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The Growth Nexus: Investigating ICT Infrastructure, Green Energy, and FDI in India's Economy

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Abstract

This study aims to investigate the empirical, long run cointegration and causal relation among ICT infrastructure (fixed telephone subscriptions, mobile cellular subscriptions, and fixed broadband subscriptions), green energy usage, and total FDI in India for the period 2000 to 2023 using ARDL model. In order to find the causality Granger causality test was done. The finding of the study confirms the existence of long term cointegrating relationship among the variable under consideration, with economic growth being elastic to any change in fixed telephone subscription, fixed broadband subscription, renewable electricity consumption and total FDI inflows. Study also showed a bidirectional relationship between green energy usage and economic growth and unidirectional causality between ICT infrastructure and FDI. The findings of the study suggest the policies to enhance the ICT efficiency, increased public private partnership investment decisions in ICT infrastructure segments and to deal with the barriers creating hindrance in promoting green energy usage.

Keywords: Information and Communication Technology (ICT), green energy, FDI, economic growth, ARDL, causality.

1. Introduction

The sufficient provision of infrastructure services is commonly acknowledged as a crucial factor for economic productivity and growth. The empirical investigation of infrastructure's role in economic growth commenced with Aschauer's important study. (1989, 1989, 1989)

The development of the financial sector and advancements in ICT area are largely regarded to be two of the critical factors to the expansion of the economy. The financial sector contributes to economic development in a number of ways, such as effective utilisation of resources for productive endeavours, offering credit and insurance, facilitating savings for a large portion of the populace (Allen et., 2018, Ruiz 2018, Onaolapo 2015).

Studies done by Inklaar et al., 2008, Jorgenson et al., 2011, Jorgenson et al., 2005 and Jorgenson 2001, showed that, in numerous prosperous nations, the role of ICT to the acceleration of economic activity has been definitively demonstrated. By investing in ICT, businesses have been able to boost efficiency and productivity through better production organisation and a significant decrease in the cost of communication and coordination. Both the immediate and long-term impacts of investments in information and communication technology (ICT) on economic growth are well-documented (van Ark, Gupta, & Erumban, 2011). The former includes the enhancement of productivity and growth in the sectors that manufacture ICT goods and services, while the latter benefits from better investment and productivity in sectors that make use of ICT assets.

Studies conducted by Pradhan et al., 2014, Timmer and Van 2005, and Dutta 2001 showed that ICT components can serve as a driver for economic progress through three avenues. Firstly, ICT enhances company efficiency, facilitating an expansion of market reach and product enrichment, so allowing firms to achieve economies of scale and scope. Investigations done by Haftu in 2019, Cordona et al., in 2013, and Nair and Shariffadeen in 2009, showed that the advancement of creative ICT has led to the establishment of new areas, employment creation, along with various network cumulative effects. This indicates that the ICT sector has emerged as a significant source of revenue for numerous governments. Thirdly, ICT is regarded as a crucial development instrument to bridge the socioeconomic gap between the affluent and the impoverished within an economic framework.

Information and communication technology offers an unparalleled chance for a developing country like India to break free of the historical and location constraints it has encountered. This paves the way for India's business and economic operations to match the efficiency of industrialised nations (Tiwari et al., 2022). The nature of global relationships, the accessibility of competitive advantages, and the possibilities for societal and economic advancement have all been significantly influenced by the improvement of the information and communication technology infrastructure. People, businesses, and governments all over the world are now part of a vastly interconnected web thanks to the proliferation of electronic devices and services (Sinha and Sengupta, 2022).

Toffel and Horvath (2004) argue that a less capital-demanding and weightless economy may benefit greatly from a transition from physical to information resources, which would have a favourable influence on energy use and the sustainability of the environment. Although portable electronic gadgets like laptops, tablets, and Liquid Cristal Displays are continually getting smaller and more energy efficient, the rising demand for these devices results in the increase of energy usage of the technology that power them (Heddeghem et al. 2014). Electricity consumption in homes and businesses has increased dramatically over the past 20 years due to the usage of ICT (Ahmed and Ozturk, 2018).

