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Effects of ICT and Energy Transition on Sustainable Fiscal Growth: Empirical Evidence from China

Shuguang Wang[1], Wantao Li[2*]

[1,2]School of Finance and Public Administration, Harbin University of Commerce
Harbin 150028, Heilongjiang, China
E-mail: [1]Shuguang34@protonmail.com; [2]101594@hrbcu.edu.cn; (*Corresponding Author)*

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It is crucial for sustainable growth policies and strategies, which are currently being used internationally, to balance the various aspects of development, including the economic, environmental, and social ones. There is currently broad agreement that energy transition and Information and communication technologies (ICT) offer fresh momentum for long-term sustainable fiscal growth. The main goal of the current research is to study the effects of energy transition and ICT on sustainable fiscal growth in China over 1995–2020 period. To empirically estimate the above mentioned nexus, the recently introduced Quantile Autoregressive Distributed Lag Model (QARDL) is applied. The study findings for long run indicate that energy transition impacts sustainable fiscal growth negatively over lower qauntiles and at extreme higher quantiles. However, the ICT is found to promote sustainable fiscal growth at all quantiles. The short run dynamics also indicate that current and previous values of ICT and energy transition have significant impact on sustainable fiscal growth. The Wald test of parameter constancy rejects the null hypothesis and shows that non linear and asymmetric impact is present between sustainable fiscal growth and ICT and energy transition in the short run and the long run. Test of Quantile Granger Causality reveals bidirectional causal association between study variables. The study recommends the Chinese government and policy makers to adopt efficient policies to promote ICT use among all the sectors of the economy that can help in achieving sustainable fiscal growth.

Keywords: *ICT; Energy Transition; Sustainable Fiscal Growth; QARDL; China.*

Introduction

The life line of an economy is the energy as it plays a crucial role in the development of an economy. Fiscal growth needs to be compatible with the environmental and socioeconomic objectives so that the development is sustainable over a longer period of time (Ayesha, 2022; Dias *et al.*, 2021; Ghosh, 2022; Gou *et al.*, 2021; L. Huang & Zou, 2020). Energy is indeed a crucial issue that affects today's corporate and social environments (Herbig & Minnaar, 2022; Ikram *et al.*, 2020; Juca & Fishlow, 2022; Kim & Upneja, 2021; Kountouridou, 2022; Mahalingam, 2022). Countries seriously need to ponder about energy transition and the generation and use of energy sources in rising enormity of the environmental threat caused by global warming and climate change that the combustion of fossil fuels is usually accounted for (Abdollahbeigi & Salehi, 2021; Mantey *et al.*, 2021; Mohammed *et al.*, 2022; Moshood *et al.*, 2022; Nagy, 2021; Nguyen *et al.*, 2021; Padmakumari & Shaik, 2023; York & Bell, 2019).

Natural gas, oil, and charcoal have typically been seen as the main drivers of economic growth (Orwig, 2021; Skare & Soriano, 2021; Suhartono, 2021; Valizadeh & Soltanpour, 2021; Zafar *et al.*, 2019), as they facilitate transportation, run factories, and generate electricity (Waheed *et al.*, 2019). Energy demand quickly rises as countries develop and raise the living conditions of their people (Al-Jundi, Shuhaiber & Al-Emara, 2022; Atance *et al.*, 2024; Saud & Chen, 2018; Vo & Ngo, 2021; Wahhab *et al.*, 2021; Wynn, 2021; Yoshimura *et al.*, 2021; Yuliana *et al.*, 2021). Fighting environmental changes and promoting sustainable development are crucial components of addressing the rising demand for energy. Vital components of the future energy supply include sustainability, efficiency, economics, and reducing the negative environmental impacts (Ogbonnaya *et al.*, 2019). Increasing global pollution emissions is also a result of the use of non-renewable energy sources (Menegaki & Tugcu, 2018). According to the (IRENA, 2020), the global energy sector is moving toward zero-carbon or decarbonization and might be able to meet 90 percent of the necessary targets of pollution emission-reduction as it transitions from non-renewable to clean energy. A substantial portion of the energy comes from renewable resources, which can also improve the current energy mix, counteract inconsistent marketing, and reduce the harms to the environment. Due to this, expanding the use of renewable energy has become essential to the transition to a zero carbon global economy (Przychodzen & Przychodzen, 2020). A step toward decarbonization, the switch from non-renewable to clean energies can close the future and current gap between supply and demand for energy (Halicka, 2024; I. Khan *et al.*, 2021).

