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Towards Achieving Sustainable Development in China: What Role Does Digital Technologies and Green Technologies Play?

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There is always discussion about how to use digitalization to promote sustainable development. While one side vehemently defends using ICT to direct and carry out sustainable development, another strongly struggles to highlight its many drawbacks. Similarly, green technologies are also under the limelight for promoting sustainable development since these technologies combine economic growth and environmental conservation. The purpose of the study is to empirically estimate the effect of digital technologies and green technologies in sustainable development in China. Time series data spanning over 1995–2021 period is analyzed using recently introduced Quantile Autoregressive Distributed Lag Model (QARDL). The findings of the study suggest that there exists positive association between digital technologies and sustainable development over (0.05–0.80) quantiles. The significant and positive association exists between green technologies and sustainable development at all quantiles (0.05–0.95). The study also finds positive and negative association of economic growth and urbanization respectively with sustainable development. The study results emphasize the limitations of conclusion of past studies and provide significant contributions by confirming that the associations among variables is quantile-dependent. The Wald test results also disprove the parameter constancy for the Chinese economy and the findings of Quantile Granger Causality prove the presence of bidirectional causal association between digital technologies, green technologies and sustainable development. The study recommends Chinese policy makers and government to adopt relevant policies to promote sustainable development by effectively utilizing digital and green technologies.

Keywords: *Digital Technologies; Green Technologies; Sustainable Development; QARDL; China.*

Introduction

Sustainable development is driven by all-encompassing and comprehensive national and international policies that take the requirements of coming future generations into consideration and is connected with less damage to the environment. The world is facing environmental issues due to rising carbon emissions caused by inefficient energy usage, which would be hard to manage without a broad coalition involving the public and commercial sectors (Aslam *et al.*, 2021; Bari *et al.*, 2021; Hussain *et al.*, 2022). All economies need to deploy technology and strategies of economic activities that are ecologically friendly and resource-conserving in view of growing global concerns like population expansion, environmental pollution, climate change and natural resource depletion. Several of these policies advocate using green technologies (Guo *et al.*, 2020; Hamid & Ibrahim, 2021; Kar *et al.*, 2021; Kusa *et al.*, 2021). Green technologies refer to inventions that specifically try to lessen the negative effects that goods and manufacturing procedures have on the environment. Diverse technology endeavors that contribute to or seek to significantly improve environmental protection are referred to as green technology innovations (Almulhim & Cobbinah, 2022; Lougheed, 2022; Melnykovych *et al.,* 2018). It comprises new management and commercial techniques, new goods or services, and new production processes that are economically, socially and environmentally sustainable (Hua, 2022). Through appropriate life cycle activities, the implementation or usage of these technologies can prevent or greatly decrease the risk of additional negative environmental effects, pollution, and resource use (Najiand *et al.*, 2022; Razzaq *et al.*, 2021; Shaker *et al.*, 2022; Silviani *et al.*, 2022). Since long time, these technologies really have drawn the consideration of academics who have attempted to describe green technologies and identify their motivating factors and challenges at several analysis levels of sustainable development (Streimikiene, 2023; Zehri *et al.*, 2023).

Recent literature supports a number of factors that make technology innovation a key component of environmental sustainability. First, innovation aids countries in improving their production efficiency. Second, as technology advances, less fossil fuel is consumed, which benefits the ecosystem by resulting in improved energy-saving goods and the use of green energy (Yun-An, Noble *et al.*, 2022). Finally, technological advancement can promote an ecological manufacturing model and more environmentally friendly and sustainable products (Amri, Belaid, & Roubaud, 2018; Suartha *et al.*, 2022; Sukpasjaroen *et al.*, 2022; Suriyanon & Sutheerawatthana, 2022; Tayler *et al.*, 2022). Green technology promotes sustainable development, which entails identifying ecologically-friendly growth sources, generating new eco-friendly sectors, and producing eco-friendly technologies (Ghisetti & Quatraro, 2017; Thuwaini *et al.*, 2022; Timothy *et al.*, 2022; Toyoshima *et al.*, 2022; Tran & Hoang, 2022; Wang, 2022; Zitouni & Almutairi, 2022). The goal of sustainable green innovations is to create high-quality, novel goods that can lessen environmental impact.

The significance of sustainable green inventions will continue to be widely understood as long as environmental problems exist (Hyung & Baral, 2019) (Guo *et al.,* 2020). In comparison to conventional economic development models, advancements in green technology are essential to achieve sustainable development goals with the less adverse environmental impacts. Thus, Innovations are required to attain sustainable development goals (Shan *et al.,* 2021).