As reported by Enerdata (2018), information and communication technologies (ICTs) presently constitute around 5% to 9% of overall electricity consumption, and their advancement indicates a significant revolution of energy systems, including smart networks, customer management, and decentralised energy exchanges. The growth rate is projected to be between 6% and 9% per annum; at the higher pace, the proportion of ICTs could reach 20% of the total use of electricity by 2030.

FDI is capable to augment the absorptive ability of Information and Communication Technology, yielding favourable results in growth of the nation. The influence of FDI on growth dynamics may fluctuate based on the number of people using information and communication technologies, which can vary across developing and industrialised nations (Vu 2011, 2019)

Through complimentary mechanisms, FDI and ICT are crucial for economic development. While FDI advances capital, technology, and management, ICT supports knowledge distribution, connectivity, and economic efficiency. Through their interaction, financial inclusion, skill development, and productivity rise, so improving competitiveness and globalisation. ICT helps to promote innovation, lower transaction costs, and improve infrastructure so that FDI has favourable spill-over benefits. Particularly in the digital sector, FDI speeds ICT adoption and stimulates an innovative cycle of growth.

The investigation examines whether economic growth is primarily driven by investment in ICT infrastructure, considering the impact of renewable energy usage, or if the relationship is reversed, utilising the Granger Causality Test. Furthermore, we employed the Auto-Regressive Distributed Lag (ARDL) model and the Error Correction Model to analyse the long-term relationships and short-term dynamics of foreign direct investment (FDI) in ICT infrastructure and economic growth to derive fresh insights. This study enhances previous research and contributes additional value to the existing literature.

2. Literature Review

Existing literature review shows that vast number of studies have been done on examining the relationship between ICT and economic growth, between FDI and Economic growth, between ICT and energy consumption, and between ICT and FDI. To the best of the researchers knowledge linking the effect of FDI and renewable energy with the impact of ICT infrastructure on economic growth will add value to the existing literature.

The investigation between ICT and economic growth was initiated in 1960s in the USA. There exists a positive correlation between Information and Communication technology and economic growth. However, the long run relationship between them is unknown (Jipp, 1963; Hardy 1980; Saunders et al., 1983). From 1995 to 2010, researchers examined how internet usage affected labour productivity using panel data from 108 countries. A robust empirical study indicated a significant correlation between internet use and worker output. (Najarzadah et al. 2014). Elgin (2013) conducted an examination of the impact of the internet on the shadow economy, utilising panel data from one hundred and fifty two countries spanning the years 1999 to 2007. He discovered a significant correlation between the usage of internet and the shadow economy, which subsequently impacts growth of the nation. Czernich (2014) conducted an investigation for 25 OECD countries

spanning the years 1996 to 2007 and found that ICT infrastructure namely broadband penetration positively causes an increase in the GDP. Majeed and Ayub (2018) found that in 149 countries during the period 1980 to 2015, ICT impact economic growth. Haftu (2019) conducted an investigation into the impact of telecom on the GDP of 40 sub-Saharan African countries, utilising panel data from the year 2006 to 2015. The author determined that the average income of the individuals of the region is likely to positively influence the growth of ICT, particularly in terms of mobile phone subscriptions during the specified timeframe. Studies done by Hussian et al., in 20124, Tule et al., in 2014, Awad and Albaity in 2022,, Pradhan et al., in 2020, Ghosh in 2016, Dvornik and Sabolik in 2007 and Wang and Chien in 2007 have found that it the ICT which granger causes economic growth. There are some studies which have also it is the economic growth of a nation which granger causes its ITC infrastructure (Sarangi and Pradhan Sarangi and Pradhan 2020; Pradhan et al. 2016; Mehmood and Siddiqui 2013; Donner and Tellez 2008; Dutta 2001).

