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The impact of digitalization on food security in G20 countries: An empirical assessment

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ABSTRACT
This study assesses the impact of digitalization on food security (FS) and its dimensions in G20 countries. Descriptive statistical techniques are applied to create a food security index (FSI) and a digital development index (DDI). The FSI is considered as a combination of its dimensions, and the DDI is the integration of 16 indicators that foster appropriate digital development (DD). Log-linear regression models are introduced to examine the coefficient of DDI with FSI and specific variables. The study employs country-wise balanced panel data from 2010 to 2022. It reports significant variation in DD and FS across G20 countries. DD has a positive and statistically significant impact on FS and its other drivers. Furthermore, FS and its four dimensions have positive and bi-directional relationships with DD. FS and its other drivers, except for food utilization, are positively associated with forest area. Protection of ecosystem services is necessary to increase FS. Environmental technologies are also found to positively influence FS. Gross domestic savings appear useful for increasing FS. Environmental technologies, foreign direct investment, and gross savings show a positive impact on DD. Moreover, all dimensions of FS are favorable for promoting DD. The findings provide multiple policy implications for improving FS and DD in G20 countries.

Contribution/Originality: This study is the first to create the Food Security Index (FSI) and the Digital Development Index (DDI), providing a comparative analysis of food security and digital development among G20 countries from 2010 to 2022. The causal relationship between FSI and its dimensions with DDI is analyzed using log-linear regression models.

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1. INTRODUCTION

Nowadays, people are using different digital devices, tools, and platforms to achieve their expected tasks in various sectors. Digitalization is a transformation of various forms of information, data, text, images, materials, news, and others into digital formats (Benfica et al., 2023). It is a state in which people can apply digital technology, information & communication technology (ICT), and other digital devices to accomplish their desired tasks. Digitalization assists in achieving their multiple purposes in education, health, market, business, medical, finance, political, media, marketing, and transport sectors (Lee, Zeng, & Luo, 2023). It helps to increase the transformation of knowledge, skills, and scientific processes in digital format. Digital formats of information bring multiple benefits for improving the livelihood security of humanity. Improving advertisement through social media, online transaction of money, online communication of consumers and producers, e-business, and sharing information through online platforms are a few examples of digitalization and digital development. Digital technologies (DTs) like mobile apps, computers, and the internet are helping people to increase their engagement in online activities and public services (World Bank Group, 2019). ICT is used to increase communication among people across the globe. Consequently, digitalization and DTs are transporting multiple benefits to large communities.

Moreover, digitalization helps to increase online business, jobs, and advertisement of new products and develops entrepreneurship and business ecosystems. It, thus, is developing an important platform for foreign trade. Thereafter, digitalization is favorable for the creation of new markets and infrastructural development, and increases a competitive business ecosystem. It increases the availability of scientific information across the globe. Hence, digitalization is helping to increase technological upgradation as per the current needs of people, businessmen, and manufacturing industries. Digital technologies (DTs) enhance business processes with innovative models (Oborin, 2019). Digitalization is creating a smooth path for technology transfer and commercialization across countries. Accordingly, the manufacturing sector can reduce its use of ecosystem services and natural resources by increasing its dependency on digital technologies (DTs).

DTs bring alternative ways to minimize the cost of production (World Bank Group, 2019). Accordingly, global countries are creating digital platforms and transforming towards digitalization to receive competitive gains in production activities. Digitalization seems highly effective in accomplishing various objectives of common people, farmers, businessmen, researchers, scientists, government, and producers in diversified areas. In the production sector, digitalization helps to increase productivity. Although, it is also reported that employment opportunities have declined due to digitalization. Despite that, multiple studies note that economic development and growth could be increased due to the commencement of digital infrastructure in most countries, especially in the European Union (e.g., Belgium, Denmark, Ireland).

Moreover, digitalization is working as a significant driver to increase health security through improving medical facilities. Digitalization, for instance, could provide significant benefits to patients, medical doctors, academicians, and educationists during COVID-19. Digitalization is providing better economic returns to farmers, businessmen, online traders, consumers, and producers (Benfica et al., 2023; Lee et al., 2023). Thus, digitalization may support reducing poverty and improving health and well-being (Vărzaru, 2024).

Agriculture and food sectors receive significant benefits from digital technologies (DTs) (Ferguson et al., 2024). These technologies enhance food security and nutritional security by improving foodgrain production, yields, and food quality (Ferguson et al., 2024). For instance, Big Data analysis can be effective in making future predictions of climate change impacts on cultivation (Herawati, Yuniningsih, & Dwimawanti, 2023; Vărzaru, 2024). Artificial intelligence (AI) brings revolution in the agricultural sector (Talaviya, Shah, Patel, Yagnik, & Shah, 2020). DTs can be used for weather forecasting and disaster response (Herawati et al., 2023). Many digital devices are also helpful in perceiving the forecasting of productivity of various crops in the presence of changing socioeconomic development and demographic patterns, ecosystem services, natural resources, and climatic factors.

Food systems and their allied sectors contribute around 21-37% of GHG emissions in the environment (Anderson & Sandin, 2022). Hence, the application of digital technologies (DTs) in food sectors would be a revolution in reducing CO_2 emissions and increasing environmental sustainability. Digital tools and DTs are vital for enhancing farm productivity by improving the quality of environmental and ecological services (Amirova, Safiullin, Bakhareva, & Sakhbieva, 2022; Chandio, Amin, Khan, Rehman, & Memon, 2024; Prause, Hackfort, & Lindgren, 2021). Further, it assists in increasing sustainable development by improving the sustainability of all inputs in the agriculture sector. Thus, it is expected that digitalization will improve the food value chain (Benfica et al., 2023; World Bank Group, 2019). While it is observed a complex association between digital transformation and FS (Vărzaru, 2024). Digitalization is providing multiple benefits to the agricultural sector (Chandio et al., 2024). It helps to increase farmers' understanding of selecting a suitable crop for cultivation in a specific season. DTs are beneficial for making future predictions of climatic events, which would suggest taking preventive actions in farming.

Moreover, digital technologies (DTs) are increasing the agricultural marketing-related information among farmers at low cost (World Bank Group, 2019). It also creates new agri-business opportunities. Thus, it is positive to increase sustainable agricultural development (SAD). Consequently, digitalization and DTs are worthwhile for improving most indicators, which nurture a suitable platform for attaining SDGs (Vărzaru, 2024). Accordingly, digitalization would assist in increasing FS. Preceding theoretical literature reveals that digitalization, digital technologies (DTs), digital development (DD), and digital platforms help to enhance agricultural productivity. Farmers are gaining innovative ideas, cultivation methods, and techniques to increase crop productivity due to DD. DD helps to increase agricultural sustainability in the presence of climate change and environmental degradation. Subsequently, DD is aiding in increasing social and economic change. Furthermore, DD is valuable for increasing the demand and supply management of agricultural commodities in the market. DD, thus, would positively contribute to increasing food security (FS) and its components.

Although existing studies could not examine the clear association between DD and FS, there is a requirement to observe the contribution of digitalization in improving FS in global countries. Therefore, countries worldwide should be more serious about adopting effective policies to increase the usability of digitalization in the agricultural and food sectors.

Hence, this study develops an empirical model for assessing the causal association of DD with FS in G20 countries. The present research is an attempt to answer the following questions:

- What is the comparative performance of FS and DD in G20 countries?
- Why does there exist diversity in digitalization and FS in G20 countries?