The speedy development of ICT, which is regarded as a basic technology of extraordinary significance for any country, is one of the main criteria for economic and social development (Rost & Sadeghimanesh, 2023). The OECD demonstrated the significance of ICT technologies to fiscal growth as soon as in 2000. ICT, which is the carrier of development processes, has highlighted changes in corporate relationships, helped construct new communication and business models, boosted the development of productivity and innovations, and confirmed an increase in overall efficiency (Al-Jundi *et al.,* 2022; Zoe, 2023). High levels of economic performance, new levels of competition, the growth and expansion of industries employing cutting-edge technology, market liberalization, a change in the marketing mix, the removal of barriers to trade and information access, and business globalization are the results of these changes. Considering the investment return in this area, some estimates place the ICT industry at roughly 50 % of the attained productivity (Komazec *et al.,* 2023). The development of ICT technology also holds the potential capability that needs to be utilized and exploited. ICT is a driver for fiscal growth that reduces the rising human inputs costs, frequently in a short time period. At both microeconomic and macroeconomic levels, ICT technologies are maintained to be the primary forces driving transformations in the world. ICT in particular is even essential to the economy irrespective of the level of development (Zarkovic *et al.,* 2022). Digital and technology innovation has recently drawn a lot of attention from academics and politicians in our economy. New technologies, big data, machine learning, and their effects on our economy and society have all drawn attention to it (Heimerl & Raza, 2018). It denotes a multipurpose technology that can be used in science and research, public administration, as well as armed services, which could be advantageous for economic activities (Arsic, 2020). Recent technological advancements have moved businesses toward virtual and paperless activities (Amankwah-Amoah *et al.,* 2021). Since its impact on the economy was revealed, the idea of digital and technical advancement has drawn a lot of attention. Due to technology's expansion into all aspects of life and its positive effects on human empowerment, communication, and connection, digitalization offers enormous potential for socioeconomic development (Zhao *et al.*, 2022).

The aim of the current study is to estimate the effect of energy transition and ICT on sustainable fiscal growth in China over 1995–2020 period. the researchers selected China to explore this nexus mainly because China's GDP increased about 90 times throughout the past 40 years of opening up and reform, from 149.5 billion US dollar to 13.6 trillion dollars between 1978 and 2018, which is referred to as the "global growth miracle" (Sheng *et al.,* 2020). Meanwhile, China successfully moved 800 million of population from poverty to above level as its per capita GNP rose to 9732 US$, exceeding the average middle income countries level in 2018 (M. Li, Patino-Echeverri, & Zhang, 2019). But this extended development strategy that is solely focused on " low efficiency" high pollution and high consumption, has only led to "quantity" growth rather than "quality" advances, and it has cost China a great deal in terms of the environment (Cheng *et al.,* 2021). Since 2010, China is the world's greatest energy consumer, which has serious environmental consequences. 121 cities only, or 35.8 % of all cities, passed the environmental air quality criteria in year 2018. Additionally, China was ranked at 120^{th} position overall in the Environmental Performance Index. This illustrates how environmental pressures have been increased by rapid economic growth. The priority then is to achieve the economic growth transformation and start on a sustainable fiscal growth path that sustains fiscal growth and also consider environmental protection and resource conservation. This is because environmental pollution in China is currently getting worse and resource constraints are getting tighter (Feng & Liao, 2020). As a result, research into the paradigm of sustainable economic growth has gained attention in academics (J. Li, Chen, Chen, & He, 2022).

ICT and energy transition has significant practical value in this situation for fostering China's sustainable fiscal growth. 7.1 percent of GDP or 6.4 trillion and 20.5 percent of the digital economy, was the level of China's digital infrastructure in 2018, according to (L. Huang & Zou, 2020). The digital economy has emerged as significant contributor of improving economic structure, accelerating fiscal growth, and strengthening strong growth skills (Veliz-Cuba *et al.,* 2022). It has emerged as a new engine for regional innovation and growth and is supporting the innovation and wiser development of Chinese economy (J. Li *et al.,* 2022; M. Li *et al.,* 2019). Side by side China is also strongly promoting energy efficiency and pledges that its energy consumption will be less than 6 billion tons of coal between 2021 and 2030 to achieve sustainable growth. China vigorously promotes energy transition. In 2018, 22.1 % of primary energy usage was made from clean sources. By 2030, China intends to raise the proportion of natural gas and non fossil fuels to 15percent and 20 percent respectively (L. Huang & Zou, 2020).

Therefore, in light of China's active development of ICTs and efforts to transition to a cleaner energy source, can these two factors successfully help China's economy achieve sustainable fiscal growth? This question is yet to be answered. This article aims to carry out a thorough analysis of the aforementioned issue, which can not only serve as a basis for China to pursue sustainable fiscal growth but also give Chinese experience for many nations to achieve sustainable economic growth. The study makes novel contributions in the existing literature in three ways: First and foremost, the study is the very first attempt to explore the contribution of ICT and energy transition in achieving sustainable fiscal growth in China context. Second, the study makes comprehensive indices for ICT and economic sustainability using Principle Component Analysis which are never used in earlier in the studies for the assessment of ICT and sustainable economic growth relationship (more details are given in section 3). Third, the study is the first attempt to explore the above mentioned nexus by applying QARDL approach because of its capability to provide non linear and asymmetric parameters over different quantile ranges.

We organize the remaining study in the following sequence. Literature is briefly reviewed and is provided in section 2. Model, variables, data and applied methodology are discussed in section 3. Section 4 gives empirical estimation findings and discussion. In section 5, conclusion of the study and policy recommendations are given.

