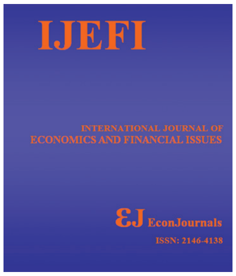

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How does Climate Technology Contribute to Economy? Empirical Evidence from Provinces in China

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ABSTRACT

Existing study has extensively explored nexus between climate change on economy. However, effect of climate technology has received limited attention, which adjust relationship between climate and economy in various scenarios. Hence, this study examined Chinese provinces from east to west, incorporating impact of climate technology from 1997 to 2022 by ARDL model. The long-run results demonstrate significant role of climate technologies on economy in reducing drawbacks of climate. Moreover, negative influence of climate is moderated in middle and west provinces through climate technology. Policymaker concern to what extent climate technology affect desert environment and local economy in middle and western regions, providing incentives to make policy. These findings imply that climate technology is imperative to ensure long-term sustainable growth, need further promoted and widely applied.

Keywords: Climate Technology, Economy, China, West Provinces
JEL Classifications: F41, F64

1. INTRODUCTION

Climate technology provides technological solution to harsh climate, minimizing risks and forming adaptation to future climate change. Growing need for climate technologies appears, like building insulation in deserts, climate-smart agriculture techniques in winter, water-saving technologies, because it minimizes drawbacks of climate, make harsh climate condition suitable for social development (Dzebo et al., 2019; Kim et al., 2023). Climate technology contributes to achieve zero carbon and sustainable development, includes utilizing renewable energy sources, wind power, solar energy, and hydropower.

Climate technology brings effective measures against climate problems (UNFCCC, 2016). The United Nations Framework Convention on Climate Change aims on improving development of climate technologies, supporting climate technology programs. Additionally, climate impacts economy activities, like climate investment. The harsh climate negatively affects capital stocks and productivity, brings long-term influence on GDP growth (Dell et al., 2012; Moore and Diaz, 2015; Moyer et al., 2013; Newell et al., 2021). Global warming, common phenomena of climate change (Dell et al., 2012; Henseler and Schumacher, 2019; Letta and Tol, 2019), adversely affects developing countries' GDP growth. Several studies have determined that more temperate countries face greater risks in GDP growth (Burke et al., 2015; Kumar and Khanna, 2019; Tanutama, 2019). Similarly, some research focus on sub-national scale; for example, in China, climate technologies have obvious effect in reducing environmental pollution (Liu et al., 2023). Technologies utilization is beneficial to reduce CO_2 emissions, promoting China's transition to low-carbon economy (Lin and Zhu, 2019; Altaee and Azeez, 2023; Wangjiraniran et al., 2023).

China, as the largest carbon emitter in the world, aims to achieve carbon peak before 2030, becomes a high-income country. Achieving these objectives requires a better understanding of technology-climate-economy link. Despite this relevance, empirical analyses of the role of climate technology for economy development are largely lacking. This research gap might stem from disciplinary divide between the research studying economy and those studying climate. For example, most economists regard climate as science factor, merely an exogenous variable. Conversely, climate technology provides important condition into long-term economy dynamics. Here, insights from technology utilization studies can contribute. Recent publications from climate economy explicitly acknowledge the need of technology tools, have started to bridge the gap conceptually and have provided individual case studies. However, to inform evidence, research needs to establish causal links, empirically test hypotheses on a quantitative basis, and provide predictive power all of which is currently lacking.

Since 1951, every 10 years, average temperature in China increase 0.23°C (Song et al., 2022). By now, what is the suitable climate for crops, livestock to develop in China? Suitable climate is beneficial for plants, animals to live and human activities to proceed, as well as industry productivity. Climate exerts influence on various activities across different dimensions, including agriculture, industry, human health etc. However, what is the standard to measure suitable climate condition? To know the optimal climate suitable for all, this study finds ideal temperature for different crops and animals, including human activity.

The range of optimum temperatures required for crops, livestock, and industrial labor in Table 1. From 12.2°C and highest ideal mean temperature is at 21.7°C. Different provinces own different climate characteristics. The temperature and precipitation vary a lot from east to west in China.

This study ranks average temperature of Chinese provinces according to data access and found four provinces are below the minimum mean temperature. Four provinces are too cold. Two provinces above ideal mean temperature, 12 provinces are within optimal temperature range. In Table 2, the ranking of each province is by temperature, from high to low. The first one in column is with highest temperature, following lower ones. Qinghai, Xinjiang, Shanxi, and Jilin have mean temperatures below the minimum mean temperature, and these four provinces have temperatures that are too low, need to increase mean temperature. Qinghai and Xinjiang are in western region, Shanxi and Jilin are in middle region. No provinces in east with too low temperatures. Middle and west of China is covered with large area of deserts, with temperature various a lot from cold to hot in short time and extremely dry condition. The arid area in western China distributes about 64% of total area of deserts of whole country (NFGA, 2023). AQ2