- How does digitalization help to increase FS?
- What is the process to increase FS through digitalization?
- How can G20 countries improve their strength in digitalization and FS in the future?
- Which components of FS will be beneficial from digitalization?
- How would digitalization be positive in increasing FS in G20 countries?

This study has the following objectives:

- To create a food security index (FSI) as a composition of its key drivers and a digital development index (DDI) as an integration of 16 variables in G20 countries.
- To examine the impact of digitalization on FS in G20 countries and vice versa.
- To provide policy proposals for improving FS and DD in G20 countries..

2. REVIEW OF LITERATURE

2.1. Importance and Perspectives of Food Security

The theoretical foundation of food security (FS) is very old in academic research, Hoddinott and Yohannes (2002). Food is an essential component for increasing economic construction and development, as it maintains the physical and mental health of all people (Wang, Li, & Hu, 2023). Accordingly, FS helps to increase participation of people in social and economic activities, and it is important to increase national security (Yao & Fu, 2025). To ensure FS is the most indispensable due to rising population, increasing loss of food and natural resources (Vărzaru, 2024; World Bank Group, 2019). Around 600 million people fall seriously ill due to eating contaminated food, and 420,000 die annually worldwide due to the unavailability of food (Konfo et al., 2023). Around 821 million people are undernourished worldwide (Gouvea, Kapelianis, Li, & Terra, 2022). Undernutrition is also responsible for an increase of 45% in child deaths globally (World Health Organization (WHO), 2023). The quality of food products, including milk, dairy products, and meat products, is decreasing due to the overutilization of fertilizers and chemicals in cultivation (Zorić, Marić, Đurković-Marić, & Vukmirović, 2023).

Lee et al. (2023) reported that 49 million people would be in trap of extreme poverty due to lack of food at global level (Lee et al., 2023). Around 1/3rd of food production is wasted in the world. Thus, it is necessary to reduce wasted food to increase FS (Anderson & Sandin, 2022; Mantravadi & Srai, 2023; Talaviya et al., 2020; Zorić et al., 2023). Wasted food contributes to increased food insecurity in urban areas (Mantravadi & Srai, 2023). While appropriate management of food systems is an essential driver to reduce poverty, hunger, and malnutrition (Benfica et al., 2023).

2.2. Components and Determinants of Food Security

Primarily, food security (FS) has four dimensions (Gouvea et al., 2022; World Bank Group (WBG), 2025). These components are divided as physical availability of food, access to food, food utilization and food stability (World Bank Group (WBG), 2025). Hence, a single variable cannot improve all dimensions of FS. Soil fertility and agricultural inputs are crucial determinants for improving foodgrain production and FS (Zakari, Ying, & Song, 2014). While agricultural sustainability cannot be achieved without increasing sustainability in ecosystem services and natural resources, FS is negatively impacted due to increasing water scarcity (Zou & Guo, 2015). Air and water pollution have a negative impact on FS. Hence, these also have a vital impact on FS. Thereupon, family size, gender ratio, literacy rate, occupation, source of income, physical assets, livestock assets, financial capability, etc., are micro-level indicators that have crucial implications on FS (Harris-Fry et al., 2015; Zakari et al., 2014). Freedom of women and their literacy rates are positive factors in ensuring food security and nutritional security of family members. Food consumption expenditure (FCE) determines food security at the micro level (Alexandri, Luca, & Kevorchian, 2015). While FCE would improve as income, purchasing power, and employment opportunities for the people increase. Thus, financial support for farmers and the creation of jobs for people are essential to increase FS (Zou & Guo, 2015).

Poverty, income inequality, urbanization, inflation, crime, government policies towards agricultural and rural development, employment opportunities, FDI, agri-business development, food production, infrastructural development, monetary and fiscal policies, and appropriate marketing determine FS at the macro level (Alexandri et al., 2015; Applanaidu, Bakar, & Baharudin, 2014; Gouvea et al., 2022; Lee et al., 2023; Wahab, Applanaidu, & Bakar, 2015; Ye et al., 2013; Zakari et al., 2014). Poverty and income inequality have caused a reduction in the food distribution pattern. Extensive urbanization has led to a diminished cropped area under food grains. Inflation negatively impacts the purchasing power of people to acquire food from the market. Increasing food prices are reducing food security (FS) (Gouvea et al., 2022). Black marketing of products increases crime in society. Moreover, FS is adversely affected due to the redistribution of land resources in China (Zou & Guo, 2015). Food supply chain efficiency is helpful to ensure food security in urban areas (Mantravadi & Srai, 2023). Thus, improving supply chains would also reduce post-harvest loss and increase food distribution channels (World Bank Group (WBG), 2025).

Land ownership shows a significant impact on FS (Harris-Fry et al., 2015). Agricultural cooperative societies and agricultural research institutions (ARIs) play an active role in improving food security. ARIs discover, invent, and develop new varieties of seed, advance mechanisms of farming, and help the farming community adopt advanced cultivation techniques. Thus, factors affecting food security can be divided according to their nature and contribution to agricultural and environmental development. Food security is also divided into multiple components such as production, accessibility, affordability, distribution, utilization, and quality (Mantravadi & Srai, 2023; Zorić et al., 2023).

2.3. Agricultural and Food Security

Agriculture is a sole source of food security (FS). While the growth of the agricultural sector is vulnerable due to rising population and decreasing freshwater resources (Talaviya et al., 2020). The progress of this sector is adversely affected due to low irrigation facilities and an increase in temperature (Talaviya et al., 2020). It is universally accepted that food security (FS) does not depend primarily on agricultural production. Most scholars have given high priority to increasing agricultural development to enhance FS. Global countries are emphasizing agricultural sustainability to ensure FS. However, the agricultural sector faces enormous pressure due to rising demand for food, fiber, and clean energy (Mondejar et al., 2021). While the growth of the agricultural sector depends on the social, economic, and financial structure of farmers, technological skills and literacy rates of farmers are positive factors for improving agricultural development. Farm management practices, high-yielding varieties of seed, fertilizer, and irrigation facilities are also useful inputs for the agricultural sector. Hence, the mentioned variables have a vital implication on FS.

2.4. Adaptation and Mitigation Strategies, and Food Security

Climatic and geographical conditions play a crucial role in enhancing FS. At present, climate change has had a negative impact on the agricultural sector (Gouvea et al., 2022). It is also expected that climate change will be responsible for pushing 100 million people into extreme poverty by 2030 through declines in agricultural production and food security (World Bank Group, 2019). Climate change, thus, is the biggest challenge for the global community to ensure FS (Gouvea et al., 2022; Raheem, 2020). The use of digital technologies (DTs) is helping to increase farmers' understanding to adopt adaptation strategies in the farming sector (Vărzaru, 2024). Thus, DTs are nurturing an effective ecosystem for the agri-food sector to fight against climate change (Vărzaru, 2024). Moreover, digitalization and DTs are working as revolutionary tools to increase environmental sustainability through reducing GHGs and CO_2 emissions. Digital platforms resolve different issues related to climate, environment, and economic situations (Ferguson et al., 2024). Climate change also increases agricultural pests and insects (Zakari et al., 2014). Occurrence of floods and drought lead to decrease FS (Badolo & Kinda, 2015; Mondejar et al., 2021; Zakari et al., 2014). Therefore, the farming community is applying several adaptation and mitigation practices in the farming sector. Thus, adaptation and mitigation approaches are crucial tools to enhance food security. Thereupon, digital development and digital technologies (DTs) are important to provide solutions to address the issues related to the mentioned problems in cultivation.