Beyond green technologies, the advent of digitalization has significantly enhanced the quality of life over recent years, making global societies more connected than ever. The widespread access to digital platforms, including the internet, social media, and smartphones, has profoundly influenced daily social interactions and has become a vital tool in the pursuit of sustainable development (Houston *et al.,* 2015). According to a statement from the International Telecommunications Union, " digital technologies can be an appropriate tool for the sustainable development if digitization spread is linked with a country's capacity for sustainable development" (Latif *et al.,* 2017). Digitalization impacts all the three aspects of sustainable development. Digital technologies have a significant impact on a country's economic development. The ability of digital financial services to bank the unbanked in light of economic growth would facilitate access for savings accounts, credit lines and other financial services in even the most distant regions of the world. Small and medium-sized businesses can benefit from digital connectivity, which can boost their revenue and competitiveness (Grandison *et al.,* 2023). Digital technologies can affect each of the three human development pillars, namely education, income and health in the social sphere. Technology adoption offers everyone better, more effective services. By effectively utilizing digital technologies, better health care services can be provided to huge populations, benefiting both the provider and the recipient economically. Digital technologies also enhances the effectiveness of the educational system. Digitization has established itself in the educational system, and in addition to supporting conventional learning, many of the old learning techniques appear to be replaced by ICT applications (Heemskerk *et al.,* 2005). ICT makes it easier to provide universal education because of its flexibility in adjusting the material and presentation according to the student needs (DeVoogd, 1998). ICT can deliver high-quality education because of this flexibility and the students' positive participation. ICT businesses and services are able to help other sectors of the economy that damage the environment by offering environmentally friendly alternatives (Watson *et al.,* 2008). For instance, by dynamically routing vehicles to avoid traffic congestion, a viable management system may lower energy usage and transportation costs. But ICT also plays a role in the issue of environmental deterioration. Numerous creative products are released onto the market each day as a result of the ever-evolving nature of technology and unending consumer needs. Due to the small amounts of rare elements, such as niobium, cobalt, tungsten and tantalum, that these devices contain, such quick death date of products causes e-waste in landfills to pose environmental risks and Chemicals that seep into the water table and soils, such as cadmium, lead, mercury, and arsenic, harm the ecosystem and habitats (Algumzi, 2022; Wager, 2011). The amount of electronic garbage produced worldwide was 44.7 MT (million metric tons) in 2016, which is equal to 4500 Eiffel towers (Jayaprakash *et al.,* 2022).

Building on the discussion above, this study seeks to evaluate the impact of green and digital technologies on sustainable development in China from 1990 to 2021. China represents a pivotal case study due to its economic trajectory over the past three decades, marked by an impressive average annual growth rate of approximately 9.9 %. This economic expansion has been accompanied by rapidly increasing CO2 emissions, positioning China as the leading emitter of CO2 globally since 2007, overtaking the United States. By 2011, China's share of global carbon emissions had risen to 24 %. Recognizing the imperative of decoupling carbon emissions from economic growth, China is actively pursuing an economic transformation. This includes a shift in economic structure aimed at reducing CO2 emissions, with the growth of the digital industry playing a critical role in this economic restructuring. (Zhang & Liu, 2015). Digital technologies including big data, Internet of Things and artificial intelligence, have significantly advanced recently. Despite the combined negative effects of the global pandemic and the economic recession, China's digital economy is growing at a quick yearly rate of 9.7 % and accounted for 38.6 percent of the country's GDP in 2020. Digitalization has permeated every element of contemporary Chinese life and the economy. It has also emerged as a powerful force for advancing technical innovation and efficiency enhancement, driving society toward a change that is inclusive and knowledge-based (Baneliene & Strazdas, 2023; Horobet *et al.,* 2023). Likewise, the level of technological progress influences the relationship between economic growth and environmental quality. Green technologies have the potential to reduce CO2 emissions while allowing for continued economic expansion. Furthermore, investments in green and digital technologies promote the adoption of sustainable industrial practices, enhancing clean productivity. Consequently, it is crucial to examine the extent and manner in which digitalization and green technologies contribute to sustainable development in China (Hao *et al.,* 2023).

The study contributes to the present literature in two prominent ways: First, the study is the initial one that estimates the effect of green technologies and digital technologies on sustainable development in China as compare to earlier studies that estimated the impact of green technologies and digital technologies on CO2 emission or economic growth (Cai & Li, 2018; Chien *et al.,* 2022; Heshmati & Yang, 2006; Hsu *et al.,* 2021; Temesgen Hordofa *et al.,* 2023; Wong, 2007; C. Zhang & Liu, 2015). Second, following (Castro & Lopes, 2022), (Fakher *et al.,* 2023), (Pardi *et al.,* 2021), (Neve & Hamaide, 2017), the study uses Adjusted Net Savings (ANS) as the measurement of sustainable development. ANS covers all the three components or aspects of sustainable development and is a comprehensive measure for sustainable development. To the best of our knowledge, except (Pardi *et al.,* 2021) for South Asian countries, none of the previous studies utilized this measurement for sustainable development when estimating the role of digitalization on sustainable development. Third, the study has methodological contribution as well as the study is the first attempt to estimate the objectives at various quantiles by applying QARDL estimation approach (Rojas *et al.,* 2022). The quantile (location) asymmetries between green technologies, digital technologies in numerous varieties of ANS are presented by QARDL for both short- and long-term adjustments. By allowing for possible asymmetries in the response of ANS to decrease or increases in green technologies, digital technologies and other variables over a wide range of quantiles, QARDL models have a relative advantage over linear ARDL models (Razzaq *et al.,* 2021).