Fambeu & Yomi (2024) studied the impact of ICT on the renewable energy consumption of 45 African countries by taking the data from the year 2000 to the year 2019. Their study showed that both the ICT and usage of internet increases the renewable energy usage. Islam et al. (2024) examined the correlations between remittance outflow and environmental quality in Saudi Arabia, while taken into consideration the information and communication technology, environmental innovation, and energy usage. It utilises annual data from 1990 to 2020 and implements the NARDL and ARDL methodologies. Yu, Zhang & Chong (2022) analyses the correlations among ICT financial development, and renewable energy usage utilising data from a panel of 35 nations spanning 1996 to 2018, concluding that both ICT and financial progress facilitate renewable energy usage. Bakry et al. (2023) examines the impact of ICT on economic development and energy usage across a panel of 27 nations from 1990 to 2019 and It was determined that both positive and negative shocks to ICT in these countries elevate energy consumption, signifying the presence of the rebound effect in these nations. Ahmed and Ozturk (2018) examined that the augmented utilisation of advanced technology could elevate energy consumption in the long term by 0.4 per cent in China. The study period spanned from 1985 to 2013, employing the autoregressive distributed lag (ARDL) model as its methodology. Ishida (2015) conducted an analysis for Japan spanning the years 1980 to 2010 to assess the long-term association among ICT, energy use, and economic growth. And found that there is a decline in energy usage through the utilisation of ICT investments. Studies have been conducted by Salahuddin and Alam in 2015, Sadorsky in 2012, Ropke et al., in 2010 and Cho et al., in 2007 to examine the impact of ICTs on energy needs.

Wang and Rukh (2021) examines the impact of ICT infrastructure accessibility on FDI inflow in D8 nations, utilising panel data from 1997 to 2018. The study concluded that ICT infrastructure has a favourable and significant impact on FDI inflows. Belloumi & Touati (2022) conducted a study that looked at 15 Arab countries from 1995 to 2019, researchers looked at the interplay between FDI inflows, ICT indicators, and economic growth. They discovered that ICT indicators had a positive effect on FDI inflows over the long term in those countries. Fakhar (2016) studied the impact of information and communication technology (ICT) investments on foreign direct investment (FDI) in Egypt from 1995 to 2013. The findings indicate a weak positive correlation between the two variables throughout the study's estimation period. Zhang & Wang (2024) looks at how controlling corruption, building up ICT infrastructure, and letting information flow freely all affect China's Outward Foreign Direct Investment (OFDI). They looks at 182 countries from 2005 to 2020 and finds that better measures to stop corruption and more advanced ICT infrastructure in those countries greatly boost China's OFDI. Yin & Cho (2021) investigated the connection between the internet and economic variables in Asian nations from 1997 to 2017. The findings of this study showed that FDI and internet use are causally related in South Asia, but only in one way in East Asia, while in West Asia, the link is unidirectional. Numerous empirical studies indicate a positive and significant relationship between ICT and FDI in both developing and developed nations (Louis et al., 2012; Leitao & Baptista, 2011; Chandra, 2010; Heshamti & Addison, 2003).

3. Data and Methodology

3.1 Data

This study employed annual data of GDP at constant prices (2015 US$) as a proxy for economic growth, renewable electricity consumption (Include Hydro, Nuclear, and other renewable sources electricity from Utilities in GWh) as a proxy for green energym, ICT infrastructure (fixed telephone subscriptions, mobile cellular subscriptions, and fixed broadband subscriptions) and FDI inflow. Data for the mentioned variables have been collected from World Bank data, Stastista and various issues of RBI handbook of statistics for the period of 2000 to 2023.

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3.2 Methodology

This study examined the long-run relationship using Autoregressive Distributed Lag (ARDL) bound test approach suggested by Pesaran et al. (2004). Following growth model has been considered for this study considering the earlier studies (Salahuddin & Alam 2015; Ozturk & Mulali 2015; Sadorsky 2012)

$$LnGDP_t = a_0 + a_2 LnFTU_t + a_3 LnMCS_t + a_4 LnFBS_t + a_5 LnEC_t + a_6 LnFDI_t + \cup_t$$

---------- eq. (1)

Equation (1) is a growth model and in this model GDP in India is determined, fixed telephone subscriptions (FTU), mobile cellular subscriptions (MCS), fixed broadband subscriptions (FBS), renewable electricity consumption (EC) and Total FDI inflow (FDI).