2.5. Technological Development and Food Security

Moreover, there are several factors that determine the FS in the era of globalization, digitalization, technological change, innovation, and technology transfer and commercialization (Ye et al., 2013). Agriculture sector is using innovative technologies due to appropriate technology transfer. Application of technologies in the agricultural sector is reported to be effective and favorable to increase FS. Use of technology would be positive to improve yield and market structure (Amirova et al., 2022; Anderson & Sandin, 2022). Technology can be useful to increase food quality, increase the income of farmers, and improve their living conditions (Lioutas, Charatsari, & De Rosa, 2021). Gouvea et al. (2022) noticed the positive impact of technology on global food security in 106 countries.

2.6. Digital Innovation and Food Security

Digital innovation supports increasing the digital transformation of the lives of common people (Aboagye-Darko & Mkhize, 2025; Benfica et al., 2023). It is apparent that digital innovation has brought significant changes in most sectors to improve their productivity, production, and efficiency (Konfo et al., 2023). Moreover, digital innovation and e-commerce would be effective in increasing a healthy food system (Mantravadi & Srai, 2023). Hence, digital innovation is found suitable for improving FS (Aboagye-Darko & Mkhize, 2025). ICT is a digital innovation that produces a positive impact on global food security (Gouvea et al., 2022). Chandio et al. (2024) opined that ICT has a greater impact on the agricultural production sector in the SAARC region.

2.7. Digital Technologies and Food Security

Food sector should adopt digital technologies (DTs) to increase FS (Raheem, 2020). Most DTs, like remote sensors, help in monitoring crop, soil moisture, and environmental conditions for further improving crop production (Benfica et al., 2023; Vărzaru, 2024). Hence, DTs are creating new approaches for improving FS (Yao & Fu, 2025). Mantravadi and Srai (2023) examined the importance of DTs for improving accessibility of healthy food and waste reduction in the food sector. Thus, at present, FS is linked with the modernization and digitalization of the food production system (Abdullayev et al., 2023). Access to social media is improving the dissemination of knowledge across farmers (Harris-Fry et al., 2015; Vărzaru, 2024). Mobile phones and the internet have a conducive impact on grain production (Lee et al., 2023). The Internet of Things helps to increase food production in a sustainable way (Mondejar et al., 2021). Yao and Fu (2025) investigated the impact of DTs on FS in China. Prause et al. (2021) examined the role of DTs for changing the food system. DTs are increasing farmers' understanding to be better decision-makers in the agricultural sector (Benfica et al., 2023). It would also improve resource management and enhance the livelihood security of farming communities worldwide (Mondejar et al., 2021). Mobile technologies are helping farmers to increase better accessibility to seed, fertilizer, food production, and pest control in cultivation (Lee et al., 2023). Ferguson et al. (2024) examined the role of digital agricultural technologies in FS in Odisha, India. It noted a significant implication of DTs on FS. DTs are helping small-scale farmers to increase the local food system (Ferguson et al., 2024). Environmental sustainability in the food system can be improved through DTs (Benfica et al., 2023; World Bank Group, 2019). Benfica et al. (2023) highlighted the role of DTs in promoting food and nutritional security. It also emphasized that DTs such as remote sensing, artificial intelligence, and digital finance help increase the decisionmaking capacity of farmers and traders. The use of artificial intelligence aids in enhancing food production and food security in the era of a rising population and climate change (Talaviya et al., 2020).

2.8. Digital Transformation and Food Security

Information communication develops an appropriate platform for digital transformation. FS improves as the use of IT increases (Amirova et al., 2022). Digital transformation of the food industry would lead to increased FS (Yao & Fu, 2025). Herawati et al. (2023) explored the impact of digital transformation on FS in Indonesia. It noted a positive trend in FS and the food sector due to digital transformation. Food industries are using digital transformation to increase FS (Dehghani, Popova, & Gheitanchi, 2022). Furthermore, digital transformation would also improve the efficiency and productivity of the food sector for improving FS (Vărzaru, 2024). Accordingly, it explained the significance of blockchain cloud technologies in various players of the food system, such as farmers, food suppliers, and investors. Blockchain cloud helps to increase efficiency and transparency in the food sector. Oborin (2019) observed the role of digitization in the industries for improving FS in the Perm region. (Vărzaru, 2024) noticed that digital transformation is useful to boost FS. FS is projected to increase as digital financial inclusion increases (Tan et al., 2024).

2.9. Digital Infrastructure, Digital Economy and Food Security

Social-economic development, technological change, financial literacy, education, skills of people, technical literacy, and trust of people in digital technologies (DTs) have a crucial contribution to increasing digital infrastructure. Exports and imports of ICT, digital tools, and the discovery and invention of digital devices also nurture a proper network of digital infrastructure. The progress of digitalization and the digital economy could be improved by using ICT, the internet, cybersecurity, etc (Chandio et al., 2024). Investment in infrastructure, construction, and empowering the capacity of the digital economy would be significant for digitalization (Lee et al., 2023). Accordingly, the digital economy would be active in improving food security (FS) as it enhances overall food systems. The digital economy supports increasing production, distribution, and consumption in cultivation (Lee et al., 2023). It is, therefore, supportive to improve production, process, and logistics operations in the agricultural industries (Amirova et al., 2022). Lee et al. (2023) observed the impact of the digital economy on FS in China.

3. RESEARCH METHODS

3.1. Study Area

This study includes G20 countries for assessing the impact of digital development (DD) on financial stability (FS). The G20 is a group of 19 countries, the European Union (27 countries), and the African Union (55 countries). However, the statistics for related indicators associated with DD and FS are not available for all G20 countries. Hence, 63 countries are considered appropriate for estimating DDI and FSI. Furthermore, statistics for the most suitable indicators are available during 2010–2022. Thus, this study develops *DDI* and *FSI* for 63 countries during this period (Table 1).

Table 1. Region-wise segregation of selected countries.

Country	Region
Australia, Japan, Korea Rep., Indonesia, China	East Asia & Pacific
Austria, Belgium, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Netherlands, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, United Kingdom, Bulgaria, Romania, Russian Federation, Turkey	Europe & Central Asia
Argentina, Brazil, Mexico	Latin America & Caribbean
Malta, Egypt Arab Rep., Morocco, Tunisia	Middle East & North Africa
Canada, United States	North America
India	South Asia
Ethiopia, Gambia, Guinea, Madagascar, Mali, Rwanda, Uganda, Cameroon, Comoros, Congo Rep., Eswatini, Kenya, Lesotho, Senegal, Tanzania, Zimbabwe, Mauritius, Namibia, South Africa	Sub-Saharan Africa

3.2. Sources of Data and Time Period

This study includes 63 countries from the G20 region, and it is proposed to create FSI and DDI for these countries. Since the availability of statistics of FS and DI related indicators is available during 2010–2022, the study compiles panel data for these countries during the above-said period. The statistics of related variables are derived from World Development Indicators (the World Bank), OECD, and FAO. Although, the statistics for a few variables are missing in this time period. The missing values are estimated using interpolation and extrapolation techniques (Singh, Singh, & Negi, 2020). These missing values are estimated to create balanced country-wise panel data of specified variables. These techniques assume that particular variables have a linear trend in their time series. Furthermore, the observed trend for a time series does not lie outside the projected range in the mentioned techniques. Most specifically, these methods also assume that there is no sudden and extreme change in the value of a specific variable within a time period.