The literature review, the model, methodology, the empirical findings and discussion, conclusions and the policy recommendations are included in the following sections of the study.

Review of Existing Literature

Due to its capacity to address environmental challenges, green technologies have drawn a lot of attention in the previous 20 years. Green technologies are ecologically friendly technologies and decrease environmental costs. By reducing environmental damage, it ensures environmental security and sustainable development (Ali *et al.,* 2022). A significant number of studies are present in the existing literature studying the effect of green technologies on environmental quality, however, the earlier researchers did not pay much attention towards the association between green technologies and sustainable development. For instance, (Ali *et al.,* 2022) studied the effect of green innovations and forgein direct investment on carbon emission in BRICS over 1995–2014 period. The authors applied Augumented Mean Group (AMG) estimation method and found negative association between green technologies and CO2 emission in BRICS. (Bilal *et al.,* 2022) considered the panel of OBOR countries for the estimation of the effect of green technologies on carbon emission and by using FMOLS and DOLS estimation, authors found negative association between green technologies and carbon emission. (Sharif *et al.,* 2022) also estimated the impact of green technologies and green finance on CO2 emission in G-7 economies and CS-ARDL findings reveal the presence of negative relationship of between green innovations with CO2 emission. for China (B. Lin & Ma, 2022) considered the panel data of 264 cities to explore the impact of green technologies on pollution emissions in the presence of urban environmental innovations and found that green technologies had heterogeneous influences on pollution emissions in different cities. (Meirun *et al.,* 2021) analyzed the impact of green or eco-technologies on carbon emissions and economic growth over 1991–2018. The authors applied boostrapping ARDL approach and concluded that green technologies had positive association with economic growth and negative association with CO2 emission.

(Habiba, Xinbang, & Anwar, 2022) analyzed the role of financial development and green technologies on carbon emissions in twelve top emitting countries and found negative relation of green technologies with carbon emission. taking the data of 71 countries, (Du, Li, & Yan, 2019) studied the effect of green innovations on CO_2 emissions and found that green innovations had no significant impact on carbon emission upto a certain threshold level of income but significantly reduced carbon emission in higher income countries. Applying CS-ARDL analysis, (Shao *et al.,* 2021) studied the relationship between green technologies and CO2 emissions over 1980-2019 period and found negative association between carbon emissions and green technologies in the long run and there was insignificant relationship between green innovations and CO2 emission in the short run. For Pakistan, (Hanif *et al.,* 2022) also found negative association between carbon emissions and green innovations in VAR estimation. (H. Zhang *et al.,* 2022) studied the effect of green technologies on environmental sustainability in China and according to the findings of NARDL approach, the authors concluded the positive association between green technologies and ecological footprints in China in the long run and short run.

In the same vein, previous research has predominantly concentrated on digital technologies due to their broad implications for environmental and economic sustainability. While numerous studies have thoroughly investigated their role in either reducing CO2 emissions or boosting economic growth, the examination of their impact on sustainable development has been relatively limited**.** For instance, (Chang *et al.,* 2022; R. Sharma & Goel, 2022; Sriyakul *et al.,* 2022) measured the role of renewable energy and ICT on environmental sustainability by taking into consideration the panel of 10 countries and concluded that renewable energy and ICT both had positive contribution in environmental sustainability. (Raheem *et al,* 2020) studied the effect of ICT and financial development on carbon emissions and economic growth in G–7 countries and according to the findings of Pooled Mean Group estimation, the effect of ICT was positive on economic growth but negative on carbon emissions positing that ICT promoted sustainable development in the studied economies. Taking the panel data of emerging economies, (Khan *et al.,* 2018) explored the role of ICT technologies on CO2 emissions. The findings of Augmented Mean Group and Pooled Mean Group indicated that ICT affected CO2 emission significantly, however the moderating role of ICT in economic growth and CO2 emission relationship was found to be negative. (Lee & Brahmasrene, 2014) studied the nexus between ICT, economic growth and CO2 emission in ASEAN economies and authors concluded that ICT affected carbon emissions and economic growth positively and significantly in ASEAN economies. (Chatti, 2021) scrutinized the data of 46 countries to estimate the impact of ICT on transport emissions and found that ICT related technologies significantly reduced the emissions from transport sector. Taking a panel data of developing and developed countries, (Niebel, 2018) explored the role of ICT in economic development. The findings of multiple regression analysis revealed the positive contribution of ICT in economic growth of the economies irrespective of the level of development. Scrutinizing global panel of 149 countries, (Majeed & Ayub, 2018) studied the effect of ICT related technologies on economic growth and according to the findings of GMM, OLS, 2SLS and Pooled OLS estimations, ICT technologies were found to promote the economic growth at regional and global level(Chau *et al.,* 2023; Dimian, Gheorghe, Boldeanu, & Maftei, 2023).