Literature Review

Literature review section includes two strands of the literature: First we review the literature on ICT and environmental and economic performance and the second strand reviews the literature on energy transition and environmental and economic performance.

Previous studies mostly studied the role of ICT either on environmental sustainability or on economic growth and provided mixed conclusions. For instance, (Higon *et al.*, 2017) studied a sample of developed and developing countries over 1995–2010 period to analyze the nonlinear impacts of ICT on ecological sustainability. The findings of the study provided the evidence for U-shaped relationship between CO2 emission and ICT in the selected countries. (Malmodin *et al.*, 2010) estimated the effect of ICT on green house gas emissions and energy consumption in media and entertainment sector globally and found that ICT was responsible for the higher energy consumption and emission of green house gases worldwide. (Miskiewicz, 2021) for Visegrad countries studied the effect of ICT on green house gases over 2000 to 2019 period using FMOLS and DOLS estimations. The findings showed that patents for ICT improved GHG emission reduction in the selected countries. (Zhang & Liu, 2015) used STIRPAT model to study the effect of ICT on CO2 emission in China at regional and national levels. The findings of ARDL analysis showed that ICT contributed in reducing carbon emission in China and the influence was greater in eastern region than in western region. For Canada, (Abdollahbeigi & Salehi, 2021) analyzed the association between GHG emission and ICT in Canada and found that ICT sectors helped in reducing GHG emissions in Canada. (Lu, 2018) estimated the ICT effect on carbon emissions in 12 Asian economies. Findings of panel cointegration revealed that ICT had negative influence on carbon emissions in Asian countries. (Khan *et al.*, 2018) studied how ICT affect CO2 emission in developing countries and from the findings of Mean Group and Pooled Mean Group it was assessed that ICT affected CO2 emission significantly. (Y. Huang *et al.*, 2022) made a comparative assessment of ICT and ecological footprints association in G-7 and E-7 countries. in E-7 countries, ICT was observed to degrade the environmental quality while in G- 7 countries, it had opposite results.

However, we can see that the number of researches that study the association between ICT and economic growth are very few. Like, (Appiah-Otoo & Song, 2021) considered the panel data of 123 countries belonging to all income groups over 2000–2007 period and observed that ICT promoted economic growth in all countries. for MENA and Sub Saharan African countries, (Bahrini & Qaffas, 2019) studied the role of ICT on economic growth over 2007 to 2016 period. Applying GMM estimation, the authors concluded that different ICT facilities promoted economic growth in MENA and SS African countries except telephone subscriptions. For OIC countries, (Aghaei & Rezagholizadeh, 2017) over 1994 to 2014 period studied the relationship between economic growth and ICT and from the findings of dynamic and static panel estimations, positive association was concluded between ICT and economic growth in studied countries. (Heshmati & Yang, 2006) explored the relationship between economic growth and ICT in China. The findings of regression analysis revealed positive relationship between economic growth and ICT. (Zhao *et al.*, 2022) studied the role of e-government and ICT exports on economic growth in Belt and Road Initiative countries. ICT exports and e-government were found to enhance economic growth as per the results of GMM estimation.

Similar to ICT, earlier studies researched for the impact of energy transition on pollution or environmental quality much extensively as compare to economic performance or sustainable fiscal growth. For instance, (Ren *et al.*, 2021) studied the impact of energy transition on CO2 emission in European economies over 1990–2015 period. Fixed effects regression findings indicated that energy transition had negative impact on carbon emissions. (I. Khan *et al.*, 2021) studied the energy transition and economic growth relationship in IEA countries over 1995 to 2015 period. The panel data estimations techniques revealed that energy transition had negative impact on economic growth. (Koengkan & Fuinhas, 2020) studied the effect of energy transition on carbon emissions in for Latin America and Caribbean countries. The findings of panel ARDL analysis revealed that energy transition had negative impact on carbon emissions. In Morocco between 1980 to 2017 period (Bouyghrissi *et al.*, 2022) estimated the association between CO2 emissions and energy transition. The basic study findings revealed that energy transition curbed CO2 emission in Morocco. (Mohsin *et al.*, 2021) studied the impact of renewable energy transition on economic growth and GHG emission nexus in top Asian countries. the findings indicated that renewable energy transition increased economic growth but reduced carbon emissions (I. Khan *et al.*, 2022). (Afshan *et al.*, 2022) studied the effect of energy transition and environmental regulations on ecological footprints in OECD countries under EKC hypothesis and MMQR regression. The findings revealed that energy transition and environmental regulations decreased ecological footprints in OECD. (Yuan *et al.*, 2022) for China found that energy transition had negative impact on different types of air pollutions like PM 2.5 and CO2 emission. (Murshed *et al.*, 2021) analyzed how energy transition and trade affect CO2 emissions in South Asian countries. CS-ARDL estimation approach was used in the study and findings indicated that renewable energy transition caused CO2 emission to decline.