Table 1: Ideal temperature for different types

Type	Temperature to grow/°C
Rice	10-30
Wheat	3-20
Corn	8-30
Rapeseed	4-20
Cotton	13-28
Soybean	10-20
Eggplant	20-25
Watermelon	10-25
Muskmelon	13-28
Potato	12-22
Carrot	15-20
Vegetables	15-20
Perennial (Grass for farming)	10-16
Alfalfa (Grass for pastures)	16-18.3
Ducks	18.3
Chicken	21.1
Goat	7.2
Beef cattle	5-18.3
Mining industry (For miners working)	21-26
Average	12.2-21.7

Source: Martin-Gatton College of Agriculture, Food and Environment; Ministry of Agriculture and Rural Affairs of the People's Republic of China; US Department of Labor, Mine Safety and Health Administration

Guangdong and Guangxi are above ideal mean temperature, too hot, need to cool down. Guangxi is in west, and Guangdong is in east. Addressing the problem, reducing CO_2 emissions stands as a fundamental way (Dzebo et al., 2019). Achieving reductions in CO_2 emissions from economic activities through two primary avenues: diminishing volume of CO_2 generated during production processes, enhancing carbon sink and storage carbon. To mitigate damages temperature cause, it is necessary to apply climate technology, ideally temperature and climate may be achieved for ecosystem (UNFCCC, 2016).

Climate technology provide important engine for high-quality economic development (Raihan, 2023; Liu et al., 2022). First, climate technology is symbol of connection between human and environment. Secondly, an ever-growing economy depends on productive and sustainable human environment which need technology as promoter. Besides, residents and government will be more capable to respond to climate-related issues and minimize negative effects of climate brings. There are many examples successful implementation in UAE and middle countries desert area (Tokbolat and Nazipov, 2021). Previous studies have predominantly focused on important role of technology (Aggarwal et al., 2019). However, there is research gap in how climate technology influences economic growth in different provinces of China. By gaining insights, it helps to develop strategies for mitigating greenhouse gas emission and adjusting adverse consequences brought by climate.

Table 2: Provinces of China in different temperature range

Below lowest temperature/12.2°C	In ideal temperature (12.2°C-21.7°C)	Higher than ideal temperature/21.7°C
M-Shanxi	E-Fujian	E-GuangDong
W-XinJiang	W-Chongqing	W-GuangXi
M-JiLin	W-SiChuan	
W-QingHai	E-ShangHai	
	E-ZheJiang	
	M-AnHui	
	E-JiangSu	
	M-HeNan	
	W-GuiZhou	
	W-Shaanxi	
	M-HuBei	
	E-Beijing	

Provinces with E are in east region. Provinces with W are in west region. Provinces with M are in middle region.

Source: Chinese National Bureau of Statistics of 1997-2022.

2. LITERATURE REVIEW

Additionally, climate technology has been utilized to increase production. By middle of 21st century, climate change might lead to potential yield increase as much as 20% in East and Southeast Asia, contrasted with possible decline up to 30% in middle and South Asia. Technological improvements appear to have large yield-enhancing impact on negative effects of climate change, at least in short term (Aggarwal et al., 2019). The European climate technology sector is growing rapidly. The panel analysis by Lasisi et al (2022) reveals that technologies play a substantial role in stimulating economic growth. The coefficients associated with oil consumption and interaction term, Oil*Tec (representing interplay between oil and environmental technologies), exhibit statistically significant implications. This underscores important function of technologies as a moderator in context of oil-related economic growth.

Technology has utilized in west China promoting higher yields. For example, to address widespread issue of grapevine root freezing and death in Xinjiang province of China during winter, by utilizing technology, with an application area harvest exceeding 70,000 acres. The research and development in areas such as soil, cultivation, and agricultural zoning, providing technical support for sustainable development of modern agriculture. West China is vital agricultural base and resource-rich area. Technology unlock substantial development potential, subsequently boosting AQ2 economic growth (National Forest and Grass Administration, 2023). As a result of growing use of technology, politicians are becoming more aware of the opportunity to invite nearby enterprises to invest and promote employment that will strengthen local economy.

2.1. Temperature Impact

Nonetheless, a rise of 0.04°C in average global temperatures, assuming elevated greenhouse gas emissions in absence of climate change mitigation policies, results in a substantial 7% reduction in the world's real GDP per capita by the year 2100 (Kahn et al., 2021). Temperature is used as a measurement of climate. The magnitude of these economic impacts differs significantly among countries. Empirical evidence points to potential of climate change causing decline in economic well-being for more than 77% of nations globally by end of this century (Burke et al., 2015). It is worth noting that beyond impacting economic output, phenomenon of global warming also impairs overall growth prospects of economies, with estimated 1% decline in economic growth for every 1°C temperature rise (Dell et al., 2012). For China, climate change has resulted in crop damages valued 595 million US dollars over past decades, and projections indicate potential future reductions in corn and soybean production by 3% and 7% respectively by 2100 (Chen et al., 2016). Furthermore, warming climate extend to significant increase in heat-related mortality, particularly within densely populated urban centers (Yu et al., 2019). The densely populated eastern region of China requires utilization of technology to minimize drawbacks brought by climate change. It is necessary to explore how technique tools can be utilized to bring benefits in poorly populated western part of China, to adjust the west to be livable to support economy growth. The government should actively seek collaborative and innovative solution to satisfy long-term needs of deserts area, aiming to safeguard right of future generations to inhabit safe and healthy environment.