In terms of sustainable development, (Latif *et al.,* 2017) estimated what role ICT played in sustainable development in South Asian countries over 2005 to 2015 period and by applying GMM estimation approach, the authors found positive effect of ICT index on economic growth, education and environmental sustainability that measured the sustainable development. (Jayaprakash & Radhakrishna Pillai, 2022) studied the relationship between three indicators of sustainable development and ICT by taking global panel data. The authors concluded positive association between economic dimension of sustainable development and ICT that were found to have spillover effects on environmental and social dimension of sustainable development. (Tjoa & Tjoa, 2016) provided an overview of the role of ICT in sustainable development indicated by the studies and found that ICT could have both positive and negative implications for sustainable development. (Pardi *et al.*, 2021) considered the panel of 10 Asian countries to analyze the effect of ICT on sustainable development measured by adjusted net savings and by applying Feasible generalized least square estimation approach found the positive effect of ICT measures on sustainable development. (Appiah-Otoo & Song, 2021) estimated the nexus between ICT and economic growth in poor and rich countries and found that ICT had positive effect on economic growth in both panels of the countries. For China, (C. Zhang & Liu, 2015) explored the role of digital technologies on carbon emissions by taking into consideration the provisional data and found that ICT had positive contribution in reducing CO2 emission in China.

To summarize, existing literature has extensively examined the impact of green and digital technologies on economic and environmental sustainability across various countries, yet the specific role these technologies play in sustainable development has received comparatively less scholarly attention. Furthermore, the intersection of green and digital technologies with sustainable development, particularly within the context of China, remains unexplored in prior research. Additionally, while previous studies have utilized various panel and time series methodologies for empirical analysis, none have applied the Quantile Autoregressive Distributed Lag (QARDL) model for estimation. These identified research gaps are addressed in the current study, positioning it as a novel contribution to the field of sustainable development literature.

Data and Methodology

The aim of the present research is estimating the impact of digital technologies and green technologies on sustainable development in China over 1995–2020 period. Using Principle Component Analysis, the study forms a comprehensive index of 3 different digital technologies: fixed broadband subscriptions (per 100 people), fixed telephone subscriptions (per 100 people) and fixed mobile phone subscriptions (per 100 people). Dependent variable of the study i.e., sustainable development is measured by Adjusted Net Savings (% of GNI). Green technologies are proxied by environmental related technologies (% of all technologies). Economic growth measured by GDP per capita, urbanization measured as percentage of urban population in total population are the control variables of the model. The data of ANS, GDP per capita, digitalization technologies and urbanization is taken from World Development Indicators whereas the green technologies data is obtained from OECD.

We form the model of the study as follows:

SD = f (DTECH, GTECH, GDP, URB) (1)

The model in econometric form is specified as:

$$SD_t = \beta_0 + \beta_1 DTECH_t + \beta_2 GTECH_t + \beta_3 GDP_t + \beta_4 URB_t + \varepsilon_t \quad (2)$$

Where,

SD= Sustainable development, DTECH= Digital technologies, GTECH= green technologies, GDP= GDP per capita, URB= Urbanization and ε_t = error term.

Research Methodology

We employ the most recent QARDL model established by (Cho *et al.*, 2015) to investigate the cointegration relationship between green technologies, digital technologies, sustainable development in China. While investigating the link between the study variables, a number of arguments for using the QARDL model are shown. The QARDL model, for instance, enables assessing the quantile long-term equilibrium effect of green technologies and digital technologies on sustainable development, among other characteristics. Comparatively to the conventional approach, which focuses on linear correlation by mean regressed results, the stated QARDL method aids in investigating the nonlinear relations among all variables. Furthermore, the QARDL justifies investigating the varied effects of various quantile types on the time series. Additionally, the QARDL technique is unique for examining the asymmetric connection between variables over the short- and long-term both. Additionally, we applied the Wald test to evaluate the hypothesis of time-varying relations and allows researchers to look into the consistency of the integrating coefficient across various quantiles. The ARDL model can be described in econometric terms as follows:

$$SD_t = \alpha + \sum_i^p \beta_1 SD_{t-i} + \sum_i^q \beta_2\, DTECH_{t-i} + \sum_i^r \beta_3 GTECH_{t-i} + \sum_i^s \beta_4 GDP_{t-i} + \sum_i^u \beta_5\, URB_{t-i} + \epsilon_t \quad \text{(a)}$$