Literature Gap

The review of above literature shows that previous studies extensively focused on the relationship of energy transition and ICT with environmental quality or environmental pollution. A very few studies are present that studied the energy transition and economic growth or ICT and economic growth nexus. In addition, the focus of earlier studies was mainly the economic growth or environmental quality without considering the sustainability issue into consideration. Moreover, the studies in the context of China are also very few. After identifying this gap in the literature, the present research attempts to explore the effect of ICT and energy transition on sustainable economic growth. Moreover, to explore this nexus, the study uses QARDL approach that has ignored by earlier researches while studying the above mentioned nexus.

Model, Data and Methodology

The main goal of the present study is the estimation of the role of energy transition and ICT on sustainable fiscal growth in China. For this purpose, the authors introduced novel sustainable fiscal growth index comprising of seven components using Principle Component Analysis (see Table 2). Similarly using PCA, a comprehensive index for ICT is also formed comprising 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). We have assessed the data spanning over 1995–2020 period obtained from secondary sources. To avoid model mis-specification, two most important variables labour and capital are added in the model.

We specified the model in its functional form as:

SEG = f (ICT, ET, LAB, CAP) (1)

Where ICT shows ICT technologies, ET denotes energy transition, LAB is the labour Force and CAP shows capital formation. The econometric expression of the above model can be written as:

$$SEG_t = \beta_0 + \beta_1 ICT_t + \beta_2 ET_t + \beta_3 LAB_t + \beta_4 CAP_t + \varepsilon_t \quad (2)$$

The relevant information of the study variables is provided in following Table.

Table 1

Variables and Sources of Data

Variable/Series	Measurement	Data Source
Sustainable fiscal growth	Sustainable economic growth index	WDI
ICT	ICT index comprising of Mobile Subscription (per 100 people) + Telephone subscription (per 100 people) ++ Fixed broadband subscriptions (per 100 people)	WDI
Energy Transition	Primary energy consumption from renewable.	Our World in Data
Labour	Labour Force (Total)	WDI
Capital	Gross Fixed Capital Formation (% of GDP)	WDI

Where WDI= World Development Indicators

Table 2

SEG Index Components

Components	Measurement	Data Sources
Agriculture, fishing and forestary value added	% of GDP	WDI
Trade	% of gross domestic product	WDI
Population growth	Annual (%)	WDI
Inflation	Annual (%)	WDI
Taxes on profits, income and capital gains	Current (LCU)	WDI
Export of services and goods	% of gross domestic product	WDI
Final expenditures on consumption	Constant 2015 US $	WDI

Methodology

The research uses the QARDL method created by (Cho, Kim, & Shin, 2015) to examine the cointegration connection between sustainable fiscal growth and explanatory and control variables for China across the various ranges of quantiles. In addition, Wald test is used to assess the relationship between time-varying integrating relationship and integrated variables around different quantiles. In terms of methodology, the QARDL technique shows that linear methods are preferable on at least three grounds. Firstly the method allows for asymmetry that is location-based since the parameters can depend on where the sustainable fiscal growth, is located within the conditional probability distribution. Second, the QARDL method simultaneously deals with the short-run fluctuations over a range of quantiles of the explained variable and the long-run association between dependent and independent variables. Thirdly, the QARDL technique, which contains both asymmetric and nonlinear linkages, is thought to be the most useful approach. The following mentions the linear ARDL model.:

$$SEG_t = \alpha + \sum_i^p \beta_1 SEG_{t-i} + \sum_i^q \beta_2 ET_{t-i} + \sum_i^r \beta_3 ICT_{t-i} + \sum_i^s \beta_4 LAB_{t-i} + \sum_i^u \beta_5 CAP_{t-i} + \epsilon_t \quad \text{(i)}$$

Where, error term is given by ε_t and the the lag orders p, q,r,s are selected by Shwartz Information Criterion. The values of sustainable fiscal growth, energy transition, ICT, labour force and capital are denoted by SEG, ET, ICT, LAB and CAP respectively. the quantile expression of equation (i) is represented by equation (ii).

$$QSEG_t = \alpha(\tau) + \sum_i^p \beta_1(\tau) SEG_{t-i} + \sum_i^q \beta_2(\tau) ET_{t-i} + \sum_i^r \beta_3(\tau) ICT_{t-i} + \sum_i^s \beta_4(\tau) LAB_{t-i} + \sum_i^u \beta_5(\tau) CAP_{t-i} + \varepsilon_t(\tau) \quad \text{(ii)}$$

In above equation, quantiles are represented by $\varepsilon(\tau) = SEG_t - Q_{SEGt}\left(\frac{\tau}{\varepsilon t-1}\right)$ & $0 < \tau < 1$. The possibility of sequential connection in the error is also provided in equation (iii).