2.2. Technology Utilized in Remote Deserts

Deserts, highly related with extreme temperatures, always lack water resources. With progress of technology, under the remote desert, human can survive and live well. Before utilizing technology tools, we need to know what tools of technology need to be invited to change harsh climate.

In transforming remote areas into habitate while achieving sustainable development, valuable lessons can be drawn from experiences and actions of Middle Eastern countries. The Saudi Green initiative aims to plant 10 billion trees across Saudi Arabia, turning deserts into green livable space, mitigating dry conditions to protect land area that has been at risk of being damaged. UAE Vision 2021 National Agenda (Krishnadas Mazumder, 2016) emphasizes preservation of water resources, increase usage of clean energy. UAE is at forefront of large-scale renewable energy projects, exemplified by initiatives like Masdar City in Abu Dhabi. These endeavors contribute to protect ecosystem and natural resources over long term (Martens and Reiser, 2019). Qatar's rapid development has prompted demands for sustainability in environment and economy (Sigsgaard et al., 2020). In pursuit AQ2 of sustainable urbanization, green building design and green urban development are in need. Recognizing significance of sustainability, Qatar initiated efforts to adopt global sustainable green building rating systems (Tokbolat and Nazipov, 2021). This proactive approach underscores Qatar's commitment to advancing sustainable practices in urban development.

Considering above action utilized, China firstly considers supply of water resources in deserts. Efficient water management is beneficial to satisfy basic needs (Du et al., 2024; Kumar et al., 2022). Managing water efficiently by drip irrigation in agriculture (Hunsaker et al., 2019), rainwater harvesting (Jamal et al., 2023; Puppala et al., 2023), atmospheric Water Generators utilization (Salek et al., 2018). Secondly, electricity relies on green and renewable energy (Chang et al., 2023; Xia et al., 2022). In high temperature deserts, green buildings with energy-efficient materials and insulation are in need (Krishan et al., 1996; Zhong et al., 2023) to maximize natural cooling and ventilation. Fourthly, afforestation and reforestation can help increase vegetation cover, stabilize soil, provide shade and habitats for wildlife (Teng et al., 2022; Zhang et al., 2021). Oases, wetlands, native flora, and fauna are essential for ecological balance. Moreover, waste management in scientific and environmental-friendly way to achieve sustainable development in deserts (Ambaye et al., 2023).

The utilization of ecosystems and its restoration has demonstrated significant success, with notably higher restoration efficiency (Villa et al., 2021). Research by Yang et al. (2023) evaluated value of ecosystem restoration in various provinces, highlighting effect in sand fixation in Mongolia, Tibet, and Xinjiang. Additionally, for climate regulation, ecosystem restoration provides benefits in Tibet, Qinghai. These technologies enhance energy yields, also positively impacts human life.

3. METHODOLOGY

Since we could not count effect of each climate technology, we apply an approach akin to general equilibrium by establishing the model to measure effect of technology on GDP. Given difficulty in measuring level of technology utilized in different region, we apply number of journal publications in Scopus (Masron et al., 2023) from 1997 to 2022 on technology applied to turn desert into livable place, to get rid of negative effects of climate. Technologies utilized, we searched for keywords, respectively under area of Water Resources (Du et al., 2024; Kumar et al., 2022), Electricity Power (Chang et al., 2023), Green Architecture (Zhong et al., 2023), Afforestation and Vegetation (Teng et al., 2022; Zhang et al., 2021), Waste Management (Ambaye et al., 2023), these five categories are necessary for development explained in Chapter 2. Under each category, there are branches for detailed technique tools. The detailed information is listed in Table 3. To limit space, several years are chosen to present.

This paper aims to know the impact of climate technology on GDP across different regions in China. An annual time series covering 1997-2022 is utilized with GDP, temperature, factor of climate technology, FDI, and export data collected from China's National Bureau of Statistics (NBS) and Bureau statistics of different provinces. The climate data is collected from China meteorological data service centre (CMDSC). To ensure data availability, this study employs annual average temperature of each provincial capital city as proxy for average temperature. Factor of Climate technology we get from the number of journal publications in Scopus on climate technology during 1997-2022. This section delineates the model for exploring influence of climate and climate technology on economy. GDP is regarded as dependent variable in model, as measured by each province's GDP amount (GDP). The model can be expressed as Eq. (1):

$$GDP_t = f(FDI_t, EXP_t, clim_t, clim_t \times Tech) \qquad (1)$$

The specified estimation model of Eq. (1) express as follows:

$$GDP_t = \beta_0 + \beta_1 FDI_t + \beta_2 EXP_t + \beta_3\, clim_t + \beta_4\, clim_t \times Tech + \varepsilon_t \qquad (2)$$

