of annual FDI inflows to Africa's manufacturing industry, expressed as percentages from various sources over two decades. Since around 2012, China has emerged as the most significant source of bilateral FDI to Africa's manufacturing industry. The U.S. has maintained a relatively stable presence, often contributing around 10 %, relative to its high initial share of about 27 % in 2004. India's share has seen sporadic peaks, such as 15 % in 2012. The Euro Area has been a consistent contributor, particularly in 2014 when it accounted for nearly half of the FDI at 48 %. Interestingly, Africa's self-investment peaked in 2013 at 21 %, reflecting a growing internal

market.

Fig. 4 presents the annual Chinese FDI inflow to Africa's manufacturing sector, categorized by sector characteristics and denominated in million USD. The sectors are divided into labor-intensive, resource-intensive, and technology-intensive. The resource-intensive sector has traditionally attracted the highest amount of FDI. However, since 2013, there has been a shift with the labor-intensive and technology-intensive sectors gradually overtaking the resource-intensive sector. This could be due to the commodity price slump since late 2013, which made resource-intensive investments less attractive.

Fig. 5 enriches the insights gleaned from Fig. 4 by showcasing the proportional distribution of China's manufacturing FDI across different sector characteristics over the years. Despite its historical dominance, the resource-intensive sector has experienced a gradual decline in its share since 2013. In contrast, the labor-intensive and technology-intensive sectors have seen their shares increase, mirroring China's strategic emphasis on these sectors. The technology-intensive sector also demonstrated a significant relative surge in its share in 2013 as per Fig. 5. This trend underscores the escalating significance of the telecommunications technology sector in China's FDI strategy in Africa, with Huawei and ZTE emerging as the leading players.

3.2. Model specification and estimation strategy

To empirically investigate how Chinese FDI affects Africa's low-carbon industrialization, the following regression models are estimated.

$$\mathcal{M}_{it} = \beta_0 + \beta_1 \text{Chineses FDI}_{it} + X_{it}\Phi + \delta_i + \delta_t + \varepsilon_{it} \quad (1)$$

where the subscript i refers to country and t refers to year, \mathcal{M} is a country's industrial carbon emission level. *Chinese FDI* is the level of FDI from China to Africa's manufacturing sector. In the analysis, we first consider total Chinese FDI in the manufacturing sector across the countries in our sample. Subsequently, we examine the effect due to the composition of the Chinese FDI, considering resource-, labor-, and knowledge-intensive manufacturing FDI. We estimate separate regressions for both the total and sub-components of FDI. X_{it} is a vector of time-varying control variables and Φ is the corresponding vector of coefficients that are to be estimated. The choice of the control variables is guided by the existing literature and is included to minimize potential omitted variable bias. Table A.5 in the appendix lists these variables and

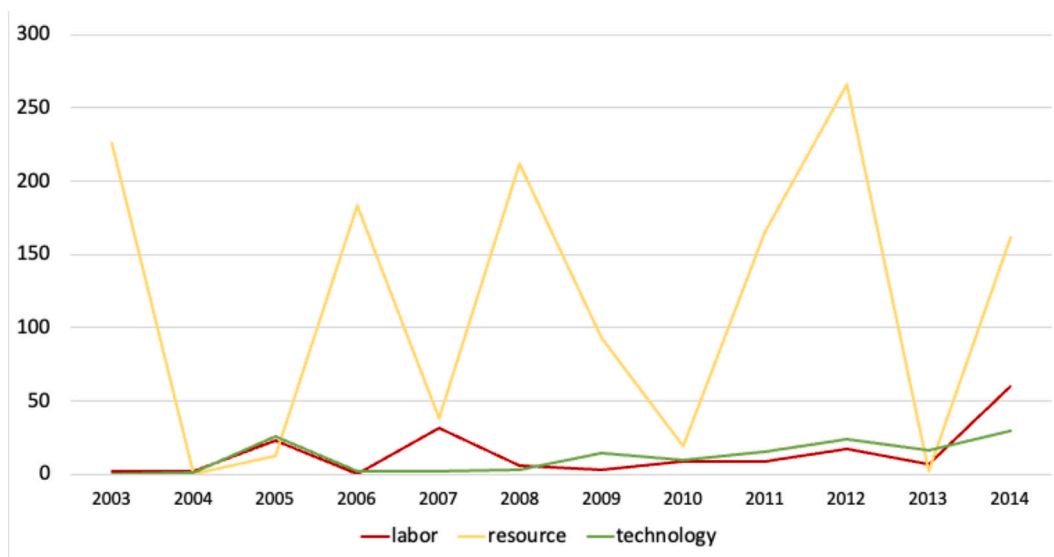


Fig. 4. Annual Chinese FDI inflow to Africa's manufacturing sector, million USD. Source: Authors' based on data from FDI Intelligence database.

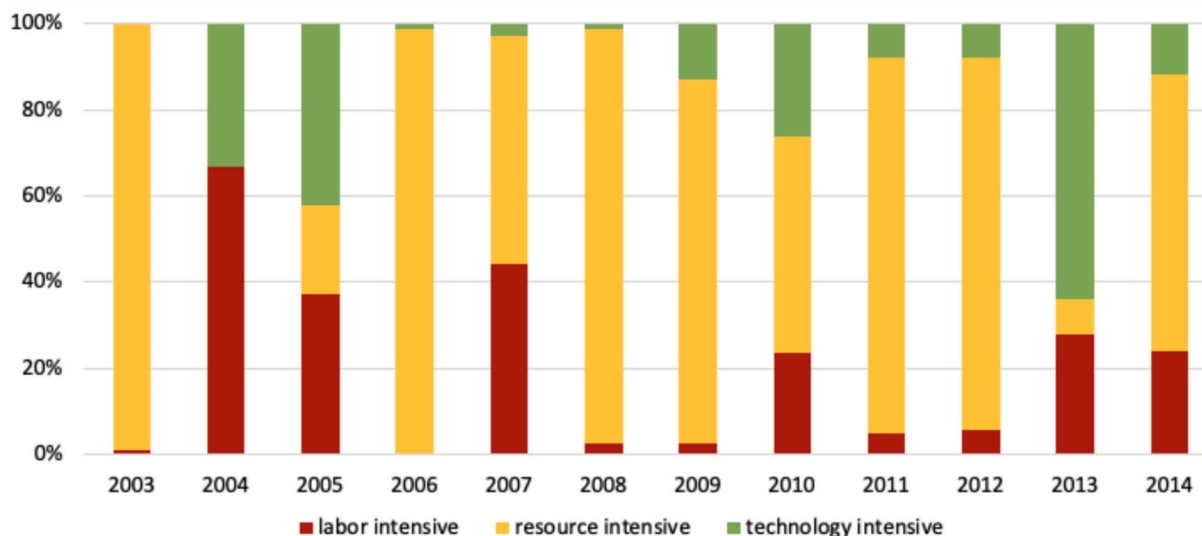


Fig. 5. Annual Chinese FDI inflow to Africa's manufacturing sector, percent. Source: Author's based on data from FDI Intelligence database.

their respective data sources.² Our empirical specification particularly controls for GDP per capita and its quadratic form, total population, energy intensity, industry value added share and environmental regulation.