To test the cointegration, following equation can be used.

$$\Delta \ln GDP_t = \beta_{01} + \sum_{i=1}^{n} \varphi_G \Delta \ln GDP_{t-i} + \sum_{i=0}^{n} \varphi_T \Delta \ln FTU_{t-i} + \sum_{i=0}^{n} \varphi_E \Delta \ln MCS_{t-i} + \sum_{i=0}^{n} \varphi_N \Delta \ln FBS_{t-i} + \sum_{i=0}^{n} \varphi_{CR} \Delta \ln EC_{t-i} + \sum_{i=0}^{n} \varphi_F \Delta \ln FDI_{t-i} + \lambda_1 \ln GDP_{t-1} + \lambda_3 \ln FTU_{t-1} + \lambda_4 \ln MCS_{t-1} + \lambda_5 \ln FBS_{t-1} + \lambda_6 \ln EC_{t-1} + \lambda_7 \ln FDI_{t-1} + \varepsilon_t$$

---------- eq. (2)

4. Analysis and discussion

4.1 Stationary Results

The bound testing method should be utilised exclusively for data sets that are either stationary at level or at first difference. Consequently, it is essential to conduct unit root testing. This study conducted the Augmented Dickey-Fuller and Phillips-Perron (PP) unit root tests (Table 1.). Results of both the tests showed that MCS was stationary at I (0) level, therefore its first difference was not carried out. All the remaining variables under study were stationary at I (1). These results showed that none of the variable taken under consideration were I (2). Therefore next step will be to test the cointegration or the long run relationship among the variables.

Table 1. Results of Unit root tests (P-values)

Variables	*ADF*		*PP*	
	I (0)	I (1)	I (0)	I (1)
LnGDP	0.8391	0.0022*	0.8237	0.0023*
LnFTU	0.4661	0.0800***	0.6952	0.0800***
LnMCS	0.0017*	--	0.0000*	--
LnFBS	0.0097	0.0304**	0.8959	0.0307**
LnEC	0.7158	0.0002*	0.1937	0.0053*
LnFDI	0.3799	0.0160*	0.8865	0.0160*

Source: Author's Calculation
Note: *, **, and *** represents statistical significance at 1%, 5% and 10% respectively.

4.2 Cointegration Results

Table 2. represents the F-bound statistics for cointegration having the null hypothesis of no level relationship. In order to have the existence of long term cointegration relationship, the value of F-statistics should be more than the critical value of I (1). If it is below the I (0), then there will be no cointegration and if the F-statistics lies between order 0 and 1 than the results will be inconclusive.

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Table 2. F- Bounds Test

Test Statistic	*Value*	*Significance (%)*	*I(0)*	*I(1)*
F-statistic	13.04802	10%	2.26	3.35
K	5	5%	2.62	3.79
		2.5%	2.96	4.18
		1%	3.41	4.68

Source: Author's Calculation

Following AIC criteria and consideration of GDP as the dependent variable yields an F-statistic of 14.04803, above the I(1) critical value of 4.68 at the 1% significance level. This indicates that the variables are in fact cointegrating with one another.

After examining the presence of cointegrating relationship, the next step is to examine the long-term and short-term effects of the independent factors on the dependent variable. Table 3. Represents the estimated long run coefficients using ARDL model and Table 4. Represents the estimated short run coefficients. In both the cases GDP as taken as dependent variable. In the long run it has been found that economic growth in India is elastic to the changes in ICT infrastructure in Indian economy measured through FTU and FBS, FDI inflow and renewable energy consumption. However, it is inelastic to the changes in MCS in the long run. Moreover, it was found that there will be negative impact of 0.5 percent on the economic growth 1 percent change in FBS. This negative impact can be attributed to the technological obsolescence, misallocation or diversion of funds from new technological equipments to old and outdated equipments and the dependency on the outdated fixed line communication hampering efficiency and productivity. In addition to that, it was also found that with 1 percent increase in FTU there will be a positive and significant impact of 0.9 percent on economic growth in India.

Table 3. Estimated long run coefficients using ARDL model

ARDL(1, 2, 2, 1, 1, 2), selected based on Akaike info criterion GDP is Dependent Variable				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
LEC	0.824755	0.101800	8.101700	0.0001*
LFBS	-0.577798	0.118623	-4.870860	0.0018*
LFTU	0.924789	0.243754	3.793946	0.0068*
LMCS	0.078684	0.078573	1.001423	0.3500
LFDI	0.554531	0.115214	4.813066	0.0019*

Source: Author's Calculation
Note: *, **, and *** represents statistical significance at 1%, 5% and 10% respectively

Considering the short term coefficients, it can be seen that coefficient of lagged value of MCS is negative and insignificant. However the coefficients of lagged values of FBS is positive and significant. Hence, the study found the mixed effects of ICT infrastructure on Indian economy in the short run.