Where: t is Time period., β_0, β_1, β_2, β_3 are evaluated coefficients. *FDI* is foreign direct investment amount at time t in certain province. *EXP* is export amount at time t in certain province. *FDI* and *EXP* are control variables. *CLIMATE* is average annual temperature at time t in certain province. ε_t is random variable. The interaction term clim*tech (climate and technology) justifies the role of climate technology (Lasisi et al., 2022). These are shown in Table 4. ARDL bounds test (Clements, 1994) is utilized to test cointegration. ARDL evaluates cointegration and long-term equilibrium relationship, capturing dynamic effect over varying time horizons. Unlike maximum likelihood estimation (MLE) approach for multivariate time series cointegration testing, ARDL model overcomes limitation by allowing integration of time-series variables in mixed orders, including level I(0), first difference I(1), or combination of both. Stationary of variables are examined using Augmented Dickey-Fuller (ADF) test. Bound test is employed to determine presence of cointegration relationship among variables. Selecting optimal lag length is crucial in constructing ARDL-ECM process. Commonly used criteria such as Akaike information criterion (AIC) and Schwarz information criterion (SC) are employed to determine appropriate model order.

$$y_t = C + \sum_{i=1}^{p} \theta_i y_{t-i} + \sum_{j=1}^{k} \sum_{i=0}^{q} \beta_{ji} x_{jt-i} + \mu_t \qquad (3)$$

The optimum lag order is denoted by p ($p \geq 1$) for dependent and explanatory variables, and q ($q \geq 0$) indicates absence or presence of lagged dependent variables. For simplicity, the study assumes equal lag order for all variables within x_{jt}. The error term is indicated by μ_t. ARDL model is transformed into dynamic error correction model (ECM) structure. ECM incorporates short-term equilibrium relationship. As a result, ARDL model is re-parameterized into extensively employed ARDL-ECM model. The representation of ARDL-ECM model is as follows:

$$\Delta y_t = C_1 - \varphi ECT_{t-1} + \sum_{i=1}^{p-1} \theta`_i y_{t-i} + \sum_{j=1}^{k} \sum_{i=0}^{q-1} \beta`_{ji} x_{jt-i} + \mu_t \qquad (4)$$

The error correction term, ECT_{t-1} quantifies disequilibrium correction when dependent variable deviates from long-run equilibrium relationship. The correction coefficient, represented by φ, reflects degree of adjustment in response to deviations.

4. RESULTS AND DISCUSSION

4.1. Unit Root Tests

Determining order of integration is necessary. Here we employ unit root test (Pesaran, 2007). The stationary test based on ADF result, as presented in Table 5, reveals all variables (GDP, FDI, Export, clim and clim *Tec) exhibit stationary, all variables pass ADF test for unit root integrated of order one or zero, denoted as I(1) and I(0). This serves as indication that ARDL (auto regressive distributed lag) is suitable approach for conducting cointegration tests to examine both long and short-term effects. ARDL bound approach is preferable when time-series variables are stationary and combination of level I (0) and first difference level I (1) (Rauf et al., 2018; Sun et al., 2022).

4.2. ARDL-ECM Bounds Test Result for Cointegration

F-statistic surpasses lower bound indicating existence of cointegration long-term relationship; ARDL model cannot be processed if F-statistic is below lower bound. As we can see from Table 6, all provinces F-statistics lies between the upper and lower bound. This substantiates presence of cointegration among variables.

The error correction term need to be negative and significant. This term signifies speed of adjustment to equilibrium after disruption in long run. A relatively high adjustment coefficient suggests swifter adjustment process.

4.3. Short Run Relationship

Table 3: Number of published journals of specific field in SCOPUS

Year	Water resources			Electricity power			Green architecture			Afforestation and vegetation						Waste management	
	Drip-irrigation	Rainwater-Harvest	Water management	Photovoltaic Panels	Energy technology	Wind-energy	Energy-efficient materials	Climate-architecture	Green roofs and walls	Ecosystem restoration	Reforestation	Agriculture	Oases	Wetland	Soil nutrition	Waste-to-energy technologies	Waste disposal
1997	11	5	80	30	27	7	5	28	16	132	11	14	127	27	234	6	47
2000	17	10	118	43	26	9	9	34	29	237	19	10	191	26	226	13	50
2003	19	16	234	97	48	12	20	91	55	430	19	22	318	48	384	18	78
2006	27	21	441	156	85	21	45	180	79	651	38	23	464	85	600	25	88
2007	49	30	504	216	103	24	62	236	100	828	53	62	471	103	527	34	79
2008	41	33	625	223	99	28	73	213	123	919	81	34	446	99	627	39	103
2009	53	50	872	369	110	56	90	306	145	1123	117	62	574	110	554	44	123
2010	36	63	1047	429	121	74	115	357	209	1313	131	56	575	121	615	58	140
2011	61	76	111	595	160	97	139	423	257	1450	128	70	557	160	656	43	148
2012	80	92	1362	735	123	120	202	466	358	1543	143	83	618	123	618	78	168
2013	106	90	1485	733	177	164	213	496	407	1776	161	82	641	177	711	66	192
2014	107	176	1732	926	181	135	260	471	485	1984	161	80	667	181	728	69	190
2015	137	250	2291	16	169	163	321	510	525	2262	159	110	656	169	796	84	212
2016	162	273	2551	1147	168	175	428	540	645	2553	201	106	694	168	716	99	230
2017	182	266	2784	1307	162	212	473	640	780	2552	183	140	724	162	811	127	246
2018	203	310	3264	1542	195	246	605	668	865	2808	223	157	764	195	943	136	252