$$Q_{\Delta SEGt} = \alpha(\tau) + \rho SEG_{t-i} + \varphi_1 ET_{t-i} + \varphi_2 ICT_{t-i} + \varphi_3 LAB_{t-i} + \varphi_4 CAP_{t-i} + \sum_i^p \beta_1(\tau) SEG_{t-i} + \sum_i^q \beta_2(\tau) ET_{t-i} + \sum_i^r \beta_3(\tau) ICT_{t-i} + \sum_i^s \beta_4(\tau) LAB_{t-i} + \sum_i^u \beta_5(\tau) CAP_{t-i} + \varepsilon_t(\tau) \quad \text{(iii)}$$

Equation (iii) is revised by equation (iv) to account for the estimated chance of serial correlation.

$$Q\Delta SEG_t = \alpha(\tau) + \rho(\tau)SEG_{t-i} - \omega_1(\tau)ET_{t-i} - \omega_2(\tau)ICT_{t-i} - \omega_3(\tau)LAB_{t-i} - \omega_4(\tau)CAP_{t-i} - + \sum_{i=1}^{p-1}\beta_1(\tau)\Delta SEG_{t-i} + \sum_{i=1}^{q-1}\beta_2(\tau)\Delta ET_{t-i} + \sum_{i=1}^{r-1}\beta_3(\tau)\Delta ICT_{t-i} \sum_{i=1}^{s-1}\beta_4(\tau)\Delta LAB_{t-i} + \sum_{i=1}^{u-1}\beta_5(\tau)\Delta CAP_{t-i} + \varepsilon_t(\tau) \quad \text{(iv)}$$

$\beta_* = \sum_{i=1}^{p-1}\beta_1$ measures the short run effect of previous SEG on present SEG. $\beta_* = \sum_{i=1}^{q-1}\beta_2$ calculates the short run effect of ET on current SEG. The impacts of earlier ICT, LAB, CAPare also calculated in the same manner. Moreover it is necessary for the disturbance term present in the above equation to be significant and negative (Cho *et al.*, 2015). The specific hypothesis behind the long and short run asymmetric impacts of all the parameters on ecological footprints are finally determined using the Wald-test. Last, we applied (Troster, 2018) Quantile Granger Causality test to estimate causality between study variables.

Results and Discussion

To start empirical estimation, first of all provide the descriptive or summary statistics results of all variables in Table 3 namely, ICT, SEG energy transition, labour and capital respectively.

Table 3

Descriptive Analysis

Variables/series	Mean value	Min Value.	Max Value.	Std Dev.	J-B Stats
SEG	15.913	34.982	57.009	17.044	12.145***
ET	22.876	678.98	999.67	18.098	24.019***
ICT	51.067	13.707	85.971	20.688	2.0926***
LAB	7623776	68115435	7955723	3435263	18.304***
CAP	39.0425	31.003	44.518	44.6334	32.452***
***=P<0.05					

The results indicate that LAB has the highest mean value at 5074.23 and that CAP is second, at 15.913. In comparison to CAP, LAB has the largest dispersion in terms of standard deviation. When it comes to average and standard deviation, ICT and ET are in third and fourth place, respectively. The last variable, SEG, is the one with the lowest average value and standard deviation. It shows that the Chinese economy's SEG is largely stable. As summarized in Table 3, the Jarque-Bera test results for normality revealed that the variables data does not have a normal distribution, rejecting H0.

Table 4

ZA and ADF Test

Series	ADF	ADF (delta)	ZA	Break-Year	ZA (delta)	Break Year
SEG	-2.812	-2.337***	-1.266	1995 Q3	-3.133***	2002Q1
ET	-1.533	-1.235***	-1.354	2000 Q1	-3.342***	2003 Q4
ICT	-2.436	-4.232***	-2.439	2003 Q4	-3.103***	2005 Q1
LAB	-1.237	-3.765***	-3.473	2006 Q3	-4.422***	2010 Q1
CAP	-1.146	-2.124***	-2.234	2017 Q1	-3.987***	2018 Q4
*Where *** shows Prob<0.05*						

To establish the integration order of the series is a necessary requirement before evaluating the QARDL model. As a result, we performed and augmented Dickey-Fuller (ADF) and the Zivot-Andrews (1992) (Z-A) tests, and Table 4 above describes the results. Additionally, the Z-A test is superior since it takes the structural break into account in time series data. The results of the ADF and Z-A tests demonstrate that all time series are integrated of order 1 and unit root since null hypothesis is rejected by both tests at a 1 significance level. Additionally, the ZA test indicates that the time series data has structural discontinuities. Therefore, the strategy that takes into consideration nonlinearity, structural breaks, and dynamic pattern is the QARDL technique (Godil *et al.*, 2020; He *et al.*, 2021; Jiang *et al.*, 2021; Razzaq *et al.*, 2021; Zhan *et al.*, 2021).