In the equation (a), εt denotes the error term described as SDt − F[SDt/Ft− 1], where Ft-1 is the lowest σ-field that ($DTECH_t$, $GTECH_t$, GDP_t, URB_t, $DTECH_{t-1}$, $GTECH_{t-1}$, GDP_{t-1}, URB_{t-1}) generates. Additionally, in the equation (a) above, the terms p, q, r, s, and u represent the lag orders chosen using the Schwarz information criteria. Furthermore, DTECHt, GTECHt, GDPt, and URBt indicate the digital technologies, green technologies, economic growth and urbanization respectively. Finally, the sustainable development is measured by SDt.

With the aid of the following model (Cho *et al.*, 2015) have formulated an expanded version of the aforementioned equation (a) in the context of some quantile and provide a better understanding of QARDL by equation (b).

$$QSD_t = \alpha(\tau) + \sum_i^p \beta_1(\tau) SD_{t-i} + \sum_i^q \beta_2(\tau) DTECH_{t-i} + \sum_i^r \beta_3(\tau)\, GTECH_{t-i} + \sum_i^s \beta_4(\tau) GDP_{t-i} + \sum_i^u \beta_5(\tau) URB_{t-i} + \varepsilon_t(\tau) \quad \text{(b)}$$

Where in equation (b) the term εt (τ) = SDt − QSDt (τ /εt− 1) shows the πth quantile of SDt conditioned on Ft-1. We have transformed the aforementioned equation (c) into the following condition in order to examine the QARDL.

$$Q_{\Delta SDt} = \alpha(\tau) + \rho SD_{t-i} + \varphi_1 DTECH_{t-i} + \varphi_2 GTECH_{t-i} + \varphi_3 GDP_{t-i} + \varphi_4 URB_{t-i} + \sum_i^p \beta_1(\tau) SD_{t-i} + \sum_i^q \beta_2(\tau) DTECH_{t-i} + \sum_i^r \beta_3(\tau) GTECH_{t-i} + \sum_i^s \beta_4(\tau) GDP_{t-i} + \sum_i^u \beta_5(\tau) URB_{t-i} + \varepsilon_t(\tau) \quad \text{(c)}$$

Equation (c) can be built and expanded as follows for the error correction term of QARDL:

$$Q_{\Delta SDt} = \mu(\tau) + \rho(\tau)(SD_{t-1} - \beta_{DTECH}(\tau) DTECH_{t-1} - \beta_{GTECH}(\tau) GTECH_{t-1} - -\beta_{GDP}(\tau) GDP_{t-1} - \beta_{URB}(\tau) URB_{t-1}) + \sum_{i=1}^p \sigma_{SDi}(\tau)\Delta SD_{t-i} + \sum_{i=0}^q \sigma_{DTECHi}(\tau)\Delta DTECH_{t-i} + \sum_{i=0}^r \sigma_{GTECHi}(\tau)\Delta GTECH_{t-i} + \sum_{i=0}^s \sigma_{GDP}(\tau)\Delta GDP_{t-i} + \sum_{i=0}^u \sigma_{URBi}(\tau)\Delta URB_{t-i} + \varepsilon_t(\tau) \quad \text{(d)}$$

The impact of earlier SD on current SD is measured by $\sum_i^p \beta_1(\tau) SD_{t-i}$ in equation © above. In the same way, the impact of earlier DTECH, GTECH, GDP, URB on current SD are captured by $\sum_i^q \beta_2(\tau) DTECH_{t-i}$, $\sum_i^r \beta_3(\tau) GTECH_{t-i}$, $\sum_i^s \beta_4(\tau) GDP_{t-i}$ *and* $\sum_i^u \beta_5(\tau) URB_{t-i}$ respectively.

Additionally, the DTECH, GTECH, GDP, and URB long-term cointegration parameters are derived as follows.

$\beta_{DTECH^*} = -\frac{\beta DTECH}{\rho}$, $\beta_{BGTECH^*} = -\frac{\beta GTECH}{\rho}$, $\beta_{GTECH^*} = -\frac{\beta GDP}{\rho}$, $\beta_{GDP^*} = -\frac{\beta URB}{\rho}$ respectively.

The parameters for both the long and short-term cointegration are calculated using the delta approach.