Source: Scopus.com. The number is based on those published journals in specific field that are searched by SCOPUS from 1997 to 2022 only. Some of the annual data between research time period is omitted to conserve space but is available upon request

Table 4: The variables, measurement, and sources AQ6

Variable	Measurement	Sources
GDP	Real GDP	National Bureau of Statistics (2022)
FDI	Net FDI inflow	
EXP	Net export amount	
Temp	Average annual temperature	
TECH	Number of technology field publications (Details seen in Table 3)	Scopus (2022)

The results of short-run are in Table 7. Variables have strong significant influence on GDP in short run. Xinjiang, coefficient shows with 1% increase in Temp*Tech, economy development increase 0.02%, hedging negative impact temperature brought. Similar trend is noticed in Shaanxi, climate technology positively influences GDP.

4.4. Long-Run Relationship

Table 8 shows the long term results. From the results of the tests , if the coefficient of temperature or precipitation is negative, and the interaction term clim*Tech shows a statistically significant positive, the desirable role of climate technology plays as a promoter of climate. When experiencing excessively hot or cold weather, the coefficient of temperature exhibits negative effects, while the coefficient of clim*Tech shows positive effects; for example, in Sichuan, Chongqing, Qinghai, Xinjiang in the western region, and Shanxi, Jilin, Anhui, Henan in the middle. Only Beijing is in the east region.

Accroding to Table 8, technology (Tech) plays a constructive role in enhancing GDP. Specifically, in the western region, Sichuan, Chongqing, Qinghai, and Xinjiang, these four provinces found that when the temperature is found to be detrimental, climate technology has a positive impact on the panel by a significant amount in the long run. Utilizing relevant technology tools makes it possible to turn remote and harsh climate conditions comfortable. According to the empirical results, climate technologies' moderate effect is more significant in the middle and West than in the east region compared to the number of provinces. The results are not consistent with Yang et al. (2022). This result is unique because the East region has been well developed compared to the Middle and the West, which has more potential to be inspired by new technology. Therefore, the moderate effect of climate technology is evident in the western region of China, which is consistent with the findings of Xu (2023).

As shown in Table 8, in Qinghai, clim*Tech significantly positively affects the dependent variable, with one increment in clim*Tech, leading to a nearly 6.4 increment in GDP. This result illustrates the effect of climate technologies used in the West, which is consistent with the argument of Borys et al. (2021) and Lasisi et al. (2022) that technology is crucial and beneficial for local economic development.

As well as Xinjiang, the temperature coefficient is negative, meaning temperature cannot benefit local GDP. Under the positive effect of technology, an increment in Temp*Tech significantly leads to GDP growth. Additionally, Qinghai and Xinjiang are districts with harsh climates and extremely low temperatures in