Results of the QARDL model estimates (Table 5) show that there exists a significant reverse mechanism towards to the long-term equilibrium between independent and dependent variables over the low (0.05–0.20) and at high (0.60–0.95) quantiles. Symbols ß represent long run parameters and according to findings, all of the selected variables are significantly affecting sustainable fiscal growth over different quantile ranges either in the negative or positive way. First of all, βET shows that energy transition has negative association with sustainable fiscal growth over lower quantiles to medium (0.05–0.50) quantiles and at extreme higher (0.90–0.95) quantiles only. It indicated that energy transition does not promote sustainable fiscal growth in China. This outcome serves as an example of the conflict between socioeconomic and environmental sustainability. These results show that, regrettably, a nation cannot exploit or maximize ecological sustainability and economic growth at the same time, but must instead determine how to balance the two essential objectives and how to attain that balance. To tackle this dilemma, effective policy regulation should take into account the structural shifts in energy transitions (Chen & Pang, 2023). The finding also implies that reducing carbon emissions from energy needs making a trade-off between economic adjustments that could harm economic expansion. The conclusions and their implication suggest that management will be necessary to achieve carbon neutrality given the current commercial and institutional settings, norms, and consumer behaviour. The findings of (Khan *et al.,* 2022) and (Khan *et al.,* 2021) provide strong support for our finding.

Next, we found positive and significant ICT's impact on sustainable fiscal growth at entire range of quantile (0.05-0.95) implying that ICT has major contribution in promoting sustainable fiscal growth in China. A number of previous studies have reached similar conclusion like (Zarkovic *et al.*, 2022) reported that ICT is related with higher economic sustainability in EU-countries. (Pradhan *et al.,* 2020) reported that ICT technologies and innovations are positively related with economic growth in European countries. Fernandez-Portillo, Almodovar-Gonzalez, Coca-Perez, and Jimenez-Naranjo (2019) also supported that more investment in ICT technologies are associated with higher sustainable growth. for China (Jiao & Sun, 2021) concluded that ICT technologies promote urban economic growth in China. (W. Zhang *et al.*, 2021) also found that ICT promote sustainable growth in China. Thus it can be concluded that ICT serves as a driving force for economic growth that reduces the rising costs of environmental degradation and promotes sustainable growth.

Last, we found that labour force has statistically significant and positive impact at all quantiles (0.05–0.95), but capital is effecting growth positively and significantly only over extreme higher quantiles (0.80–0.95) range of quantiles, these findings confirm the fact that labour and capital are is the main important determinants of the economic growth according to traditional growth models like Cobb Douglas Production function. The finding is consistent with the results of (Solarin, 2020), (Ayres & Voudouris, 2014), (Nweke *et al.*, 2017) and (Khan *et al.*, 2021). The results imply that labour force expansion and capital formation raise the economy's potential for production and spur economic growth. The finding suggests that more capital, labor and sustainable economic strategies frequently improve production, promoting growth and sustainable development.

Shuguang Wang was born in Qingdao, Shandong, P.R. China, in 1963. He received the doctor's degree from Huazhong University of science and technology, P.R. China. Now, he is the dean of the school of Finance and public management of Harbin University of Commerce, the head of the national first-class major in finance, the provincial key major in finance, the first-class major, the key discipline, and the provincial excellent course "finance", and the leader of the talent echelon of the provincial public management discipline. His research interest include Fiscal policy and public management.

Wantao Li was born in Harbin, Heilongjiang, P.R. China, in 1976. He received the Master degree from Harbin University of Science and Technology, P.R. China. Now, he works in school of Finance and public management of Harbin University of Commerce, His research interests include Fiscal policy and public management.