We used the Wald test to evaluate the null study hypotheses for both long and short term parameters of asymmetric and non linear impacts of digital technologies and green technologies on sustainable development.

$$H_0^{\emptyset} = F\emptyset_*(\tau) = f \text{ verses } H_1^{\emptyset} : F\,\emptyset_*(\tau) \neq f$$
$$H_0^{\emptyset} = S\omega_*(\tau) = s \text{ verses } H_1^{\emptyset} : S\,\omega_*(\tau) \neq s$$
$$H_0^{\emptyset} = S\beta_{i*}(\tau) = s \text{ verses } H_1^{\emptyset} : S\,\beta_{i*}(\tau) \neq s$$
$$H_0^{\emptyset} = S\rho_{i*}(\tau) = s \text{ verses } H_1^{\emptyset} : S\,\rho_{i*}(\tau) \neq s$$

In the scenario described above, f and F are the *h* ps* pre- determined matrices, s and S are h*1 and h*s pre determined matrices, where h is the limitations as given by (Cho *et al.*, 2015). i denotes digital technologies, green technologies, economic growth and urbanization. To examine the non-linearities of the parameters of adjustment speed and the long run integration coefficients, we conducted the Wald test. The study also applies the Quantile Granger Causality Test in addition to the Wald Test to estimate the causal association between sustainable development and explanatory variables at various quantiles.

Results and Discussions

To begin the empirical estimation, Table 1 provides the descriptive or summary statistics results of all study variables namely sustainable development, digital technologies, green technologies, economic growth and urbanization respectively.

Table 1

Descriptive Statistics Results

Variables	Mean	Min	Max	Std. Dev.	J-B Stats
SD	21.44605	16.02820	27.59344	3.341954	1.198319***
DTECH	51.067	13.707	85.971	20.688	2.0926***
GTECH	8.2852	3.97	11.16	1.5886	2.7777***
GDP	5074.234	1520.027	10358.26	2934.368	2.3286***
URB	45.87204	30.96100	61.42800	9.665674	1.198319***

*Where *** shows Prob<0.05*

The study's findings suggest that highest mean value is of GDP, at 5074.23, and that DTECH is second, at 51.067. it assert that DTECH in China is less than GDP values. Similarly in terms of standard deviation, GDP has the highest dispersion as compare to DTECH.URB and SD occupy third and fourth position respectively on average and standard deviation terms. The final variable that has the lowest average value and standard deviation is GTECH. It indicates that the GTECH sector of the Chinese economy is reasonably stable. Jarque-Bera findings for the test for normality showed that the research variables' data do not have normal distribution rejecting H0 as provided in Table 1.

The next step is to apply Augmented Dickey-Fuller (ADF) as well as Zivot and Andrews (2000) tests to determine whether the series is stationary or unitroot. After 1st difference, both test showed that all variables become stationary. Given the structural flaws in the values, such funding supports QARDL's decision. Unit root test findngs are provided in Table 2.

Table 2

ZA and ADF Test Results

Variables/ Series	ADF	ADF (delta)	ZA	Break Year	ZA (delta)	Break Year
SD	-1.688	-3.433***	-1.300	1998 Q3	-8.913***	2001 Q1
DTECH	-0.752	-2.425***	-1.209	2004 Q1	-5.234***	2004 Q4
GTECH	-1.244	-3.521***	1.148	2015 Q4	-4.514***	2009 Q1
GDP	-0.422	-4.202***	-1.417	2007 Q3	-5.341***	2007 Q1
URB	-0.611	-3.413***	-1.325	2019 Q1	-4.044***	2015 Q4

*Where *** denotes Prob<0.05*

The results for QARDL are displayed in Table 3 below. It is indicated that the parameter P* is considered to be significantly negative. This pattern is seen across entire quantile range in China pointing to a return to the long run equilibrium relationship between digital technologies, green technologies and sustainable development. First of all the parameter for DTECH for China economy is positive and significant for 0.05-0.80 quantiles. Numerous studies have discovered and confirmed the favourable relationship between DTECH and SD. As stated in literature review section, (Latif *et al.,* 2017) stated that digital technologies promote sustainable development in South Asian countries. (Jayaprakash & Radhakrishna Pillai, 2022) in cross country analysis evidenced that digital technologies have positive influence on every dimension of sustainable development i.e., economic, environmental and social. (Nchofoung & Asongu, 2022) also found that ICT related technologies have positive contribution in sustainable development globally even when modulated by globalization. (Nwabueze & Ozioko, 2011), (Dedaj *et al.,* 2022), (Asongu & Odhiambo, 2022) also explained the positive contribution of digital technologies on sustainable development.

Next, the parameter of GTECH is positive and significant from 0.05-0.95 quantiles. It implies positive association between GTECH and SD. The finding is justifiable because green technologies have favourable environmental and economic impacts which are endorsed by a number of previous studies. Like, (Meirun *et al.,* 2021) found positive association between green technologies and environmental and economic dimension of sustainable development in Singapore. (T. Lin *et al.,* 2022) concluded strong moderating impact on the relationship between environmental regulations and economic growth showing positive contribution of GTECH in economic growth in China. Green innovation contributes significantly in job creation, improved economic activities, and increased environmental sustainability (Li *et al.,* 2022). In fact green technologies can help promote sustainable development by improvements in air purification system, waste and sewage management, water treatments, energy conservation, sustainable transportation and sustainable agriculture etc. (Shaikh, 2017). (Madaleno *et al.,* 2022), (Tong *et al.,* 2022), (D'Amato *et al.,* 2021) also found positive association between green technologies and environmental, social and economic sustainability.