3.3. Estimation of Food Security Index (FSI) and Digital Development Index (DDI)

The composite Z-score method is adopted to estimate FSI and its other components, as well as DDI for selected G20 countries. Zou and Guo (2015) created FSI using factor analysis in China. Singh et al. (2020) also preferred a similar method to develop a sustainable development index across countries. The same statistical technique is used to estimate various indexes in the areas of digitalization and FS in this research.

3.4. Indicators of DDI

The process of digitalization cannot be explained by a specific indicator. Thus, most scholars consider diverse indicators for digitalization when assessing its impact on energy intensity, financial stability, economic growth, foreign trade, social development, environmental development, business creation, entrepreneurship ecosystem, sustainable development, and agricultural development (Benfica et al., 2023; Lee et al., 2023). Another group of scholars used a composite index of digitalization-enhancing variables for assessing the progress of digital development (DD). Vărzaru (2024) also assessed the impact of digital transformation on FS using indexes. Wang et al. (2023) exposed the significant impact on digital technologies, digital finance and human capital on the food system. Lee et al. (2023) created a Digital Economy Index to explore its implications on FS in China. Sixteen indicators are compiled to estimate the DDI in this study (Table 2). These indicators are divided into three categories, which are explained in Table 2.

Table 2. Indicators of DDI.

Category of indicators	Indicators name	Code
ICT access	Fixed telephone subscriptions (per 100 people)	FTSPHP
	Mobile cellular subscriptions (per 100 people)	MCSPHP
	Secure Internet servers (per 1 million people)	SISPMP
	ICT goods exports (% of total goods exports)	ICTGEPTGE
	ICT goods imports (% total goods imports)	ICTGIPTGI
	ICT service exports (% of service exports, BoP)	ICTSEPSEBOP
	Communications, computer, etc. (% of service exports, BoP)	CCPSEBOP
	Communications, computers, etc. (% of service imports, BoP)	CCPSIBOP
ICT use	Fixed broadband subscriptions (per 100 people)	CI_FBSPHP
	Individuals using the Internet (% of population)	IUIPP
	Automated teller machines (ATMs) (per 100,000 adults)	ATMPLA
	Computer, communications and other services (% of commercial service exports)	CCOSPCSE
	Computer, communications and other services (% of commercial service imports)	CCOSPCSI
ICT skills	Adjusted savings: Education expenditure (% of GNI)	EEPGNI
	Compulsory education, duration (years)	CEDY
	School enrolment, secondary (% gross)	SESPG

3.5. Indicators of FSI

Most scholars agree that the Food Security Index (FSI) is a crucial policy tool for measuring food security at the national level. The FSI includes multiple indicators that promote food security (Gouvea et al., 2022; Herawati et al., 2023; Lee et al., 2023; Wahab et al., 2015). These indicators can be divided into three to five categories (Harris-Fry et al., 2015; Herawati et al., 2023). For instance, Ye et al. (2013) created FSI in China using supply and demand of food-associated indicators. Mantravadi and Srai (2023) considered distribution, access and affordability of food to explore the situation of urban FS. Zou and Guo (2015) develop FSI in China using 12 different indicators associated with FS. Alexandri et al. (2015) created the Berry index to measure the FS in Romania. Harris-Fry et al. (2015) developed FSI to examine the factors affecting household FS in Bangladesh. Herawati et al. (2023) analyze the FS as using availability, access and consumption of food in Indonesia. Lee et al. (2023) developed an FS evaluation index to detect the FS across provinces of China. The above-mentioned review infers that past studies could not pursue a uniform pattern to examine the FS at the macro level. The authors of this article, therefore, considered the most useful indicators associated with FS for measuring the FSI. The sufficiency of food for all people shows the FS (Herawati et al., 2023). Most significant indicators associated with FSI are finalized as per the existing studies. These indicators are divided into four categories (World Bank Group (WBG), 2025), and their enlightenment is given as:

Table 3. Indicators of FSI.

Indicator's category	Indicators	Code	Source of data
Food availability	Crop production index (2014-2016 = 100)	CPI	
	Per capita availability of cereal production (Kg./Person)	PCAOPKP	WDI
	Food production index (2014-2016 = 100)	FPI	
	Livestock production index (2014-2016 = 100)	LPI	
	Population growth (Annual %)	PGA	
	Agricultural land (% of land area)	ALPLA	
	Fertilizer consumption (Kg//Ha. of arable land)	FCKPHAL	
Food accessibility	GDP per person employed (constant 2017 PPP $)	GDPPPE	
	Labor force participation rate, total (% of total population ages 15-64)	LFPRTPTP	
	Inflation GDP deflator (annual %)	IGDPDA	
	GDP per capita (Constant 2015 US$)	PCGDP	
	Vulnerable employment, total (% of total employment)	VETPTE	
	Employment to population ratio (15+, total (%)	EPRT	
	Purchasing power parity	PPP	OECD

Indicator's category	Indicators	Code	Source of data
	Control of corruption: Number of Sources	CCNS	WDI
Food stability	Age dependency ratio (% of working-age population)	ADRPWAP	
	Cereal yield (Kg./Ha.)	CYKPH	
	Arable land (Ha./person)	ALHPP	
	Population density (people per sq. km of land area)	PD	
	Employment in agriculture (% of total employment)	EAPTE	
	Per capita land under cereal production (Hectares)	PCLUCP	
	Per capita food production variability (Constant 2014-2016 thousand int$ per capita)	PCFPV	FAO
Food utilization	Annual freshwater withdrawals, agriculture (% of total freshwater withdrawal)	AFWWAPTFWW	WDI
	Mortality rate infant (per 1,000 live births)	IMRPTLB	
	People using at least basic drinking water services (% of population)	PULBDWSPP	
	People using at least basic sanitation services (% of population)	PUBSSPP	
	Life expectancy at birth, total (Years)	LEBTY	
	Fertility rate total (births per woman)	FRTBPW	
	Renewable internal freshwater resources per capita (Cubic meters)	RIFWRPC	
	Average dietary energy requirement (kcal/cap/Day)	ADER	FAO
	Average fat supply (g/cap/day) (3-year average)	AFS	
	Average protein supply (g/cap/Day) (3-year average)	APS	
	Average supply of protein of animal origin (g/cap/day) (3-year average)	ASPAO	
	Minimum dietary energy requirement (kcal/cap/day)	MDER	
	Share of dietary energy supply derived from cereals, roots and tubers (kcal/cap/Day) (3-year average)	SDESDFCRT	
	Sex ratio at birth (male births per female births)	SRB	WDI

Food Availability Associated Variables: Food availability cannot be sustained without an agricultural production system and livestock. Agricultural land (Badolo & Kinda, 2015), cereal production (Badolo & Kinda, 2015), and use of fertilizer help to increase crop production. The use of fertilizer is useful to increase the yield and production of crops (Chandio et al., 2024). Thus, it is positive to increase FS (Scanlan, 2001). Food production and livestock ensure the FS and nutritional security. Population pressure increases additional pressure on the agricultural sector and FS (Ye et al., 2013). High population growth causes an increase in food demand (Zou & Guo, 2015). Hence, FS is negatively affected due to increased population growth (Applanaidu et al., 2014; Badolo & Kinda, 2015; Scanlan, 2001). Thus, per capita availability of cereal production, food production index (Applanaidu et al., 2014), livestock production index, agricultural land and fertilizer consumption, crop production index and population growth (Badolo & Kinda, 2015) are integrated to develop *AVFI* in this study (Table 3).