The GDP per capita and its quadratic form capture and test the Environmental Kuznets Curve (EKC) hypothesis, which postulates that environmental damage increases in the early stages of growth but diminishes once nations reach higher levels of income (Grossman and Krueger, 1995; Stern, 2004). Total population is used to capture the effect of population growth which extant studies suggest increases carbon emission levels due to among other things, high demand for industrial products arising from the population growth (Kaufman et al., 2007). The industry value added share captures the composition effect, delineating the strong positive association between industrial activities

and carbon emissions. High energy consumption often signals less efficient technologies used in the production process leading to unnecessary carbon emissions. The environmental regulation is included to capture the regulatory environment. For the latter, we rely on a self-constructed index, defined as the sum of environmental treaties a country is a member of. We provide a detailed explanation of how we computed this variable in Appendix C. To isolate the effect of environmental regulation from broader country regulatory institutional quality, we also control for regulatory quality using the regulatory quality index from the World Governance Indicator. Finally, ε_{it} is the error term, while δ_i and δ_t are sets of country and year dummies, respectively. The country dummies are included to control for time-invariant country-specific characteristics such as culture, while the year dummies account for time-shocks such as the effect of the global financial crisis that are common across countries but vary over time.

As is obvious by now, one of our research objectives is to examine how the levels of environmental regulation across African countries shape effect of Chinese FDI on Africa's industrial carbon emission. To

² Table A.6 in the appendix reports the correlation matrix of the variables used in our analysis.

achieve this, we augment Eq. (1) with an interaction term comprising the Chinese FDI and the country characteristic of environmental regulatory. More formally, the model specification that guides our analysis is as expressed in Eq. (2).

$$\mathcal{M}_{it} = a_0 + a_1 \text{Chinese FDI}_{it} + a_2 ER_{it} + a_3 (\text{Chinese FDI} * ER)_{it} + W_{it} \psi + \delta_i + \delta_t + \mu_{it} \quad (2)$$

where all variables are as defined in Eq. (1), ER_{it} is a country-level measure of environmental regulation. W_{it} is a vector of time-varying control variables. $\text{Chinese FDI}_{it} \times ER_{it}$ is an interaction term comprising Chinese FDI and environmental regulation. a_1 , a_2 , a_3 and ψ are coefficients to be estimated, μ is the error term. The total effect of Chinese FDI on the industrial carbon emission level in Eq. (2) is captured by $a_1 + a_3$. Here, we are more interested in the differential effect of Chinese FDI given the FDI host country's environmental regulatory system. This is given by the parameter a_3 . Hence, a_3 is the key parameter of interest in Eq. (2). In line with our second hypothesis, $a_3 < 0$ is expected, implying that the adverse effect of Chinese FDI on low-carbon industrialization in Africa decreases with effective environmental regulation in the FDI host country.

Estimating Eqs. (1) and (2) with OLS could yield biased estimates due to endogeneity issues, especially those arising due to simultaneity bias and omitted variable bias. While it cannot be taken for granted that the inclusion of country and year fixed effects help in ameliorating omitted variable bias concerns, it does not address concerns that may result from omitted time-varying country characteristics. Even more, endogeneity issues due to reverse causality still remain. Addressing these concerns calls for an alternative estimation strategy designed for such purpose. Accordingly, our empirical analysis employs the instrumental variable (IV) technique, which is best designed to address endogeneity issues arising from omitted variable bias and simultaneity bias. Particularly, we utilize the Lewbel (2012) IV approach for this purpose.

Contrary to the conventional IV approach requiring an external instrument for appropriate endogenous variable identification, the Lewbel (2012) IV approach identifies regressors uncorrelated with the product of heteroskedasticity errors, a feature present in many models with error correlations due to an unobserved common factor (Baum et al., 2013, p.13). However, this method also allows the inclusion of external instruments, recommended by Baum and Lewbel (2019) for enhancing IV estimator efficiency when available.

In our analysis, we employ Lewbel (2012) IV estimation strategy with and without external instruments. For the external instrument, we use two instruments. First, the average Chinese FDI share to other African countries as an instrument referred hereafter as average country peer FDI. The choice of this instrument is inspired by the trade literature (Autor et al., 2013; Bloom et al., 2016), aiming to capture variation in the share of Chinese FDI driven by changes in supply conditions in foreign, but similar, countries not influenced by domestic industry-specific shocks potentially endogenous to carbon emissions. The method we employ to compute this index is as defined in Eq. (3).

$$\text{Average Chinese FDI}_{it} = \frac{\text{Chinese FDI}_t - \text{Chinese FDI}_{it}}{n - 1} \quad (3)$$

Where n is the total number of countries in the sample, Chinese FDI_t is the sum of Chinese FDI across the African countries in the sample in period t , while Chinese FDI_{it} is country-time-specific Chinese FDI. By substituting the latter for the total FDI, we generate an instrument that varies across country and time.

For the second instrument, we use Chinese bilateral investment treaty (BIT) dummy interacted with a country's probability of receiving Chinese FDI. Notably, the Chinese bilateral investment treaty dummy is

a dummy variable that takes the value of 1 from the year a country enforces a bilateral investment treaty with China, and zero otherwise. We sourced this data from the UNCTAD Investment Policy Hub database.³ We observe that 20 African countries among the 34 in our sample has an enforced BIT with China, albeit the date of enforcement varies. While we do not expect these treaties to directly affect carbon emission, we expect that having bilateral investment treaty will increase investment among country-pairs as have been shown in the literature (Egger and Pfaffermayr, 2004; Neumayer and Spess, 2005). Nevertheless, anecdotal evidence suggests that the amount of investment resulting from a bilateral investment treaty varies, as country-pair idiosyncrasies play a significant role. Accordingly, we expect that any investment effect associated with having a BIT should be higher for countries with a higher probability of receiving the investment in question, which in our case is Chinese FDI. To compute the probabilities, therefore we follow Eq. (4).

$$\text{Chinese FDI Probability}_i = \frac{J_i}{j_i} \quad (4)$$

Where J is the number of years we observe country i has received FDI from China, j is the number of years we observe the country in our dataset.