The parameter of GDP is significant and positive but only at lower quantiles 0.05–0.40 implying that GDP promotes sustainable development in China. This finding is justifiable in the light of a number of previous studies like (Dietz *et al.,* 2007), (Sato *et al.,* 2018), (Castro & Lopes, 2022), (Din *et al.,* 2021) and (Wei & Huang, 2022) who also conclude that income is a major factor for rising sustainable development. Thus higher economic growth is a viable channel for promoting sustainable development in China. However, like the earlier studies (Chen Yu, 2022), (Almulhim & Cobbinah, 2022), (Dietz *et al.,* 2007), we found negative but significant impact of urbanization on sustainable development implying that rising urbanization is associated with rising environmental un-sustainability in China.

The results of the Wald test provided in Table 4 below demonstrate that the hypothesis of parameter constancy or the H0 of linearity of parameter of speed of adjustment for the Chinese economy is strongly rejected. Additionally, the long-term integrating parameter DTECH' H0 of parameter stability across all quantiles exhibits a substantial Wald test result. That would assert that, for China's economy, the cointegrating parameter between sustainable development and DTECH is dynamic under various quantiles. Additionally, Table 4's data indicate that the H0 of parameter constancy for GDP, GFCF, and TOP for the Chinese economy is accepted as the parameters significant for all quantiles.

Additionally, Table 5 displays the Granger causality test results at each quantile level. This test was developed by (Troster, 2018) and explains the causal relationship between the change in the independent variable and the change in the dependent variable. The findings show that all the study variables have a bidirectional causal association, both in the low and high quantiles. The findings demonstrated a causal association between sustainable development and economic growth, urbanization, green technologies, digital technologies, and the Chinese economy.

Table 4

QARDL Estimations for Sustainable Development

Quantiles	**Constant**	**ECM**	**Long-Run Coefficients**						**Short-Run Coefficients**		
(τ)	**$\alpha_*(\tau)$**	**$\rho_*(\tau)$**	**$B_{DTECH}(\tau)$**	**$B_{GTECH}(\tau)$**	**$B_{GDP}(\tau)$**	**$B_{URB}(\tau)$**	**$\varphi_1(\tau)$**	**$\omega_0(\tau)$**	**$\lambda_0(\tau)$**	**$\theta_0(\tau)$**	**$\acute{\varepsilon}_0(\tau)$**
0.05	0.113	-0.432***	0.645***	0.945***	1.846***	-0.721	0.345***	1.938***	0.412***	1.354***	-1.322***
	(0.046)	(-2.024)	(3.945)	(3.644)	(4.310)	(-2.685)	(2.331)	(3.212)	(2.734)	(3.535)	(-2.435)
0.1	0.032	-0.242***	0.484***	0.214***	1.098***	-0.540	0.274***	1.430***	1.231***	1.422***	-1.534***
	(0.048)	(-3.133)	(3.342)	(3.094)	(2.132)	(-2.334)	(2.734)	(4.743)	(3.934)	(3.266)	(-2.433)
0.2	0.056	-0.346***	0.952***	0.456***	0.834***	-0.193	0.156***	0.366***	0.545**	0.498***	-0.133***
	(0.077)	(-3.145)	(3.614)	(4.846)	(3.725)	(-4.811)	(2.556)	(2.454)	(4.833)	(2.345)	(-2.044)
0.3	0.049	-0.155***	0.394**	0.233***	1.023***	-0.298	0.156***	0.732**	1.808***	1.475***	-0.183***
	(0.012)	(-3.545)	(3.999)	(4.324)	(3.614)	(-4.367)	(3.175)	(2.118)	(3.412)	(3.742)	(-2.533)
0.4	0.031	-0.135***	1.423**	1.283**	0.073***	-0.836	1.284***	0.335**	0.133***	0.545***	-0.333***
	(0.019)	(-2.444)	(3.245)	(3.744)	(3.534)	(-4.184)	(4.554)	(3.834)	(3.556)	(3.656)	(-2.634)
0.5	0.047	-0.241***	1.634**	0.545**	0.093	-0.109	0.374***	1.935**	0.145***	0.449**	-1.938***
	(0.060)	(-3.645)	(3.834)	(2.842)	(0.726)	(-3.781)	(4.645)	(3.933)	(4.945)	(3.255)	(-3.614)
0.6	0.056	-0.265***	0.334**	0.657***	0.736	-0.245***	0.567***	1.309**	0.540**	0.457***	-1.343***
	(0.075)	(-4.237)	(3.715)	(4.743)	(0.321)	(-3.322)	(2.256)	(3.087)	(2.348)	(2.232)	(-4.112)
0.7	0.040	-0.335***	0.425**	1.973***	0.313	-0.446***	0.461***	0.345**	1.942***	0.645***	-0.721***
	(0.017)	(-2.344)	(4.946)	(3.436)	(0.087)	(-2.534)	(4.633)	(3.542)	(3.013)	(4.111)	(-3.432)
0.8	0.018	-0.176**	0.624***	0.133***	0.445	-0.434***	0.223***	0.445***	0.877***	0.446***	-0.834***
	(0.024)	(-3.413)	(3.434)	(2.144)	(0.745)	(-3.124)	(4.716)	(3.929)	(4.467)	(3.565)	(-3.724)
0.9	0.031	-0.253**	1.444	0.334***	0.332	-1.632***	0.578***	1.316***	0.888***	0.246***	-1.933***
	(0.022)	(-3.425)	(0.546)	(4.222)	(0.006)	(-2.614)	(2.845)	(3.912)	(2.876)	(2.915)	(-4.164)
0.95	0.043	-0.299**	1.625	1.391***	0.981	-1.132***	1.334***	1.330***	0.765***	0.903***	-1.633***
	(0.031)	(-3.346)	(0.814)	(2.551)	(0.028)	(-4.340)	(3.303)	(3.837)	(2.556)	(3.074)	(-4.933)