Food Accessibility Related Indicators: This component of FS depends on the purchasing power of the people. Per capita income (Scanlan, 2001) and purchasing power parity is positive in increasing the economic capacity of people to purchase food (Abdullayev et al., 2023). On the other hand, the economic capacity of people is expected to decline as inflation, vulnerable employment, and corruption increase. Hence, these variables have a negative impact on the accessibility of food. Accordingly, 8 indicators are composed for developing the accessibility of food index (*ACFI*) in this study (Table 3).

Food Stability Related Indicators: Efficient use of arable land is crucial to increase FS (Abdullayev et al., 2023). Employment in the agricultural sector helps to increase agricultural production and the economic capacity of workers. Conversely, the age dependency ratio (Scanlan, 2001) and variability in food production are negatively associated with this component of FS. Thus, 7 different indicators are considered to develop the stability of food index (*STFI*) in this study (Table 3).

Food Utilization Related Indicators: Food utilization ensures the food quality that maintains the health security of the people. Annual freshwater withdrawals and per capita renewable freshwater are supportive of increasing health security. Infant mortality rate (IMR) increases due to lack of nutritional security and basic medical facilities (World Health Organization (WHO), 2023). Food utilization has a negative impact on IMR. Lack of proper dietary patterns is also responsible for increasing IMR. Fertility rate and life expectancy increase as nutritional security and FS increase (Scanlan, 2001). There are other measures like average dietary energy requirement, average fat supply, minimum dietary energy, and dietary energy supply from cereals that are also important to increase the utilization of food. The contribution of women is essential to increase the utilization of food. Thus, the sex ratio at birth is used to examine the role of women in promoting FS. Hence, 14 different indicators are used to develop the food utilization index (*UTFI*) in this study (Table 3).

3.6. Regression Analysis

Previous studies used different models to assess the factors affecting FS. Harris-Fry et al. (2015) applied a multinomial logistic regression model to examine the determinants of FS at households in Bangladesh. Using a logistic regression model, Zakari et al. (2014) observed the food availability improving factors in Niger. Vărzaru (2024) examined the impact of digital economy and society index on FS. This research is intended to examine the impact of digital development (DD) on FS and vice-versa. Hence, *FSI* and *DDI* are included as core variables in simultaneous regression equations. Gouvea et al. (2022), Lee et al. (2023), and Wang et al. (2023) also observed the interconnection of various indexes associated with FS and digitalization is analyzed. The development of environment-related technologies, inventions per capita in this area, final consumption expenditure, foreign direct investment net inflows, forest area, and gross domestic saving are included as explanatory variables. The study also examines the impact of DD on the accessibility of food index (*ACFI*), availability of food index (*AVFI*), stability of food index (*STFI*), and utilization of food index (*UTFI*). These variables are considered as dependent variables, with DDI used as the independent variable. Log-linear regression models are employed to analyze the impact of *DV*s on *IV*s. The following regression models are adopted in this article:

$$log(ACFI)_{ct} = \alpha_0 + \alpha_1 log(DDI)_{ct} + \alpha_2 log(DERTPAT)_{ct} + \alpha_3 log(DERTIPC)_{ct} + \alpha_4 log(FCEPGDP)_{ct} + \alpha_5 log(FDINIPGDP)_{ct} + \alpha_6 log(FAPLA)_{ct} + \alpha_7 log(GDSPGDP)_{ct} + \mu_{ct} \quad (1)$$

$$log(AVFI)_{ct} = \beta_0 + \beta_1 log(DDI)_{ct} + \beta_2 log(DERTPAT)_{ct} + \beta_3 log(DERTIPC)_{ct} + \beta_4 log(FCEPGDP)_{ct} + \beta_5 log(FDINIPGDP)_{ct} + \beta_6 log(FAPLA)_{ct} + \beta_7 log(GDSPGDP)_{ct} + \acute{\varepsilon}_{ct} \quad (2)$$

Here, *log* is natural logarithm of corresponding *DV*s and *IV*s; *c* is cross country; *t* is time; α_0, and β_0 are constant-term; μ_{ct} and $\acute{\varepsilon}_{ct}$ are error-term; α_1... and β_1... are the unknown parameters of associated variables that are estimated through regression analysis in the above-mentioned Equations 1 and 2. The detailed description of all *IV*s and *DV*s is presented in Table 4. Accordingly, other regression equations are developed to examine the impact of DDI and other explanatory variables of *STFI*, *UTFI*, and *FSI*. Thereupon, regression equations that examine the impact of FS and its dimensions on DDI are also formulated in this research. The detailed explanation of these equations is given in Appendix A.

Table 4. Explanation of *DV*s and *IV*s.

Indicators	Code	Source of Data
Accessibility of Food Index	ACFI	Estimated by authors
Availability of food index	AVFI	
Stability of food index	STFI	
Utilization of the Food Index	UTFI	
Food security index	FSI	
Digital development index	DDI	
Development of environment-related technologies (% of all technologies)	DERTPAT	OECD
Per capita development of environment-related technologies and inventions	DERTIPC	
Final consumption expenditure as a percentage of GDP	FCEPGDP	WDI
Foreign direct investment net inflows as a percentage of GDP	FDINIPGDP	
Forest area (% of land area)	FAPLA	
Gross domestic savings as a percentage of GDP	GDSPGDP	

3.7. Statistical Software

The proposed descriptive and regression analyses are completed using MS Excel, SPSS, and STATA statistical software in this study.

4. DESCRIPTIVE RESULTS

The comparative performance of G20 countries in FS and its four different components is provided in Figure 1-5, respectively. Figure 6 infer the progress of G20 countries in digital development (DD). The performance of G20 countries in DD and FS is presented in Figure 7. The ranking of these countries in various measures of FS and digitalization is provided in Table 5. The statistical values of *AVFI* lie between 0.2059 to 0.5362 across G0 countries (Figure 1). It demonstrates that G20 countries could not uniformly improve their performance in the availability of food (AVF). Ireland and Denmark hold the 1st and 2nd positions in *AVFI*. In the European Union, many countries such as Malta and Sweden have lower values of *AVFI*. Consequently, these countries have the poorest positions in food availability. In the African Union, Lesotho, South Africa, and Eswatini have average positions in AVF. The remaining countries in the African Union have not established an adequate platform to sustain AVF.

Figure 2 explains the comparative performance of G20 countries in food accessibility (ACF). It reports a high and significant diversity in ACF across G20 countries. Luxembourg has the highest value of *ACFI*. It could achieve the best position in this ACF compared to other countries. Thereafter, Ireland has the second-best performing country in ACF. Most high-income group countries could attain greater positions in ACF. Conversely, low-income group countries such as Rwanda, Gambia, Mali, Guinea, Uganda, Ethiopia, and Madagascar have the poorest performance in ACF. All income group countries (except Indonesia) could not improve their position in ACF. Most upper-income countries (except China, Mauritius, and Russia) have a poor position in ACF. European countries (excluding Romania, Bulgaria, and Croatia) demonstrate the best, medium, and average performance in ACF. Most countries (excluding Mauritius) can improve their performance in ACF by increasing food production, arable land, and cereal production. Countries with low rankings in food accessibility should create income-generating opportunities to enhance their performance. Senegal, India, Zimbabwe, Morocco, Egypt, Tunisia, Rwanda, Gambia, Mali, Comoros, Guinea, South Africa, Argentina, Uganda, Congo, Kenya, Cameroon, Türkiye, Ethiopia, Eswatini, Namibia, Lesotho, Mexico, Brazil, Romania, Tanzania, Bulgaria, Croatia, and Madagascar have AVFI values less than 0.40. Hence, these countries appear as the poorest performers in ACF.