Table 5

QARDL Estimations for Sustainable Fiscal Growth

Quantiles	C	ECM	Long-Run						Short-Run		
(τ)	$\alpha_*(\tau)$	$\rho_*(\tau)$	$B_{ICT}(\tau)$	$B_{LAB}(\tau)$	$B_{CAP}(\tau)$	$B_{ET}(\tau)$	$\varphi_1(\tau)$	$\omega_0(\tau)$	$\lambda_0(\tau)$	$\theta_0(\tau)$	$\acute{\varepsilon}_0(\tau)$
0.05	1.092	-0.427 ***	1.687 ***	1.434 ***	1.433	-2.098 ***	0.567 ***	1.543 ***	0.354 ***	0.533 ***	-2.212 ***
	(0.434)	(-3.098)	(3.456)	(2.454)	(0.010)	(-3.832)	(3.344)	(4.152)	(3.344)	(2.342)	(-3.325)
0.1	0.153	-0.543 ***	1.403 ***	2.153 ***	0.094	-0.533 ***	0.245 ***	2.310 ***	0.341 ***	2.345 ***	-0.334 ***
	(0.188)	(-5.009)	(2.435)	(2.143)	(0.345)	(-3.134)	(3.355)	(3.453)	(2.355)	(2.633)	(-3.355)
0.2	0.254	-1.489 ***	1.534 ***	1.544 ***	0.354	-2.933 ***	0.546 ***	0.636 ***	0.653 **	1.934 ***	-1.213 ***
	(0.273)	(-4.870)	(4.632)	(3.457)	(1.233)	(-3.487)	(3.543)	(3.544)	(3.832)	(3.445)	(-3.036)
0.3	0.132	-0.122	1.935**	0.245 ***	0.033	-0.343 ***	0.243 ***	0.325 **	0.105 ***	2.725***	-1.845 ***
	(0.134)	(-0.353)	(2.443)	(3.235)	(0.114)	(-3.647)	(2.154)	(3.184)	(2.113)	(2.432)	(-3.100)
0.4	0.012	-0.111	2.235**	0.834 **	0.034	-0.346 ***	2.844 ***	0.587 **	1.343 ***	0.035	-0.109
	(0.915)	(-0.009)	(4.465)	(2.577)	(0.322)	(-2.834)	(3.564)	(4.333)	(2.546)	(0.536)	(-0.318)
0.5	0.421	-0.341	2.354 **	1.488 **	0.165	-0.239 ***	0.475 ***	0.345 **	0.244 ***	0.009	-0.321
	(0.157)	(-0.430)	(4.354)	(3.433)	(0.123)	(-4.714)	(3.465)	(4.323)	(3.466)	(0.025)	(-0.104)
0.6	1.064	-1.635 ***	1.432 **	1.575 ***	0.306	-0.487	1.647 ***	2.094 **	0.344 **	0.132	-1.875
	(1.073)	(-3.323)	(3.155)	(3.456)	(0.312)	(-0.232)	(3.546)	(2.073)	(3.445)	(0.0312)	(-0.013)
0.7	1.043	-1.534 ***	1.235 **	0.921 ***	0.113	-0.331	1.661 ***	0.445 **	2.445 ***	0.387	-0.024
	(1.073)	(-3.098)	(3.456)	(4.666)	(0.177)	(-0.356)	(3.353)	(2.425)	(2.353)	(0.121)	(-1.345)
0.8	1.035	-1.163 **	1.234 ***	0.234 ***	2.425 ***	-0.974	2.334 ***	0.533 ***	1.734 ***	0.222	-0.254
	(0.223)	(-2.420)	(4.374)	(3.653)	(2.435)	(-1.122)	(3.136)	(4.225)	(3.645)	(0.646)	(-0.235)
0.9	0.013	-1.543 **	1.365	0.445 ***	1.202 ***	-1.754 ***	0.786 ***	2.164 ***	1.848 ***	0.765	-0.324
	(0.124)	(-2.222)	(0.434)	(3.198)	(4.004)	(-3.134)	(3.435)	(4.144)	(3.744)	(0.166)	(-0.356)
0.95	0.033	-1.909 **	0.235	2.510 ***	1.834 ***	-1.345 ***	0.487 ***	0.232 ***	0.656 ***	0.087	-0.483
	(0.233)	(-4.478)	(0.315)	(4.010)	(3.143)	(-3.432)	(2.100)	(2.337)	(3.546)	(0.156)	(-0.467)

Concerning short run dynamics, it is found that current values of SEG are significantly and positively affected by its own previous values at all quintiles (0.05–0.950). Similar to long-run dynamics, the effect of previous and current ICT on SEG is significant as well as positive at (0.05–0.95) quantiles in short run dynamics also. The current and past values of ET are significantly negative at lower quantiles (0.05-0.30) only which is inconsistent with long run dynamics. And last, similar to long run, that current and previous values of LAB and CAP impact SEG positively and significantly at (0.05–0.95) and (0.05–0.30) quantiles respectively in the short run dynamics. Thus it can be concluded from the findings that ICT sector can help China to pursue sustainable economic growth.

The relevant Wald test results are presented below Table 6, which show that the null hypothesis of linearity for the parameter of speed of adjustment is not accepted. Given this, it is not believed that the long-run integration parameters ICT, ET, LAB and CAP will remain constant around the grid of quantiles. These findings show that cointegration between SEG and ICT, energy transition and SEG, SEG and labour and SEG and capital is dynamic over different quantile ranges, confirming the asymmetry. Moreover the Wald test results, which are shown in Table 6, firmly reject the null hypothesis of stability of parameter across the range of quantiles with regard to the short run cumulative impacts of the previous year's sustainable fiscal growth measurements. The results of Wald test disprove the parameter constancy hypothesis regarding the short-term effects of ICT on SEG, ET on SEG, LAB on SEG and CAP on SEG, revealing an asymmetric aggregate short-term effect of ICT, ET, LAB and CAP on SEG.

Table 6

Wald Test Findings

Series	Wald-stat [Prob-Value]
P	14.632***
	[0.000]
B_{ET}	13.442***
	[0.000]
B_{ICT}	19.412***
	[0.000]
B_{LAB}	21.434***
	[0.000]
B_{CAP}	21.532***
	[0.004]
φ_1	43.420***
	[0.003]
ω_0	11.043***
	[0.000]
λ_0	12.362***
	[0.000]
θ_0	14.641***
	[0.000]
ȹ$_1$	17.522***
	[0.000]
∂_0	10.321***
	[0.000]
Cumulative short run effect	
£$_0$	1.976***
	(0.007)

And at last step of empirical estimation, the study has applied Quantile Granger Causality test proposed by (Troster, 2018). The null hypothesis of the test assumes that no causal association exists between series over quantiles whereas the alternative hypothesis is the reverse. The findings of the test are given in Table 7. The findings indicate that null hypothesis is rejected at 1 % significance level. It concludes that bidirectional granger causality exists between SEG, LAB, ICT, ET and CAP at all (0.05–0.95) quantiles.