Table 4. Estimated short run coefficients using ARDL model

ARDL(1, 2, 2, 1, 1, 2), selected based on Akaike info criterion GDP is Dependent Variable				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
LGDP(-1)*	0.360583	0.090856	3.968727	0.0054*
LEC(-1)	-0.297392	0.051460	-5.779086	0.0007*
LFBS(-1)	0.208344	0.032939	6.325157	0.0004*
LFTU(-1)	-0.333463	0.056423	-5.910012	0.0006*
LMCS(-1)	-0.028372	0.028817	-0.984578	0.3576
LFDI(-1)	-0.199954	0.027203	-7.350570	0.0002*
D(LEC)	-0.178480	0.034458	-5.179717	0.0013*
D(LEC(-1))	0.080726	0.035457	2.276724	0.0569**
D(LFBS)	0.015519	0.020964	0.740252	0.4832
D(LFBS(-1))	0.054656	0.016236	3.366390	0.0120*

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D(LFTU)	0.800843	0.099320	8.063289	0.0001*
D(LMCS)	0.127946	0.060282	2.122461	0.0715***
D(LFDI)	-0.092378	0.016333	-5.655831	0.0008*
D(LFDI(-1))	0.043931	0.017520	2.507476	0.0405**

Source: Author's Calculation
Note: *, **, and *** represents statistical significance at 1%, 5% and 10% respectively

Diagnostic tests namely Breusch-Godfrey test for serial correlation (Table 5) has been done. Breusch-Godfrey-Pagan to check the absence of Heteroskedasticity (Table 5) has also been done. In order to check the stability of the model, CUSUM (Fig 1) and CUSUM of square test (Fig 2) were done. The results showed that data under considerations is free from serial correlation and heteroskedasticity. In addition to that CUSUM and CUSUM square test reveal that the model is stable at 5% significance level.

Table 5. Diagnostic tests of ARDL model

Test Statistics	*Results*
Serial Correlation	7.5176
	[0.0311]
Heteroskedasticity	1.0822
	[0.4826]

Source: Author's Calculation

Fig 1. Cusum test

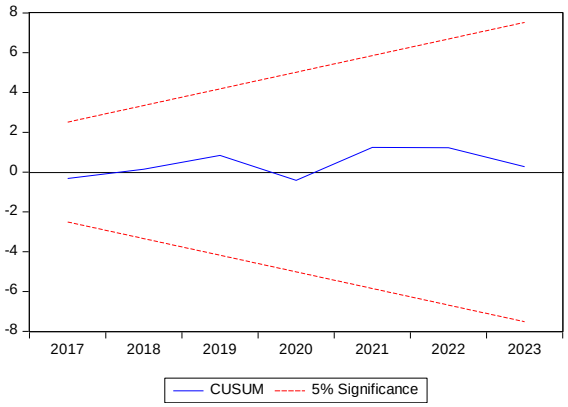
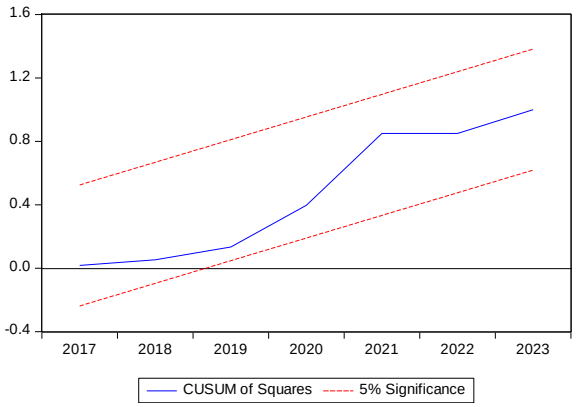


Fig 2. Cusum test



4.3 Causality Results

The Granger causality test has been conducted to check the direction of the causality among the variables under consideration (Table 6). Considering the causality between ICT infrastructure (FBS, FTU, and MCS) and economic growth, results showed the existence of unidirectional causality between GDP and FTU, and between GDP and MCS. It has been found from the results that it is the GDP which granger causes FTU and MCS component of ICT infrastructure. The study also found the existence the bidirectional causality between renewable electricity consumption and economic growth.