4. Results and discussion

4.1. Chinese FDI and industrial carbon emission

Table 1 reports results from estimating Eq. (1) using the Lewbel-IV approach. As noted in the method section, we apply the method with and without external instrument. Accordingly, Column 1 shows the result without external instruments, while Columns 2–4 show the result with external instruments. The external instrument in Column 2 is Chinese bilateral investment treaty dummy multiplied by the country's probability of receiving Chinese FDI. The external instrument in Column 3, on the other hand, is the average country peer Chinese FDI inflows. Column 4 jointly introduces both external instruments.

We observe that employing these external instruments either individually (see Columns 2 and 3) or jointly (see Column 4) does not change the results obtained without external instrument (see Column 1) in any significant way. In fact, we observe that the variation in the results across the columns is rather infinitesimal. Concerning the variable of interest, Chinese FDI enters all the regression with a positive and highly statistically significant coefficient, implying that an increase in Chinese FDI to Africa leads to higher industrial carbon emissions. More specifically, the results show that, on average, a 1 % increase in Chinese FDI into Africa increases industrial carbon emission by 0.02 % across African countries. This effect is statistically significant at the 1 % level.

In Table A.7 in the appendix, we show results using the OLS (see Columns 1 and 2) and System GMM (Column 3). In both cases, we observe that our main result on the impact of Chinese FDI on Africa's industrial carbon emission remain unchanged. Notably, the OLS results show that this result holds without (see Column 1) or with (see Column 2) the inclusion of control variables. In Table A.8, we further expand our model by accounting for the FDI shares coming from other sources. We find that accounting for these other FDI sources does not change our result, implying that our baseline result is unlikely to be driven by spillovers from other FDI sources. Overall, our baseline result indicates that Chinese FDI presence across Africa's manufacturing sector is impeding the region's transition to low-carbon industrialization. This finding corroborates our first hypothesis. As noted earlier, one of the explanations of this adverse effect is rooted in the weak implementation of environmental, social, and governance (ESG) standards that guide the

³ See <https://investmentpolicy.unctad.org/international-investment-agreements/countries/42/china>

Table 1
Chinese FDI and low-carbon industrialization in Africa.

	(1)	(2)	(3)	(4)
Chinese FDI (log)	0.020*** (0.007)	0.020*** (0.007)	0.019*** (0.007)	0.019*** (0.007)
Environmental regulation	-0.000 (0.260)	-0.000 (0.260)	-0.001 (0.260)	-0.001 (0.260)
GDP pc (log)	1.250 (0.912)	1.249 (0.912)	1.257 (0.911)	1.257 (0.910)
GDP pc squared	-0.068 (0.064)	-0.068 (0.064)	-0.069 (0.064)	-0.069 (0.064)
Population (log)	0.353 (0.497)	0.353 (0.497)	0.351 (0.498)	0.351 (0.498)
Energy consumption (% GDP)	0.060** (0.026)	0.060** (0.026)	0.060** (0.026)	0.060** (0.026)
Regulatory quality	-0.141* (0.083)	-0.141* (0.083)	-0.141* (0.083)	-0.141* (0.083)
Industry (% GDP)	0.010*** (0.004)	0.010*** (0.004)	0.010*** (0.004)	0.010*** (0.004)
Constant	-9.633 (7.588)	-9.631 (7.588)	-9.645 (7.585)	-9.644 (7.585)
Observations	335	335	335	335
R-squared	0.89	0.89	0.89	0.89
Country Dummies	YES	YES	YES	YES
Year Dummies	YES	YES	YES	YES
Hansen J stat	56.6	56.6	56.6	56.6
Hansen J stat p-val	0.12	0.14	0.14	0.16

Robust standard errors in parentheses.

Note: The table reports results from estimating a Lewbel-IV- model with country and year dummies. Column 1 shows the result without external instruments, while Columns 2–4 show the result with external instruments. The external instrument in Column 2 is Chinese bilateral investment treaty dummy multiplied by the country's probability of receiving Chinese FDI. The external instrument in Column 3 is the average country peer Chinese FDI inflows. Column 4 jointly introduces both external instruments. We log transform the Chinese FDI variable by adding a constant i.e., $\ln(\text{Chinese FDI} + 1)$.

* $p < 0.10$.

** $p < 0.05$.

*** $p < 0.01$.

actual operational processes of Chinese manufacturing investment projects in FDI host countries.

On the one hand, the result broadly aligns with patterns observed in other studies, which suggest the adverse environmental impacts of Chinese investment in BRI countries (Tawiah et al., 2021; Yang et al., 2021; Chen et al., 2023) or increase local energy consumption (Shinwari et al., 2024). This is particularly pronounced in lower-income countries, where environmental and social regulations tend to be laxer (Mahadevan and Sun, 2020). This race to the bottom mentality aims to attract more investment and create jobs, but at the cost of environmental protection (Springer et al., 2023). On the other hand, the result also contradicts some studies that find Chinese FDI reduces carbon emission level across all BRI countries and sectors (Su et al., 2022). However, it is important to note that our sample is limited to the manufacturing sector in some of the world's poorest countries with the least developed institutional regulations. In this context, the technological innovation of Chinese manufacturing investment may not be the highest. Previous literature has documented that within the manufacturing sector, Chinese FDI in these countries tends to concentrate in light manufacturing industries, such as low-skilled apparel and footwear production and other resource-intensive sectors such as minerals, metals and oil and gas (Bräutigam and Tang, 2011). As a result, the emissions-reducing effects of technological transfer through FDI observed by other literature may be quite small in the manufacturing sector in these countries.

4.2. Composition of Chinese FDI and industrial carbon emission

A second major contribution of this study is to examine whether Chinese FDI's impact on Africa's low-carbon industrialization varies depending on the sector receiving the FDI. To address this, we categorize

Chinese FDI into three sectors: labor-intensive, resource-intensive, and knowledge-intensive manufacturing.⁴ FDI in knowledge-intensive sectors, such as technology and R&D, typically drives the adoption of advanced and cleaner technologies. These sectors prioritize efficiency and innovation, leading to reduced emissions and pollution. Consequently, we anticipate a positive environmental impact from this type of FDI. Conversely, FDI in labor-intensive or resource-intensive sectors may overlook environmental concerns, focusing instead on maximizing production and minimizing costs. Without stringent environmental regulations, this can result in higher emissions and pollution. Additionally, competition among developing nations for FDI in these sectors may lead to a race to the bottom in environmental standards. Thus, the sector receiving FDI plays a significant role in shaping the environmental implications of Chinese manufacturing FDI flows in Africa.

Accordingly, we examine whether the effect of Chinese FDI on Africa's industrial carbon emission level varies based on the sector receiving the FDI. The findings of this exercise are reported in Table 2. As in the previous section, the reported results are based on estimating Eq. (1) using the Lewbel-IV approach. Each regression includes the sets of control as discussed in the method section. For the purpose presentation, however, we do not report them in Table 2. Panel A reports the result for labor-intensive Chinese FDI, while Panels B and C report the respective results for resource-intensive and knowledge-intensive Chinese FDI. We follow the structure used in Table 1 to present the results across each panel.