Figure 3 provides the comparative performance of G20 countries in the stability of food (STF). Australia and Canada have the 1st and 2nd highest values in *STFI*, respectively. Hence, both countries could achieve 1st and 2nd positions, respectively, in STF. Malta has the poorest performance in STF. Furthermore, the statistical values of *STFI* indicate high diversity in STF across G20 countries. Australia has the highest value of *STFI* and holds the best position in STF. Malta appears to be in the poorest position in STF. Most countries have the poorest positions in AVF within the African Union. However, many countries such as Madagascar, Guinea, Egypt, Mali, and South Africa from the African Union could achieve better positions in STF. The cross-comparison of G20 countries in the utilization of food (UTF) is given in Figure 4. Australia and Canada hold the 1st and 2nd positions, respectively, in UTF according to the estimated statistical values of *UTFI*. Uganda has the lowest value of *UTFI*. Therefore, Uganda seems unable to improve its performance in UTF. All countries can be considered as performers ranging from best, better, good, to average in STF. All European countries have better positions in UTF. Most countries in the African Union, excluding Tunisia, Egypt, Mauritius, and South Africa, have *UTFI* values below those of other nations.

FSI is the integration of *AVFI*, *ACFI*, *STFI* and *UTFI*. Thus, those countries that have good performance in the mentioned indicators will be in good positions in food security (FS) (Figure 5). Netherlands, Finland, China, Germany, United Kingdom, Austria, Lithuania, France, Luxembourg, Canada, Ireland, United States, Denmark, and Australia are reported as the best performing countries in FS based on the statistical values of *FSI*. Tunisia, Egypt, Morocco, South Africa, Mexico, Malta, Mauritius, Türkiye, Brazil, Croatia, Slovak Republic, Indonesia, Japan, Cyprus, Slovenia, Korea Rep., Argentina, Czechia, Estonia, Romania, Hungary, Bulgaria, Italy, Russian Federation, Portugal, Poland, Latvia, Greece, Belgium, Spain, and Sweden have better performance in FS. Remaining countries have average performance in FS.

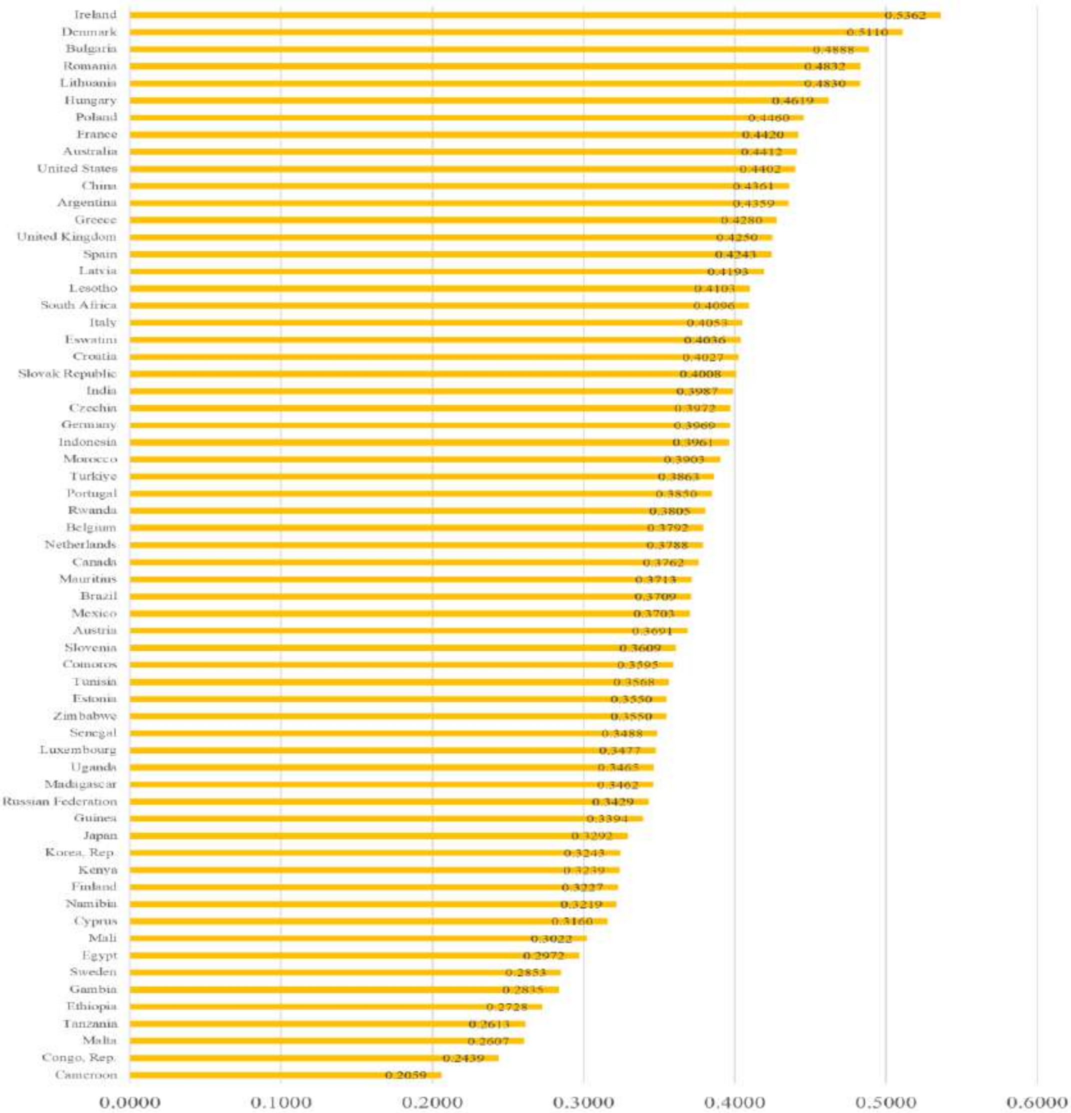

Figure 1. Cross-comparison of countries in *AVFI* as per its mean value during 2010-2022.