Table 6. Granger Causality among GDP, FTU, MCS, FBS, EC, and FDI

Null Hypothesis:	*F-Statistic*	*Prob.*
LEC ⇏ LGDP	3.46224	0.078***
LGDP ⇏ LEC	6.72481	0.017*
LFBS ⇏LGDP	1.15586	0.295
LGDP ⇏ LFBS	0.18917	0.668
LFTU ⇏ LGDP	1.78944	0.196
LGDP ⇏ LFTU	3.22050	0.088**
LMCS ⇏ LGDP	1.05468	0.317

LGDP ⇏ LMCS	6.19809	0.022**
LFDI ⇏ LGDP	0.00015	0.991
LGDP ⇏ LFDI	6.35956	0.034**
LFBS ⇏ LEC	0.01228	0.913
LEC ⇏ LFBS	7.07635	0.056**
LFTU ⇏ LEC	2.01290	0.171
LEC ⇏ LFTU	1.96408	0.176
LMCS ⇏ LEC	1.9E-05	0.997
LEC ⇏ LMCS	2.93756	0.032**
LFDI ⇏ LEC	1.88772	0.185
LEC ⇏ LFDI	0.40414	0.532
LFTU ⇏ LFBS	4.51617	0.046**
LFBS ⇏ LFTU	9.78721	0.005*
LMCS ⇏ LFBS	7.08735	0.015*
LFBS ⇏ LMCS	0.57709	0.456
LFDI ⇏ LFBS	0.95776	0.339
LFBS ⇏ LFDI	9.07484	0.007*
LMCS ⇏ LFTU	10.2249	0.005*
LFTU ⇏ LMCS	12.6752	0.002*
LFDI ⇏ LFTU	6.25956	0.021**
LFTU ⇏ LFDI	0.16496	0.689
LFDI ⇏ LMCS	0.66374	0.425
LMCS ⇏ LFDI	5.13590	0.035**

Source: Author's Calculation
Note: *, **, and *** represents statistical significance at 1%, 5% and 10% respectively
⇏ represents "does not granger cause"

Considering the FDI and ICT infrastructure components, it has been found from the results that a unidirectional causation exists between FBS and FDI at 1% significance level, between FDI and FTU at 5% significance level and FDI and MCS at 5% significance level. It is the FBS and MCS which granger causes FDI and on the other hand it the FDI which granger causes FTU. Results also showed the existence of unidirectional causality between renewable electricity consumption and FBS and between renewable electricity consumption and MCS, running from renewable electricity consumption towards FBS and MCS.

5. Conclusion and Policy Suggestions

The study examined the nexus between economic growth, ICT infrastructure, renewable electricity consumption, and total FDI inflows in India for the period 2000 to 2023 using ARDL approach. The results confirms the existence of a long term cointegrating relation among the variables under consideration, with economic growth being elastic to any change in fixed telephone subscription, fixed broadband subscription, renewable electricity consumption and total FDI inflows. Contrarily, it has been found that mobile cellular subscriptions have an inelastic impact on economic growth in the long run. On one hand rise in FTU positively affects economic growth and on the other hand, a rise in FBS negatively impacts economic growth.

Considering short run, the study found the existence of mixed effects of ICT infrastructure on economic growth, with the lagged values of FBS having a positive and significant impact and MCS having a negative and insignificant impact. The study also reveals a unidirectional causality running from GDP towards FTU and MCS, showing that rise in the economic growth leads to advancements in the components of ICT infrastructure. In addition to that, a bidirectional causality has also been found between renewable energy consumption and economic growth. Furthermore, it was also found that FBS and MCS granger causes total FDI inflow in India, and FDI granger causes FTU.

As the study showed a strong positive and significant impact of FTU on economic growth, the policymakers should take necessary measures so that investment in ICT infrastructure could be enhanced. Encouraging the foreign investors by giving

them incentive schemes, tax breaks subsidies and ease of doing business, so that the braoadband and telecom networks enhances the ICT infrastructure role in the development of the economy. In order to achieve the balanced broadband and mobile subscription growth, focus needs to be given for the enhancement of the quality, and affordability of these services. Public-Private partnerships in this area could be increased so that these services can reach even to the remote locations.

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