Table 5: Unit root test – ADF

Variable	West region				West region				East region			
	Level		1st difference		Level		1st difference		Level		1st difference	
	C	C and T	C	C and T	C	C and T	C	C and T	C	C and T	C	C and T
Sichuan					**Guangxi**				**Beijing**			
GDP	2.62	−0.67	−6.17***	−4.19**	7.24	−0.86	−0.43	−3.34**	9.53	−1.17	0.26	−4.05**
FDI	−0.78	−3.09	−2.69*	−2.62	0.13	−1.37	−5.89***	−5.47**	−0.71	−4.49**	−3.32**	−3.53**
EXP	1.84	−0.99	−3.52**	−4.58***	1.05	−2.99	−4.87***	−5.2***	−3.16	−2.38	−2.84**	−2.70
clim	−1.55	−1.22	−3.23**	−3.64*	−4.10**	−3.99**	−4.98***	−4.83***	−1.67	−4.79***	−4.89***	−4.52***
clim*Temp	5.78	3.33	1.79	−6.93***	3.01	2.64	−3.02*	−4.25**	4.54	0.04	−5.23***	−9.47***
					Middle region							
ChongQing					**Hubei**				**Shanghai**			
GDP	−0.36	−0.61	−2.55*	−3.33*	3.29	0.54	0.29	−3.91**	7.62	0.18	0.54	−3.8*
FDI	−1.33	−2.12	−6.24***	−6.09***	0.15	−3.22	−3.07**	−2.92	0.03	−2.4	−2.98**	−2.78
EXP	2.69	−2.52	−2.72*	−4.73**	−1.15	−2.03	−1.52	−4.76***	−0.89	−1.10	−3.89***	−3.91**
clim	0.04***	−5.09***	−4.59***	−4.49***	−4.43***	−4.33**	−4.66***	−4.59**	−2.49	−2.27	−3.77**	−3.81**
clim*Temp	5.81	0.85	−0.28	−7.06***	3.77	1.89	−3.46**	5.32***	4.80	1.92	0.68	−3.86**
Guizhou					**Shanxi**				**Guangdong**			
GDP	−3.99**	−3.44**	−2.96**	−3.56*	−1.51	−4.28**	−4.44**	−4.25**	−4.33***	−4.23***	−6.85***	−6.70***
FDI	−0.68	−2.15	−4.03***	−4.91***	−0.86	−3.03	−3.78**	−3.69**	−0.83	−2.04	−4.56***	−4.45**
EXP	−1.11	−1.98	−3.99***	−3.76**	−0.61	−3.73**	−5.90***	−5.83***	−0.34	−1.72	−3.46 **	−3.36*
clim	−2.79*	−2.62*	−5.63**	−4.78**	−1.61	−2.69	−4.37**	−4.44**	−4.92***	−4.98**	−7.54***	−7.36***
clim*Temp	4.35	2.16	0.516	−6.20***	4.51	1.45	1.01	−4.91***	3.82	2.24	0.85	−5.66***
Shaanxi					**Jilin**				**Jiangsu**			
GDP	−1.17	−2.88	−5.43***	−4.29**	−1.82	−2.70	−5.07***	−4.85***	−2.85**	−0.59**	−6.54***	−3.99**
FDI	0.13	−1.37	−5.89***	−5.47**	1.10	−7.61***	−4.39***	−4.03**	−1.31	−1.6	−2.85**	−2.91
EXP	1.05	−2.99	−4.87***	−5.2***	−1.24	−1.80	−4.34***	−4.33**	0.05	−2.28	−4.18***	−4.09**
clim	−4.25***	−4.53***	−4.32***	−4.28**	−7.46***	−4.04**	−3.57**	−3.47*	−3.66**	−4.32**	−4.77***	−4.59**
clim*Temp	−1.07	−2.49	−6.18***	−4.74***	2.47	−0.39	−3.37**	−4.71***	4.86	1.96	0.62	−3.78**
Qinghai					**AnHui**				**Zhejiang**			
GDP	−1.35	−4.47***	−7.97***	−7.85***	−2.17	−2.67	−5.39***	−5.58**	−2.85**	−3.59**	−6.54***	−3.99**
FDI	−2.44	−0.92	−3.70	−4.82***	0.10	−1.87	−1.63	−1.97	0.43	−5.86	−4.29***	−4.09**
EXP	−1.67	−3.78**	−3.53**	−3.39*	0.72	−1.83	−3.23**	−3.41**	0.74	−2.76	−3.79***	−3.88***
clim	−4.78**	−4.66***	−9.29***	−9.36***	−3.78***	−4.33**	−6.72***	−6.49***	−3.25**	−3.29*	−5.39***	−5.24***
clim*Temp	−0.05	−3.60**	−7.35***	−7.12***	5.27	1.69	0.41	−4.67***	4.78	2.09	0.85	−3.56**
Xinjiang					**Henan**				**Fujian**			
GDP	−1.39	−4.45**	−3.82**	−3.63**	−2.19	−2.53	−5.24***	−5.27***	−3.44**	−3.36**	−5.50***	−5.31***
FDI	−2.89*	−2.49	−3.38**	−3.43**	6.18	−1.23	−1.39	−2.94*	−2.06	−2.01	−3.88**	−3.82**
EXP	−1.18	−1.95	−4.59**	−4.52**	0.64	−2.83	−2.85**	−2.89	0.05	−2.59	−3.13**	−3.06
clim	−4.38**	−4.28**	−6.62***	−6.43***	−4.24***	−4.22**	−8.56***	−8.36***	−5.39***	−4.24**	−5.46***	−5.48***
clim*Temp	−0.01	3.54	−4.22***	−6.34***	−0.83	−2.60	−6.28***	−3.71**	5.55	1.62	0.17	−5.31***

C is constant without trend, and C and T refers to constant with trend. Asterisks *, ** and *** denote significance at 10%, 5% and 1% critical values, respectively. clim represents Climate, clim*Tech represents climate*Technology

Table 6: Bound cointegration test

West region	GDP	Middle region	GDP	East region	GDP
Sichuan	6.12***	Shanxi	5.91**	Beijing	6.91***
Chongqing	8.43***	Jilin	8.18***	Shanghai	7.84***
Guizhou	8.83***	Anhui	5.99**	Guangdong	3.89**
Guangxi	6.78***	Henan	7.18***	Jiangsu	7.78***
Shaanxi	7.96**	Hubei	8.17***	Zhejiang	5.67***
Qinghai	6.33***			Fujian	9.27***
Xinjiang	9.13**				
1%=3.29		5%=2.56		10%=2.2	

Asterisks *, ** and *** denote significance at 10%, 5%, and 1% critical values, respectively

the western region, as shown in the introduction. By utilizing technology on climate, the western districts' climate might become more suitable for agriculture and humans to live (Aggarwal et al., 2019; Li et al., 2022). In the West, Chongqing, Guizhou, and clim*Tech significantly and positively affect GDP in the long run. Its GDP ranks low behind the average level of the whole country. It is necessary for these regions to develop climate technology, which is in deep need.

Moreover, provinces with high temperatures are Guangdong and Guangxi province. Although the average temperature is higher than the average national level, the utilization of technology in these two districts is great utilization to bring benefits. With technology, the interaction term clim*Tech shows statistically significant positive results for all provinces; the desirable role of climate technology is to help bring benefits to GDP. In the middle region, Anhui province has the most significant correlation coefficient, positively and significantly affecting GDP. With one increase in the climate technology index, Anhui province positively impacts GDP at 10.44 increace. This aligns with the expectation that technology is one of the main driving forces of economic growth.