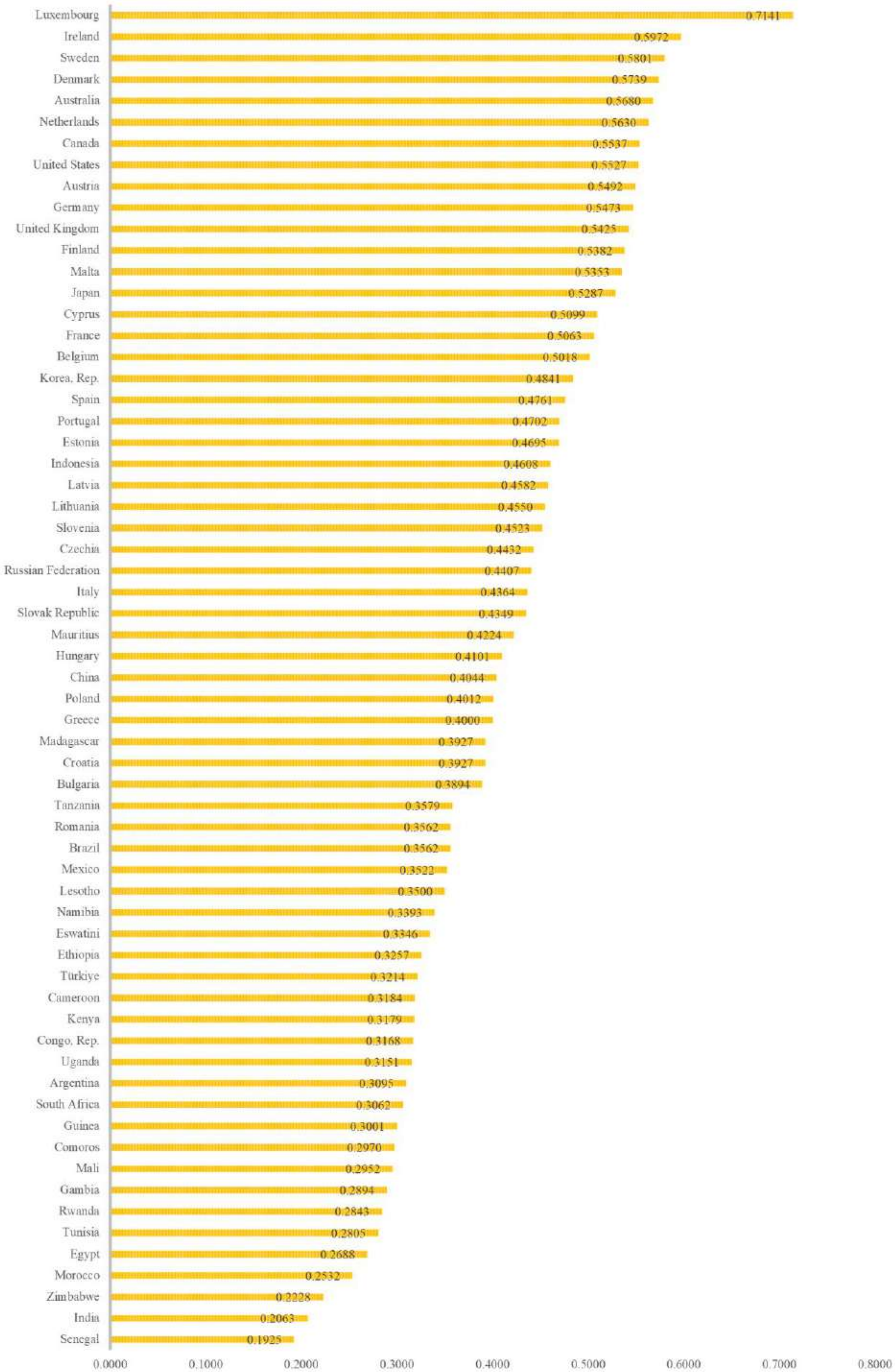

Figure 2. Cross-comparison of countries in *ACFI* as per its mean value during 2010-2022.

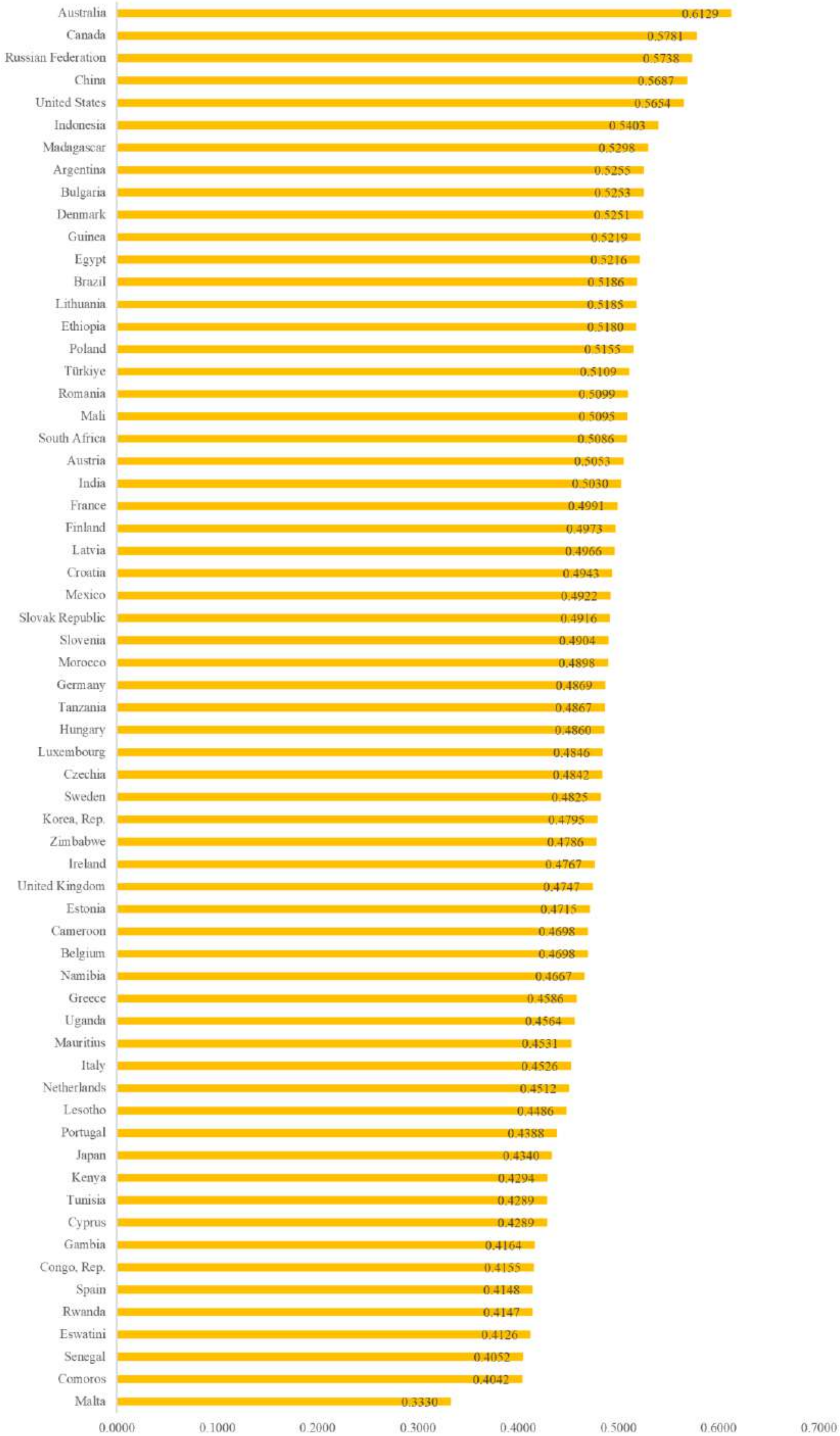

Figure 3. Cross comparison of countries in *STFI* as per its mean value during 2010-2022.