Moving on, we continue to observe that employing the external instruments either individually (see Columns 2 and 3) or jointly (see Column 4) does not change the results obtained without external instrument (see Column 1) in any significant way. Concerning the variables of interest, labor- and resource intensive FDI both enters the respective regressions with positive and statistically significant coefficient as seen in Panels A and B. Conversely, Chinese FDI into African country's manufacturing that is more knowledge-intensive does not significantly affect industrial carbon intensity as presented in Panel C. In Table A.9 in the appendix, we further report the results for the OLS and System GMM estimation. The results largely align with those reported in Table 2. The only exception is system GMM results for labor intensive FDI, that albeit remains positive, turns statistically insignificant at all conventional significance level.

The results, thus, put together indicate that the effect of Chinese FDI on Africa's industrial carbon emission level depends on the composition of or the sector receiving the FDI. More specifically, they imply that the adverse Chinese FDI effect on Africa's low carbon industrialization we previously documented are mostly driven by resource-seeking, and to some extent by labor-intensive, Chinese FDI into Africa. The findings thus corroborate our third hypothesis. Furthermore, the findings align with previous research demonstrating that low- and middle-income countries generally bear the negative environmental effects of FDI, as these countries disproportionately shoulder the export-related ecological burdens driven by production-focused FDI (Doytch and Uctum, 2016; Doytch, 2020). While Doytch (2020) highlights the distinctions between consumption-focused and production-focused FDI across high- and low-income countries, our analysis delves deeper into the heterogeneity within production FDI in low-income African countries, revealing notable differences between knowledge-intensive versus labor- and resource-intensive sectors.

4.3. Accounting for the role of environmental regulation

Thus far, the analysis has focused on the industrial carbon emission effect of Chinese FDI in Africa and how this effect depends on the composition of Chinese FDI. The current findings indicate that Chinese FDI into Africa undermines Africa's industrial carbon emission

⁴ Classification seen in Table A.2 in the Appendix B.

Table 2
The composition of Chinese FDI and low-carbon industrialization in Africa.^{a, **}

	(1)	(2)	(3)	(4)
Panel A				
Labor intensive Chinese FDI (log)	0.020** (0.009)	0.020** (0.009)	0.021** (0.009)	0.021** (0.009)
Constant	-10.228 (7.612)	-10.227 (7.612)	-10.232 (7.611)	-10.231 (7.611)
Controls	YES	YES	YES	YES
Observations	335	335	335	335
R-squared	0.88	0.88	0.88	0.88
Country Dummies	YES	YES	YES	YES
Year Dummies	YES	YES	YES	YES
Hansen J stat	56	57	58	58.6
Hansen J stat p-val	0.12	0.12	0.11	0.12
Panel B				
Resource intensive Chinese FDI (log)	0.018** (0.008)	0.019** (0.008)	0.016** (0.007)	0.017** (0.008)
Constant	-9.914 (7.680)	-9.910 (7.680)	-9.933 (7.677)	-9.929 (7.678)
Controls	YES	YES	YES	YES
Observations	335	335	335	335
R-squared	0.88	0.88	0.88	0.88
Country Dummies	YES	YES	YES	YES
Year Dummies	YES	YES	YES	YES
Hansen J stat	38	40.8	39.7	42.7
Hansen J stat p-val	0.74	0.68	0.73	0.65
Panel C				
Knowledge intensive Chinese FDI (log)	0.009 (0.008)	0.008 (0.008)	0.008 (0.008)	0.008 (0.008)
Constant	-10.314 (7.658)	-10.313 (7.658)	-10.298 (7.661)	-10.301 (7.661)
Controls	335	335	335	335
Observations	0.88	0.88	0.88	0.88
R-squared	YES	YES	YES	YES
Country Dummies	YES	YES	YES	YES
Year Dummies	YES	YES	YES	YES
Hansen J stat	51.3	51.9	51.9	52.6
Hansen J stat p-val	0.23	0.25	0.25	0.26

Robust standard errors in parentheses.

Note: All panels contains unreported controls as in Table 1. The table reports results from estimating a Lewbel-IV- model with country and year dummies. Column 1 shows the result without external instruments, while Columns 2–4 show the result with external instruments. The external instrument in Column 2 is Chinese bilateral investment treaty dummy multiplied by the country's probability of receiving Chinese FDI. The probabilities are computed based on FDI type. Depending on the FDI type, the external instrument in Column 3 is the average country peer Chinese FDI inflows. Column 4 jointly introduces both external instruments. Each FDI type is log transformed by adding a constant. i.e., $\ln(\text{Chinese FDI} + 1)$.

* $p < 0.10$.

** $p < 0.05$.

*** $p < 0.01$.

performance, especially when the FDI is resource seeking and labor intensive. Conversely, this adverse environmental impact diminishes when the FDI from China is channeled into the knowledge-intensive manufacturing of recipient countries in Africa. In this section, we further examine whether the adverse Chinese FDI effect on Africa's low carbon industrialization is contingent upon other country characteristics. Building on discussions from Section 2.3, we particularly examine the role of environmental regulation in moderating this adverse effect.

Table 3 reports the results for this analysis. Again, the analysis is based on the Lewbel-IV. Across the models, we endogenize Chinese FDI, environmental regulation, and the interaction variable comprising both variables. Furthermore, Column 1 shows the result without external instruments, while Columns 2–4 show the result with external instruments. The external instrument in Column 2 is Chinese bilateral investment treaty dummy multiplied by the country's probability of receiving Chinese FDI. The external instrument in Column 3, on the

Table 3
Chinese FDI, Environmental Regulation and low-carbon industrialization.

	(1)	(2)	(3)	(4)
Chinese FDI (log)	0.052 (0.045)	0.050 (0.045)	0.052 (0.044)	0.050 (0.045)
Environmental Regulation	0.027 (0.266)	0.026 (0.266)	0.028 (0.266)	0.026 (0.266)
Chinese FDI (log) × Environmental Regulation	-0.039 (0.052)	-0.037 (0.052)	-0.039 (0.052)	-0.037 (0.052)
GDP pc (log)	1.254 (0.892)	1.252 (0.892)	1.255 (0.892)	1.253 (0.892)
GDP pc squared	-0.068 (0.063)	-0.068 (0.063)	-0.068 (0.063)	-0.068 (0.063)
Population (log)	0.310 (0.501)	0.312 (0.501)	0.309 (0.501)	0.312 (0.501)
Energy consumption (% GDP)	0.060** (0.027)	0.060** (0.027)	0.060** (0.027)	0.060** (0.027)
Regulatory quality	-0.144* (0.083)	-0.144* (0.083)	-0.144* (0.083)	-0.144* (0.083)
Industry (% GDP)	0.010*** (0.004)	0.010*** (0.004)	0.010*** (0.004)	0.010*** (0.004)
Constant	-9.039 (7.623)	-9.064 (7.618)	-9.032 (7.623)	-9.060 (7.618)
Observations	335	335	335	335
R-squared	0.891	0.891	0.891	0.891
Country Dummies	YES	YES	YES	YES
Year Dummies	YES	YES	YES	YES
Hansen J stat	155	156	155	156
Hansen J stat p-val	0.10	0.10	0.10	0.10

Robust standard errors in parentheses.