Table 7

Quantile Granger Causality Test Findings

Quantiles	ΔSEG_t ↓ ΔICT_t	ΔICT_t ↓ ΔSEG_t	ΔSEG_t ↓ ΔET_t	ΔET_t ↓ ΔSEG_t	ΔSEG_t ↓ ΔLAB_t	ΔLAB_t ↓ ΔSEG_t	ΔSEG_t ↓ ΔCAP_t	ΔCAP_t ↓ ΔSEG_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 Recommendations

Balancing the aims of sustainable fiscal growth and minimizing environmental effect is one of the fundamental issues that modern society is facing. We evaluated the impact of certain factors on China's sustainable fiscal growth in the study. In particular, the effect of digital technologies and energy transition controlling for labour and capital formation is examined on sustainable fiscal growth which makes the study a novel contribution in existing literature.

For this purpose, the study formulates novel indices for sustainable fiscal growth and ICT using Principle Component Analysis comprising of all relevant components of the both variables. Time series data over 1995 to 2020 period is obtained from different secondary sources. To estimate the model empirically, we applied recently introduced QARDL estimation technique. All of the variables are found to impact sustainable growth significantly. The study findings for long run indicate that energy transition impacts sustainable fiscal growth negatively over lower qauntiles and at extreme higher quantiles. However, the ICT, labour and capital are found to promote sustainable fiscal growth at different quantiles in the long run. The dynamics of short run dynamics also show that current and previous values of ICT, energy transition, labour force and capital have significant impact on sustainable fiscal growth either positively or negatively. The Wald test of parameter constancy shows non linear and asymmetric impact is present between sustainable fiscal growth and ICT, energy transition, labour force and capital in the long and short run and test for Quantile granger causality reveal the presence of bidirectional causal association between study variables.

ICT projects serve as a foundation for sustainable development since they are a global factor in the realisation of modern advantages. Government should prioritize improving and expanding China's ICT infrastructure in order to support future economic growth. This improves the association between ICT and long run economic growth. On the basis of the study findings, we recommend that to further enhance the ICT's effect on sustainable fiscal growth, government should implement policies to boost the activities that have the highest capability to develop new value, notably the software and internet. In addition, China needs to step up its collaboration in the ICT research and development field with other Asian nations (who have emerged as the leaders in these technologies). The Chinese government must exert coordinated efforts to promote the usage of ICT through its relevant policies. To do this, China should expand the reach of its digital networks and its internet, promote ICT applications available to a wide range of users, synchronies its many communication channels, and promote the use of smart technology by all ability levels across the Chinese population. Additionally, regulations that assist internet finance should be given special consideration by Chinese policymakers. This lessens information asymmetry and broadens accessibility to outside funding, which promotes the steady growth of economic units. When the aforementioned relation is realized, ICT is given the responsibility of generating new value, or increasing sustainable fiscal growth. In addition, the Chinese government should promote policies to reap the advantage from potential in labour force and capital investments that are revealed to be significant contributors in sustainable fiscal growth. In addition, there is a dire need to transform the economic growth model that is heavily reliant on fossil fuel energy sources towards renewable resources. Significant efforts are needed by the government to transform the growth strategy so that energy transition might bring some fruitful contributions towards economic sustainability.

Like many studies, this study is also not without its limitation. The present study selected only China as a case study. Future studies can choose other countries or other panel of countries to study the same objective. In addition, several other variables beside energy transition and ICT like energy efficiency, trade, financial development, technological innovation, globalization can should also be studied in the future studies. Similarly besides ICT, digital economy and digital infrastructure can also be used to explore its impact on sustainable economic development. like wise there is also room for future researchers in methodological aspects. Researchers must make some novel additions in the literature by applying other empirical methodologies (panel as well as time series) like ARDL, NARDL, CS-ARDL, AMG, CCEMG, MMQR etc.

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Authors' Biographies

Shuguang Wang received a doctor's degree from Huazhong University of Science and Technology, P.R. China. Now, he is the dean of the School of Finance and Public Management of Harbin University of Commerce, the head of the national first-class major in finance, the provincial key major in finance, the first-class major, the key discipline, and the provincial excellent course "finance", and the leader of the talent echelon of the provincial public management discipline. His research interests include Fiscal policy and public management.

Wantao Li has built a commendable academic and professional profile centered around his expertise in fiscal policy and public management. After earning his Master's degree from Harbin University of Science and Technology, he has taken up a significant role at the School of Finance and Public Management at Harbin University of Commerce. Here, his research efforts delve into the intricacies of fiscal policy's impact on public administration and governance. Li's work aims to contribute to the understanding and improvement of financial management practices within the public sector, reflecting a deep commitment to enhancing fiscal policies for better governance and societal benefit.

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