According to the results, Shanxi, Jilin, Anhui, and Jilin's temperatures hurt GDP in the middle region; only Hubei had a positive impact. Although temperature is found to be detrimental, climate technology

Table 7: Error correction model (GDP)

Panel I: Error correction model	Panel II: Diagnostic test[a]			
	AC	HET	NORM	STAB
East provinces				
Beijing: ΔGDP=-0.03ECT(-1)***+ 1.96ΔFDI ***+ 2.97ΔFDI(-1)** + 0.74ΔEXP***-0.61ΔEXP(-1)** +25.77ΔCT**	0.18	0.46	0.21	0.27
Shanghai: ΔGDP = - 0.09ECT(-1)*** - 0.99ΔFDI + 0.31ΔEXP***	0.14	0.15	0.22	0.39
GuangDong: ΔGDP = -0.22ECT(-1)***+0.26ΔEXP***-0.35ΔEXP**-2.8ΔFDI(-1)***-0.09ΔCT*	0.37	0.31	0.76	0.29
Jiangsu: ΔGDP = -0.42ECT(-1)*** -2.19ΔFDI** + 4.23ΔFDI(-1)** + 0.54ΔEXP*** -0.30ΔEXP(-1)*** - 25.79 Δclim*** + 261.11Δ clim (-1)***+ 0.02 Δ CT*	0.33	0.15	0.24	0.27
Zhejiang:ΔGDP= -0.29ECT(-1)***+5.46ΔFDI** + 0.28ΔEXP** - 1.10ΔEXP(-1)*** -0.07Δ CT**-0.007 ΔCT(-1)**	0.16	0.24	0.29	0.36
Fujian: ΔGDP = - 0.01ECT(-1)*** + 0.68ΔEXP***	0.12	0.16	0.13	0.12
Middle provinces				
ShanXi: ΔGDP = - 0.21ECT(-1)*** + 1.44ΔEXP +5.07ΔTEMP + 11.56ΔCT+ 23.41ΔCT(-1)**	0.13	0.19	0.22	0.45
Jilin:ΔGDP=-0.52ECT(-1)***+6.19ΔFDI+0.49ΔEXP***-0.49ΔTEMP +32.09ΔTEMP(-1)** -0.06ΔCT**-0.09ΔCT(-1)**	0.23	0.43	0.34	0.21
Anhui:ΔGDP=-0.29ECT(-1)***+9.68ΔFDI*** + 22.68ΔFDI(-1)*** - 4.62 ΔEXP***-15.02 Δclim -46.95 Δclim (-1)	0.31	0.36	0.44	0.28
Henan: ΔGDP = - 0.54ECT(-1)*** + 7.16ΔFDI***+7.78ΔFDI(-1)**+0.59ΔEXP+0.01 ΔCT***- 0.04 ΔCT(-1)**	0.25	0.14	0.48	0.22
Hubei: ΔGDP = - 0.16ECT(-1)*** + 0.05 ΔCT**	0.36	0.21	0.34	0.25
West Provinces: AC HET NOR STAB				
Sichuan:ΔGDP=-0.43ECT(-1)***-4.49ΔFDI***-6.25ΔFDI(-1)***+0.91ΔEXP***+3.96 Δclim +18.09 Δclim(-1)***- 0.05ΔCT***	0.21	0.25	0.32	0.15
ChongQing:ΔGDP=-0.58ECT(-1)***+1.93ΔFDI**-7.88ΔFDI(-1)**+0.29ΔEXP**-0.73ΔEXP(-1)***+ 0.03 ΔCT*** -0.03 ΔCT(-1)***	0.44	0.23	0.27	0.15
GuiZhou: ΔGDP = - 0.03ECT(-1)*** +1.05ΔEXP** - 4.74 Δclim -0.04 ΔCT	0.27	0.25	0.53	0.59
ShaanXi: ΔGDP = -0.55ECT(-1)*** +3.19ΔEXP- 55.80 Δclim***+ 0.04 ΔCT**	0.42	0.24	0.33	0.38
QingHai: ΔGDP = -0.29ECT(-1)*** -1.57ΔFDI+0.09 Δclim	0.27	0.36	0.32	0.35
XinJiang:ΔGDP=-0.20ECT(-1)***-3.82ΔFDI-83.67ΔFDI(-1)***+0.29ΔEXP-0.83ΔEXP(-1)*** -41.51 Δclim*** -13.14 Δclim**+0.02ΔCT***	0.34	0.49	0.53	0.42
GuangXi: ΔGDP = -0.47ECT(-1)*** + 0.04ΔFDI -0.02 ΔEXP - 0.08Δ clim + 0.04 Δclim(-1)* + 0.02ΔCT	0.63	0.74	0.61	0.17