Note: The table reports results from estimating a Lewbel-IV- model with country and year dummies. Column 1 shows the result without external instruments, while Columns 2–4 show the result with external instruments. The external instrument in Column 2 is Chinese bilateral investment treaty dummy multiplied by the country's probability of receiving Chinese FDI. The external instrument in Column 3 is the average country peer Chinese FDI inflows. Column 4 jointly introduces both external instruments. Note that across the models, we endogenize Chinese FDI, environmental regulation and the interaction variable comprising both variables. We log transform the Chinese FDI variable by adding a constant i.e., $\ln(\text{Chineses FDI} + 1)$.

* $p < 0.10$.

** $p < 0.05$.

*** $p < 0.01$.

other hand, is the average country peer Chinese FDI inflows. Column 4 jointly introduces both external instruments. Across the columns, the estimated coefficient of the interaction variable turns out statistically insignificant, albeit they are consistently negative. In Table A.10 in the appendix, we further report OLS and System GMM results. The results using these alternative methods align with those reported in Table 3.

Therefore, while statistically insignificant, the results collectively underscore a systematic way environmental regulation shapes the nature of the relation between Chinese FDI and industrial carbon emission. Notably, it has the potency of attenuating the adverse environmental effect of Chinese. The observed insignificant result may thus be highlighting the ineffective implementation of environmental regulation across African countries. In this case, effective implementation of environmental regulation in the region may hold a promise in counteracting the adverse environmental effect of Chinese FDI in Africa.

5. Conclusions and policy implications

China has emerged as Africa's largest trading partner, the biggest bilateral provider of development finance, and a major source of FDI to Africa's manufacturing industry. This paper examined the effects of Chinese manufacturing FDI on low-carbon industrialization in Africa, addressing inquiries regarding China's economic engagement and its broader effects on the continent's low-carbon transition. Employing panel econometrics techniques, our analysis relied on a panel dataset

comprising 34 African countries from 2003 to 2014.

Findings from the analysis reveal that Chinese FDI in Africa's manufacturing sector undermines Africa's prospect of low-carbon industrialization. This effect is particularly pronounced when Chinese FDI targets labor and resource-intensive manufacturing sectors, yet it diminishes within knowledge-intensive sectors. We argue that besides sector concentration, this adverse effect stems from the less stringent implementation of ESG standards during the manufacturing process. In an extended analysis, we further found that the adverse effect of Chinese FDI on Africa's low-carbon industrialization is moderated, albeit statistically insignificant, by the FDI host countries' environmental regulation. We attribute this statistically insignificant moderation effect to the long legacy of ineffective institutional enforcement that is prevalent on the Africa continent. Overall, our findings suggest a nuanced relationship between Chinese economic engagement and environmental outcomes in Africa, emphasizing the necessity for sustainable development strategies and robust regulatory frameworks to effectively address environmental challenges. This is particularly relevant as global pressure to address climate change intensifies, potentially exposing African economies reliant on high-emission industries to future economic risks and trade barriers.

Several policy recommendations emerge from our findings. First, there is an urgent need to bolster environmental regulation. African governments and policymakers must prioritize enhancing environmental regulations to ensure strict adherence to environmental standards by industries, especially those receiving Chinese FDI. This entails establishing and enforcing emissions limits, promoting the adoption of cleaner production technologies, and implementing effective monitoring and enforcement mechanisms. While this may require difficult conversations about short-term trade-offs between rapid industrialization and environmental protection, it is essential for securing a prosperous, sustainable and a more resilient future. As China seeks to burnish its credentials as a responsible global player, particularly in the realm of climate action, it can also leverage its recent emphasis on greening the Belt and Road Initiative (BRI) to improve the sustainability of its African investments. By working together to promote green industrialization in Africa, China and its African partners can set a new standard for South-South cooperation in the age of climate change.

Second, our findings advocate for the promotion of sustainable financing on the continent. It is imperative to encourage Chinese investors and other foreign investors to prioritize investments in into high-tech and innovative industries and environmentally sustainable projects. This can be achieved through incentives like tax breaks or subsidies for investments in green industrial sectors, leveraging existing comparative advantages and pre-existing capabilities, and gradually transitioning to new productive and innovative green industries over the long term. This strategic shift is crucial for reducing the carbon footprint of industrial activities and promoting a green industrial future across the continent. By prioritizing investments in knowledge-intensive, low-carbon sectors and implementing robust environmental safeguards, African nations and China can forge a partnership that balances economic growth with environmental stewardship. This approach not only

Appendix A

Process of aggregating FDI transactions

1. **Data Import and Cleaning:** We started by importing the raw FDI data, capturing capital investments by source country and destination country for each year. The main variable of interest `Total capital investment in million USD` was destrired to ensure proper numerical treatment.
2. **Collapsing Data by Key Groupings:** To ensure comparability across countries, we collapsed the data by grouping it based on `Destinationcountry`, `Sourcecountry`, `Industrysector`, and `Year`. This allowed for aggregation of total capital investments by recipient country, source country, and activity over time.
3. **Handling Missing Values:** We applied specific transformations to handle missing values effectively, replacing missing or null values (`.`) with zeroes in cases where the corresponding data did not exist for certain countries or sectors. This ensures no countries or sectors were omitted due to

addresses the pressing challenge of climate change, but positions Africa at the forefront of the global green economy, setting a powerful example for sustainable development in the Global South.

Third, our results underscore the importance of investment-promoting policies facilitating technology transfer and capacity-building initiatives through FDI. These efforts should empower African countries to adopt and implement low-carbon manufacturing practices, supporting domestic manufacturing firms in integrating low-carbon manufacturing innovations and technologies to enhance resource efficiency in their production processes in line with the objectives of green industrial policy.