Table 4

Wald Test Findings

Series	**Wald-stat [Prob-Value]**
P	33.341***
	[0.000]
B_{DTECH}	16.543***
	[0.000]
B_{GTECH}	14.542***
	[0.000]
B_{GDP}	23.349***
	[0.010]
B_{URB}	11.754***
	[0.050]
φ_1	45.346***
	[0.002]
ω_0	16.445***
	[0.000]
λ_0	13.346***
	[0.000]
θ_0	15.863***
	[0.000]
p_1	18.652***
	[0.000]
∂_0	16.457***
	[0.000]

Table 5

Results of Quantile Granger Causality Test

Quantiles	ΔSD_t ↓ $\Delta DTECH_t$	$\Delta DTECH_t$ ↓ ΔSD_t	ΔSD_t ↓ $\Delta GTECH_t$	$\Delta GTECH_t$ ↓ ΔSD_t	ΔSD_t ↓ ΔGDP_t	ΔGDP_t ↓ ΔSD_t	ΔSD_t ↓ ΔURB_t	ΔURB_t ↓ ΔSD_t
[0.05-0.95]	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.05	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.40	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.60	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.70	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.90	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.95	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Source: Authors Estimation								

Conclusion and Policy

Nations have long been contemplating the formulation of appropriate policies to address climate change risks in alignment with the United Nations' sustainable development goals. In pursuit of sustainable development, there has been a continuous effort to advance and implement green and digital technologies. Recognizing the critical role that both digital and green technologies play in sustainable development, this research delves into their impact on China's sustainable development from 1995 to 2021. Utilizing the Quantile Autoregressive Distributed Lag (QARDL) estimation approach, the study assesses the influence of digital and green technologies on sustainable development across various quantiles. This investigation into the effects of digital and green technologies on China's sustainable development is unprecedented in existing literature, marking the study as a unique contribution.

The preliminary findings indicate that digital and green technologies exert a significant and positive impact on sustainable development across different quantiles. Economic growth shows a positive but only significant effect at lower quantiles (0.05-0.40), whereas urbanization has a negative impact on sustainable development at all quantiles. The results from the Wald test refute the hypothesis of parameter linearity, and the Quantile Granger causality test uncovers a bidirectional causal relationship between digital technologies, green technologies, and sustainable development.

We might draw the conclusion that digital and green technologies are essential in the modern world. Green technologies must be utilized because traditional technology challenges sustainability and to ensure the sustainability of the eco-social environment. To attain sustainable development, Chinese government should reform and execute green technologies programs and policies. Government should devote a significant portion of green public spending to green innovations. Utilizing green technology, China can raise awareness of environmental issues and sustainable development. Moreover, ICT help China achieve sustainable development, and the perfect balance of ICT use would accelerate this goal. As a result, we urge the government to embrace ICT growth as a catalyst for sustainable development. ICT has a history of advancing social, political, and cultural variables in settings that have a positive impact on society when managed properly. ICT policy must be carefully created with the proper amount of governmental oversight. China has the opportunity to construct a digital economy that supports sustainable development by investing in technical advancements like mobile and internet to support digital infrastructure for businesses. A strong economic foundation and competent administration of the digital economy environment could eventually develop and preserve the synergy between environmental and socioeconomic protection.

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