TT represents Tech*Temp. Asterisks *,**, and *** denote significance at 10%, 5%, and 1% critical values, respectively. Figure in ( ) refers to lag. [a]All refer to the *P* value. AC refers to an autocorrelation test based on the LM test. HET denotes heterogeneity test based on the BPG-LM test. NORM represents the normality test based on the Jarque-Bera test, and STAB refers to the stability test based on the Ramsey RESET test

Table 8: Long-run estimates of ARDL of Technology on Economic Growth Model [IV: TEMPERATURE]

West	Sichuan	Chongqing	Guizhou	Guangxi	Shaanxi	Qinghai	Xinjiang
Constant	256.22	354.31	142.28	475.39	306.49	-315.08	94.21
	[0.07]*	[0.06]*	[0.06]*	[0.03]**	[0.02]**	[0.03]**	[0.06]*
FDI	-9.31	6.66	4.58	-6.57	28.26	-41.62***	10.65
	[0.06]**	[0.09]*	[0.06]**	[0.07]*	[0.05]**	[0.04]**	[0.05]**
EXP	5.47	0.56	8.59	8.84	-0.95	-0.19	-0.85
	[0.08]*	[0.01]**	[0.03]**	[0.04]***	[0.09]*	[0.09]*	[0.01]***
clim	-3.47	-7.32	7.93	-7.68	25.30	-33.57	-7.91
	[0.04]**	[0.05]**	[0.06]*	[0.06]**	[0.02]**	[0.07]**	[0.09]*
clim*Tech	2.36	8.01	4.45	6.06	6.01	6.37	7.02
	[0.07]**	[0.03]**	[0.06]**	[0.01]**	[0.06]**	[0.09]**	[0.03]**
Middle	**Shanxi**	**Jilin**	**Anhui**	**Henan**	**Hubei**		
Constant	-1.36	523.08	176.52	-194.13	235.99		
	[0.04]**	[0.03]**	[0.01]***	[0.02]**	[0.04]**		
FDI	9.63	14.75	11.33	0.62	-41.59		
	[0.06]**	[0.08]*	[0.05]***	[0.01]***	[0.04]**		
EXP	-1.42	10.54	5.24	-1.64	14.89		
	[0.05]*	[0.03]**	[0.02]***	[0.05]*	[0.03]**		
clim	-14.12	-8.74	-54.95	-18.58	13.12		
	[0.09]*	[0.08]*	[0.08]*	[0.09]*	[0.07]*		
clim*Tech	7.89	4.09	10.44	6.05	8.05		
	[0.04]**	[0.05]*	[0.02]**	[0.07]*	[0.04]**		

spurs economic growth positively. It is meaningful to implement climate technology to stimulate economy development. The positive effect of climate technology mitigates the negative influence of climate. Climate technology benefits local economic growth, consistent with the conclusion of Lasisi et al. (2022). Each region would benefit positively from using climate technology on GDP.

5. CONCLUSION

This study investigates the influence of climate technology on economy of too-hot, too-cold provinces in China from 1997 to 2022. For this purpose, eighteen provinces were selected based on data access. According to the results, the remote areas in the middle and West could be changed to be livable with technological tools. Advanced econometric methods like unit root tests, bound cointegration tests, Error Correction Model, and ARDL estimation were applied to examine the long-run and short-run associations between the variables of interest. The long-run results indicate that climate technology is a significant tool to moderate the negative impact of climate. This study chooses temperature as a factor to measure climate.

Moreover, the moderating effect of technology is desirable in all regions from East to West. The interaction term clim*Tech (climate and climate technology) shows statistically significant inference, thus justifying the desirable role of climate technology as a climate moderator, showing a desirable impact on dependent variables. Considering these findings and while acknowledging the inherent limitation, future research could adopt a similar approach to investigate various combinations of factors and apply the study to multiple scenarios.

Based on the study findings, various policy implications are also stated. Firstly, governments in different regions should integrate climate objectives within respective technology progress and related policies while achieving sustainable objectives. As a result, sustainable economic development would be achieved with the help of climate technology. Meanwhile, middle and western economies are suggested to improve climate technology skills and transform more climate technologies into sustainable practices.

Secondly, it is widely recommended that provinces communicate economic and technological experiences so local authorities can efficiently utilize different resources in their respective economies. The results consistently suggest that huge positive potential can be revealed in climate technology so far to be explored further. The positive effect of climate technology mainly contributes to economic development in the western and middle regions, compared to the well-developed east regions. The problem in the West is to explore large areas of remote deserts to be livable. So, the following research can concentrate on creating ideal living conditions by utilizing technology in the western provinces. In the eastern region of China, with a suitable climate, substantial progress has already been made in stimulating economic development. However, the middle and western regions are still exploring practical applications of technology to make the local environment livable.

There is a need to boost public funding for research, development, and demonstration (RD&D) related to climate technologies. Making these investments is vital for facilitating improvement in infrastructure technologies. For example, utilizing venture capital to help finance high-risk, high-reward innovations that lead to significant advancements in climate technologies. Also, it is important to start with infrastructure improvements like green roofs, rainwater harvesting systems, and other measures that can enhance urban resilience to extreme climate, reduce natural risks, and protect residents' property. Such infrastructure improvements contribute to better environmental quality, sustainable development and economy growth.

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