Finally, although our study provides new empirical evidence and policy insights, it can also be improved in several ways. First, while China has made recent strides in promoting green development through initiatives like the BRI, it is important to note that our analysis covers the period 2003–2014, before these commitments were made. Therefore, the actual on-the-ground implementation of these standards in overseas investments during the study period may not reflect the more recent improvements in China's green development initiatives. Future studies can reexamine this relationship using more recent data when they become available. Second, our moderation analysis only considered environmental regulation. However, several other factors such as a country's preexisting technological capacity and financial capacity to fund large-scale projects can also play a significant role in influencing the observed nature of the relationship between Chinese FDI and industry environment outcomes. Future research could consider these other sources of heterogenous effects. Our analysis also considers only the effect of Chinese FDI on industrial carbon emission level. As data becomes available, future research can extend our analysis to consider the effect of Chinese FDI on other sector-specific environmental-related outcomes or sustainability practices such as green investment and innovation, and adoption of sustainability standards.

CRedit authorship contribution statement

Solomon Owusu: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Keyi Tang:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Gideon Ndubuisi:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

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

incomplete data. For countries receiving no FDI from certain sources and sectors, we assigned them a value of zero.

4. Sector-Level Aggregation: The data was categorized into distinct sector types (`labor`, `resource`, and `technology`), allowing for a clearer analysis of which sectors receive the most investment. This categorization helps in distinguishing between labor-intensive and resource- or technology-driven investments. Our detailed categorization is listed in Appendix [Table A.2](#).
5. Merging and Harmonization of Different Sources: Merging multiple FDI source files (China, OECD, non-OECD, etc.) was essential for comparing FDI inflows by different source regions. The process ensured that country-year-level data was consistent across all regions and included adjustments like filling in gaps for missing data for certain years.
6. Manufacturing emission Data Merging: The final steps involved merging the cleaned FDI data with the emission in manufacturing data and other control variables. This was done with careful handling of the key country-year variables, and additional steps were taken to exclude irrelevant records (e.g., Somaliland and specific years).
7. Sector-Level Analysis: After finalizing the FDI, emission in manufacturing data, and relevant control variables, we combined them into a format that allows for sector-level analysis by country and source region. This step provides a more granular view of how different sectors in various countries are impacted by FDI from different regions.

The overall approach was designed to minimize data loss while ensuring a consistent, merged dataset for further analysis.

Appendix B

Table A.1
Country list in sample.

Country Name	Country Code
Algeria	DZA
Angola	AGO
Benin	BEN
Botswana	BWA
Cameroon	CMR
Democratic Republic of Congo	COD
Republic of Congo	COG
Cote d'Ivoire	CIV
Egypt	EGY
Equatorial Guinea	GNQ
Eritrea	ERI
Eswatini	SWZ
Ethiopia	ETH
Gabon	GAB
Ghana	GHA
Kenya	KEN
Libya	LBY
Madagascar	MDG
Mauritius	MUS
Morocco	MAR
Mozambique	MOZ
Niger	NER
Nigeria	NGA
Rwanda	RWA
Senegal	SEN
South Africa	ZAF
South Sudan	SSD
Sudan	SDN
Tanzania	TZA
Togo	TGO
Tunisia	TUN
Uganda	UGA
Zambia	ZMB
Zimbabwe	ZWE

Table A.2
Industry classification based on activities.

Industry sectors	Classification
Beverages	Labor-intensive
Building & Construction Materials	Labor-intensive
Consumer Electronics	Labor-intensive
Consumer Products	Labor-intensive
Food & Beverage	Labor-intensive
Food & Tobacco	Labor-intensive
Hotels & Tourism	Labor-intensive
Leisure & Entertainment	Labor-intensive

(continued on next page)

Table A.2 (continued)

Industry sectors	Classification
Non-Automotive Transport OEM	Labor-intensive
Paper, Printing & Packaging	Labor-intensive
Real Estate	Labor-intensive
Textiles	Labor-intensive
Transportation	Labor-intensive
Warehousing & Storage	Labor-intensive
Alternative/Renewable energy	Resource-intensive
Ceramics & Glass	Resource-intensive
Chemicals	Resource-intensive
Coal, Oil and Natural Gas	Resource-intensive
Metals	Resource-intensive
Minerals	Resource-intensive
Plastics	Resource-intensive
Renewable energy	Resource-intensive
Rubber	Resource-intensive
Wood Products	Resource-intensive
Aerospace	Technology-intensive
Automotive Components	Technology-intensive
Automotive OEM	Technology-intensive
Biotechnology	Technology-intensive
Business Machines & Equipment	Technology-intensive
Business services	Technology-intensive
Communications	Technology-intensive
Electronic Components	Technology-intensive
Engines & Turbines	Technology-intensive
Financial Services	Technology-intensive
Healthcare	Technology-intensive
Industrial Machinery, Equipment & Tools	Technology-intensive
Medical Devices	Technology-intensive
Pharmaceuticals	Technology-intensive
Semiconductors	Technology-intensive
Software & IT services	Technology-intensive
Space & Defense	Technology-intensive

Appendix C. Computing environmental regulation

No readily available environmental regulation index is encompassing, especially as it covers several developing countries over several years. Accordingly, we compute an alternative index, relying on countries' participation in international environmental treaties and conventions. Other things equal, our implicit assumption is that the more environmental treaties a country participates in, the more stringent the country is about preserving the environment. Original data used to identify the treaties and years a country formalized its participation is sourced from <https://unstats.un.org/unsd/envstats/qindicators>. Notably, the data contains information on the years of formalization of participation in 14 international environmental treaties and conventions for the 194 United Nations member states. The list and names of the environmental agreements are as follows:

1. Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (<http://www.basel.int/>)
2. Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (<https://cites.org/eng>)
3. Convention on Biological Diversity (CBD) (<http://www.cbd.int/>)
4. Convention on the Conservation of Migratory Species of Wild Animals (CMS) (<http://www.cms.int/en>)
5. Kyoto Protocol (http://unfccc.int/kyoto_protocol/items/2830.php)
6. Montreal Protocol on Substances that Deplete the Ozone Layer (<http://ozone.unep.org/>)
7. Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar Convention) (<http://www.ramsar.org/>)
8. Paris Agreement (<https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement>)
9. Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade (<http://www.pic.int/>)
10. Stockholm Convention on Persistent Organic Pollutants (<http://chm.pops.int/>)
11. United Nations Convention on the Law of the Sea (http://www.un.org/Depts/los/convention_agreements/convention_overview_convention.htm)
12. United Nations Convention to Combat Desertification in Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa (UNCCD) (<https://www.unccd.int/convention/about-convention>)
13. United Nations Framework Convention on Climate Change (<http://unfccc.int/2860.php>)
14. Convention Concerning the Protection of the World Cultural and Natural Heritage (UNESCO World Heritage Convention) (<http://whc.unesco.org/en/conventiontext/>)

To compute the index, we proceed in four steps. First, we create a dummy variable for each treaty that takes the value one from the year the country formalized it and zero otherwise. Second, we compute the total number of environmental treaties (V_{it}) for each country observed in the data each year. This includes each of the 194 countries observed in the original data. The data show considerable variations on the number of environmental treaties both within-country and across country over time. Third, we normalize the resulting index to have a minimum of zero and a maximum of 1, relying on Eq. (4).

$$EnvReg_{it} = \frac{V_{it} - \min(V_{it})}{\max(V_{it}) - \min(V_{it})} \quad (4)$$

Finally, we extract a subsample comprising 34 African countries from the global dataset. Table A.4 presents a summary statistics of the subsample our empirical analysis relies on. Across the panel, the index ranges from a minimum of 0.07 to a maximum of 0.9 with a mean of 0.8 and a standard deviation of 0.14. We observe that there are variations both within and across African countries, further corroborating our initial conjecture. In fact, it is only in three countries including Ghana, South Africa and Senegal that we do not observe within country variation.

Table A.4
Summary statistics of environmental regulation.

	Obs	Mean	Std. dev.	Min	Max
Algeria	12	0.815	0.083	0.643	0.857
Angola	12	0.595	0.107	0.429	0.714
Benin	12	0.917	0.041	0.786	0.929
Botswana	12	0.827	0.037	0.786	0.857
Cameroon	12	0.875	0.062	0.786	0.929
DR Congo	12	0.810	0.165	0.571	0.929
Republic of Congo	12	0.893	0.083	0.714	0.929
Cote d'Ivoire	12	0.893	0.065	0.714	0.929
Egypt	12	0.845	0.028	0.786	0.857
Equatorial Guinea	12	0.756	0.094	0.643	0.857
Eritrea	12	0.714	0.167	0.357	0.786
Swaziland	12	0.643	0.183	0.357	0.929
Ethiopia	12	0.732	0.054	0.643	0.786
Gabon	12	0.827	0.131	0.643	0.929
Ghana	12	0.929	0.000	0.929	0.929
Kenya	12	0.899	0.071	0.714	0.929
Libya	11	0.838	0.046	0.714	0.857
Madagascar	12	0.887	0.071	0.714	0.929
Mauritius	12	0.905	0.063	0.714	0.929
Morocco	12	0.851	0.071	0.714	0.929
Mozambique	12	0.821	0.120	0.571	0.929
Niger	12	0.827	0.089	0.643	0.929
Nigeria	12	0.917	0.041	0.786	0.929
Rwanda	12	0.810	0.107	0.500	0.857
Senegal	12	0.929	0.000	0.929	0.929
South Africa	12	0.929	0.000	0.929	0.929
South Sudan	3	0.190	0.149	0.071	0.357
Sudan	12	0.792	0.127	0.500	0.857
Tanzania	12	0.923	0.021	0.857	0.929
Togo	12	0.905	0.082	0.643	0.929
Tunisia	12	0.851	0.021	0.786	0.857
Uganda	12	0.893	0.048	0.786	0.929
Zambia	12	0.774	0.085	0.643	0.857
Zimbabwe	12	0.619	0.176	0.500	0.929
Panel Data	398	0.837	0.136	0.071	0.936

Table A.5
Detailed information of variables.

Variables	Variables (model)	Source	Function
Total of Chinese greenfield FDI into the manufacturing	Chinese FDI (log)	Authors computation based on FDI Intelligence Dataset	Explanatory variable
Total of Chinese greenfield FDI into labor-intensive manufacturing sector	Labor intensive Chinese FDI (log)	Authors computation based on FDI Intelligence Dataset	Explanatory variable
Total of Chinese greenfield FDI into resource-intensive manufacturing sector	Resource intensive Chinese FDI (log)	Authors computation based on FDI Intelligence Dataset	Explanatory variable
Total of Chinese greenfield FDI into knowledge-intensive manufacturing sector	Knowledge intensive Chinese FDI (log)	Authors computation based on FDI Intelligence Dataset	Explanatory variable
CO2 emission from manufacturing and construction	Industry carbon emission (log)	World Bank World Development Indicator	Outcome variable
Environmental regulation	Environmental regulation	Authors computation based on the number of membership in environmental-related treaties and conventions	Moderation variable
GDP per capita	GDP pc (log)	World Bank World Development Indicator	Control variable
GDP Per capita squared	GDP pc squared	World Bank World Development Indicator	Control variable
Total population	Population (log)	World Bank World Development Indicator	Control variable
Industry value added	Industry (% GDP)	World Bank World Development Indicator	Control variable
Energy consumption	Energy consumption (% GDP)	US Energy Information Administration (EIA)	Control variable
Regulatory quality	Regulatory quality	World Governance Indicator	Control variable
Total "Other" greenfield FDI into the manufacturing	Other FDI (log)	Authors computation based on FDI Intelligence Dataset	Explanatory variable

Table A.6
Correlation between main variables.

	CM	FDI	L-FDI	R-FDI	K-FDI	GDPpc	GDPpc Sq.	POP	ENC	REG	IVA	ER
Carbon emission (CM)	1.000											
Chinese manufacturing FDI (FDI)	0.217	1.000										
Chinese labor-intensive manufacturing FDI (L-FDI)	0.138	0.686	1.000									
Chinese resource-intensive manufacturing FDI (R-FDI)	0.116	0.570	0.300	1.000								
Chinese knowledge-intensive manufacturing FDI (K-FDI)	0.161	0.629	0.224	0.213	1.000							
GDP per capita (GDPpc)	0.057	0.054	0.112	0.060	-0.043	1.000						
GDP per capita squared (GDPpc sq)	0.058	0.044	0.106	0.058	-0.047	0.998	1.000					
Total Population (POP)	0.115	0.378	0.340	0.217	0.204	-0.347	-0.359	1.000				
Energy consumption (ENC)	0.045	0.165	0.143	0.156	0.118	0.350	0.355	-0.052	1.000			
Regulatory (REG)	0.336	0.062	0.121	0.084	0.051	0.380	0.381	-0.154	0.147	1.000		
Industry value added (IVA)	-0.133	-0.039	-0.034	0.006	-0.123	0.575	0.586	-0.280	0.075	-0.133	1.000	
Environmental regulation (ER)	0.034	0.078	0.111	0.046	0.024	0.082	0.083	0.108	-0.013	0.385	-0.155	1.000

Note: Except for Energy consumption (ENC), Regulatory (REG), Industry value added (IVA), and Environmental regulation (ER), all other variables in the table are log transformed.

Table A.7
Chinese FDI and low-carbon industrialization in Africa.

	(1)	(2)	(3)
	OLS		Sys-GMM
Lag Industry Carbon emission (log)			1.142*** (0.092)
Chinese FDI (log)	0.020*** (0.007)	0.019*** (0.007)	0.010*** (0.004)
Environmental regulation		-0.002 (0.282)	0.285 (0.287)
GDP pc (log)		1.258 (0.974)	-2.349** (0.941)
GDP pc squared		-0.069 (0.069)	0.161** (0.065)
Population (log)		0.351 (0.538)	-0.144 (0.089)
Energy consumption (% GDP)		0.060** (0.029)	0.008 (0.014)
Regulatory quality		-0.141 (0.090)	0.231** (0.110)
Industry (% GDP)		0.010** (0.004)	0.003 (0.003)
Constant	2.377*** (0.066)	-10.177 (8.584)	10.282** (4.238)
Observations	338	335	306
R-squared	0.885	0.891	
Country Dummies	YES	YES	YES
Year Dummies	YES	YES	YES
AR(2)			0.24
Hansen J stat p-val			0.99

Standard errors in parentheses.

*** $p < 0.01$.

** $p < 0.05$.

* $p < 0.10$.

Table A.8
Chinese and "Other" Source FDI and low-carbon industrialization in Africa.

	(1)	(2)	(3)
Chinese FDI (log)	0.020*** (0.007)	0.020*** (0.007)	0.020*** (0.007)
Others FDI (log)	0.018 (0.012)	0.018 (0.011)	0.016 (0.010)
Environmental regulation	-0.015 (0.261)	-0.016 (0.261)	-0.014 (0.261)
GDP pc (log)	1.052 (0.886)	1.057 (0.886)	1.077 (0.891)
GDP pc squared	-0.056 (0.061)	-0.056 (0.061)	-0.057 (0.062)

(continued on next page)

Table A.8 (continued)

	(1)	(2)	(3)
Population (log)	0.274 (0.492)	0.274 (0.491)	0.282 (0.491)
Energy consumption (% GDP)	0.062** (0.026)	0.062** (0.026)	0.062** (0.026)
Regulatory quality	-0.164* (0.084)	-0.164* (0.084)	-0.162* (0.084)
Industry (% GDP)	0.009** (0.004)	0.009** (0.004)	0.009** (0.004)
Constant	-7.714 (7.550)	-7.743 (7.537)	-7.931 (7.544)
Observations	335	335	335
R-squared	0.89	0.89	0.89
Country Dummies	YES	YES	YES
Year Dummies	YES	YES	YES
Hansen J stat	114	114	117
Hansen J stat p-val	0.05	0.06	0.04

Robust standard errors in parentheses.

Note: The table reports results from estimating a Lewbel-IV- model with country and year dummies. Column 1 shows the result without external instruments, while Columns 2–3 show the result with external instruments. The external instruments in Column 2 include i) Chinese bilateral investment treaty dummy multiplied by the country's probability of receiving Chinese FDI, and ii) the average country peer Chinese FDI inflows. In addition to the two instruments introduced in Column 2, Column 3 uses average peer other FDI as external instruments. We log transform the Chinese FDI variable by adding a constant i.e., $\ln(\text{Chinese FDI} + 1)$.

To compute this, we follow equation 3, replacing Chinese FDI with "Other" FDI.

* $p < 0.10$.

** $p < 0.05$.

*** $p < 0.01$.

Table A.9

The composition of Chinese FDI and low-carbon industrialization in Africa.

	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	Sys-GMM	OLS	Sys-GMM	OLS	Sys-GMM
Lag Industry Carbon emission (log)		1.014*** (0.032)		1.081*** (0.049)		1.123*** (0.119)
Labor intensive Chinese FDI (log)	0.019** (0.009)	0.007 (0.006)				
Resource intensive Chinese FDI (log)			0.014* (0.008)	0.023*** (0.007)		
Knowledge intensive Chinese FDI (log)					0.007 (0.009)	0.008 (0.006)
Environmental regulation	-0.012 (0.282)	-0.108 (0.268)	-0.008 (0.283)	-0.140 (0.326)	-0.041 (0.285)	0.037 (0.329)
GDP pc (log)	1.298 (0.997)	-0.358 (0.811)	1.467 (0.982)	-1.356* (0.761)	1.491 (0.980)	-1.538 (0.943)
GDP pc squared	-0.071 (0.071)	0.023 (0.056)	-0.079 (0.070)	0.093* (0.052)	-0.081 (0.070)	0.105 (0.065)
Population (log)	0.377 (0.546)	0.007 (0.032)	0.314 (0.544)	-0.110 (0.103)	0.332 (0.547)	-0.127 (0.096)
Energy consumption (% GDP)	0.059** (0.028)	0.001 (0.015)	0.061** (0.028)	-0.004 (0.017)	0.057** (0.029)	0.006 (0.013)
Regulatory quality	-0.144 (0.092)	0.100* (0.056)	-0.143 (0.092)	0.142 (0.100)	-0.148 (0.092)	0.137 (0.089)
Industry (% GDP)	0.010** (0.004)	0.005** (0.002)	0.010** (0.004)	0.004* (0.002)	0.010** (0.004)	0.007*** (0.002)
Constant	-10.767 (8.633)	1.215 (3.007)	-10.498 (8.698)	6.563* (3.643)	-10.837 (8.687)	7.201** (2.980)
Observations	335	306	335	306	335	306
R-squared	0.88		0.88		0.88	
Country Dummies	YES		YES		YES	
Year Dummies	YES	YES	YES	YES	YES	YES
AR(2)		0.26		0.25		0.30
Hansen J stat p-val		0.98		0.96		0.99

Standard errors in parentheses.

*** $p < 0.01$.

** $p < 0.05$.

* $p < 0.10$.

Table A.10
Chinese FDI, Environmental Regulation and low-carbon industrialization.

	(1)	(2)	(3)
	OLS		Sys-GMM
Lag industry carbon emission (log)			1.110*** (0.119)
Chinese FDI (log)	0.038 (0.052)	0.048 (0.049)	0.009 (0.057)
Environmental regulation		0.024 (0.288)	0.230 (0.544)
Chinese FDI (log) × Environmental Regulation	-0.021 (0.060)	-0.033 (0.057)	-0.007 (0.068)
GDP pc (log)		1.249 (0.966)	-0.162 (1.234)
GDP pc squared		-0.068 (0.068)	0.012 (0.087)
Population (log)		0.316 (0.544)	0.008 (0.070)
Energy consumption (% GDP)		0.060*** (0.029)	0.017 (0.016)
Regulatory quality		-0.143 (0.090)	0.088 (0.079)
Industry (% GDP)		0.010** (0.004)	0.005** (0.002)
Constant	2.371*** (0.070)	-9.625 (8.662)	-0.206 (4.270)
Observations	338	335	306
R-squared	0.88	0.89	
Country Dummies	YES	YES	
Year Dummies	YES	YES	YES
AR(2)			0.25
Hansen J stat p-val			0.99

Standard errors in parentheses.

*** $p < 0.01$.

** $p < 0.05$.

* $p < 0.10$.

Appendix D. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.eneco.2025.108352>.

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