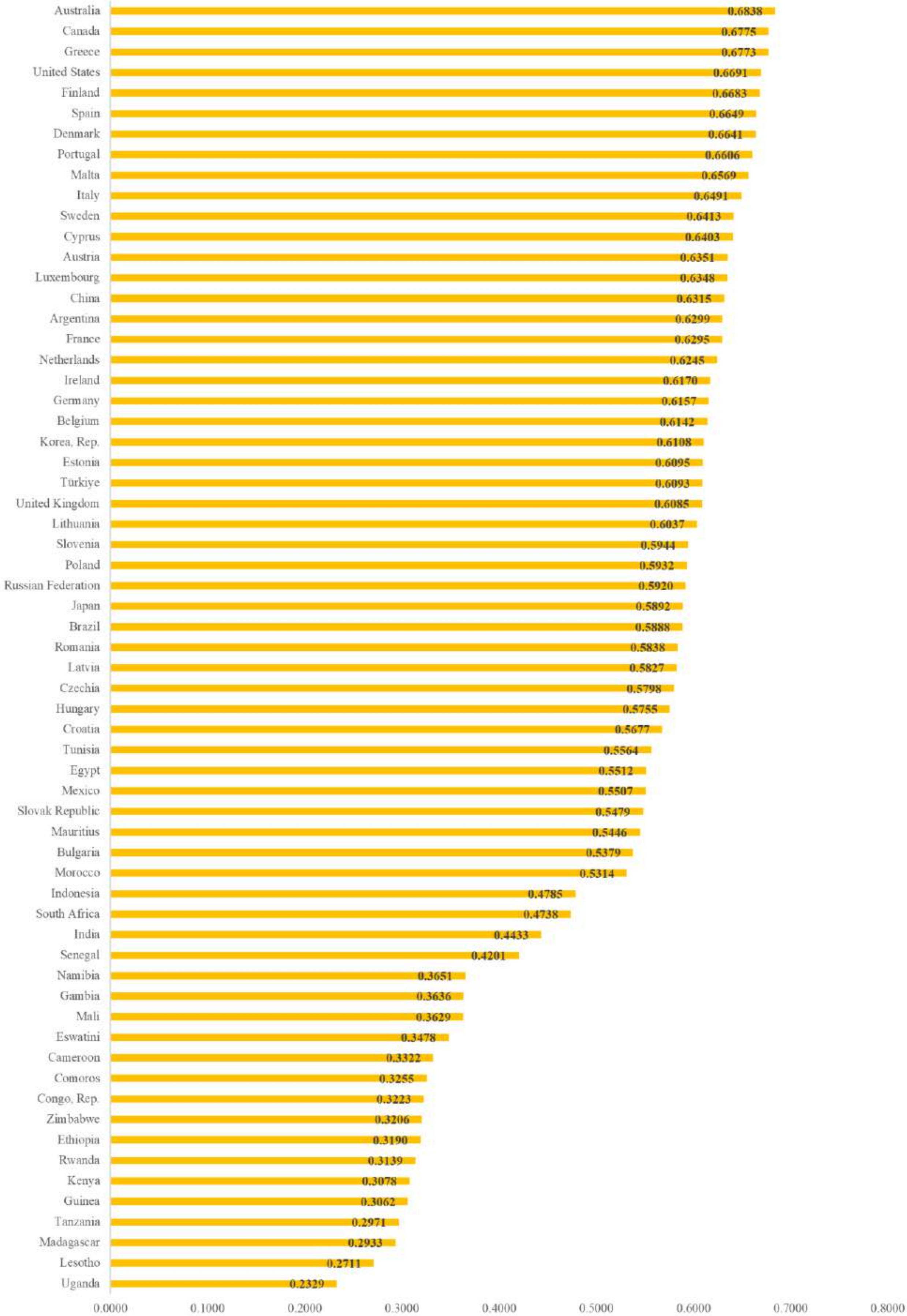

Figure 4. Cross comparison of countries in *UTFI* as per its mean value during 2010-2022.

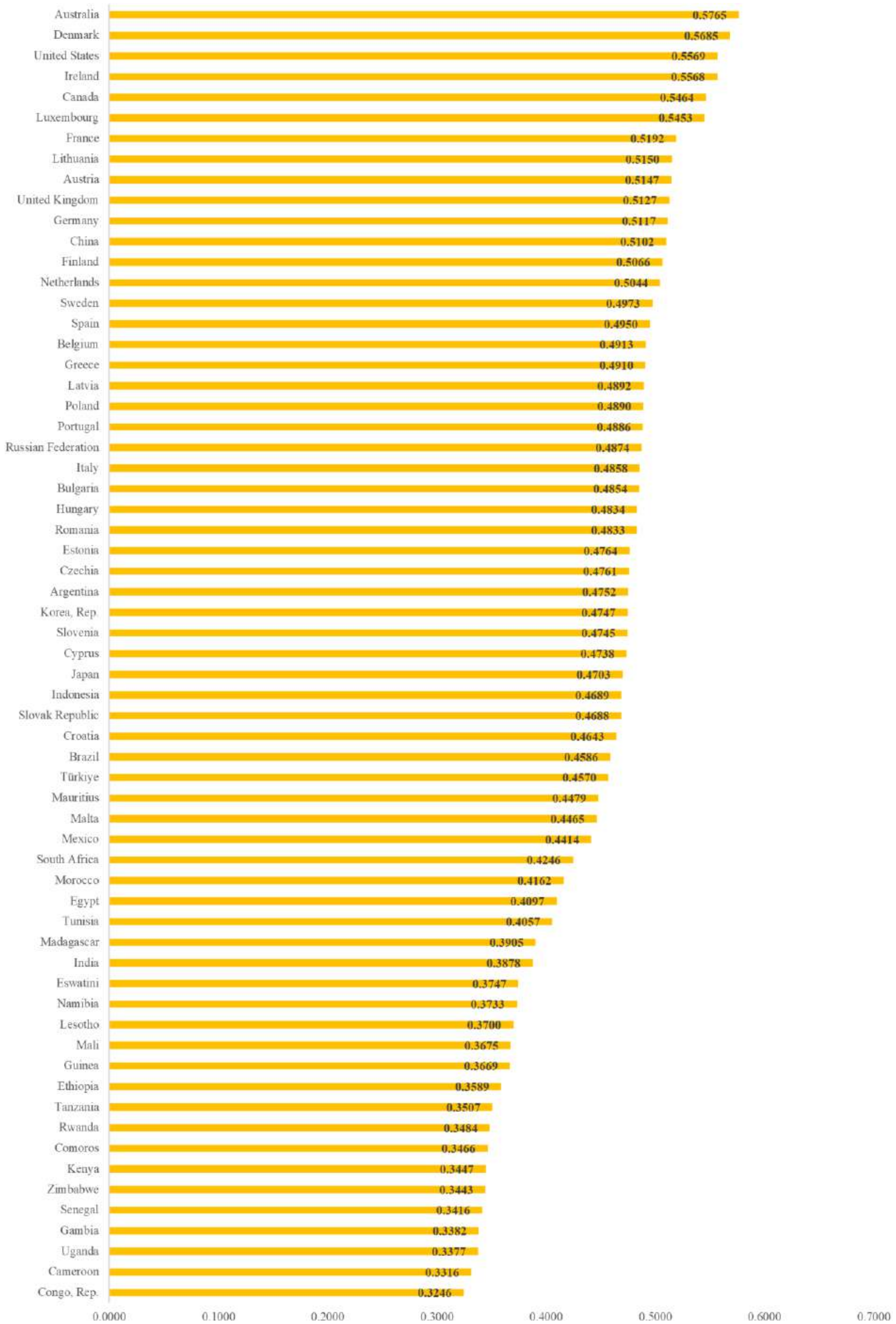

Figure 5. Cross comparison of countries in *FSI* as per its mean value during 2010-2022.

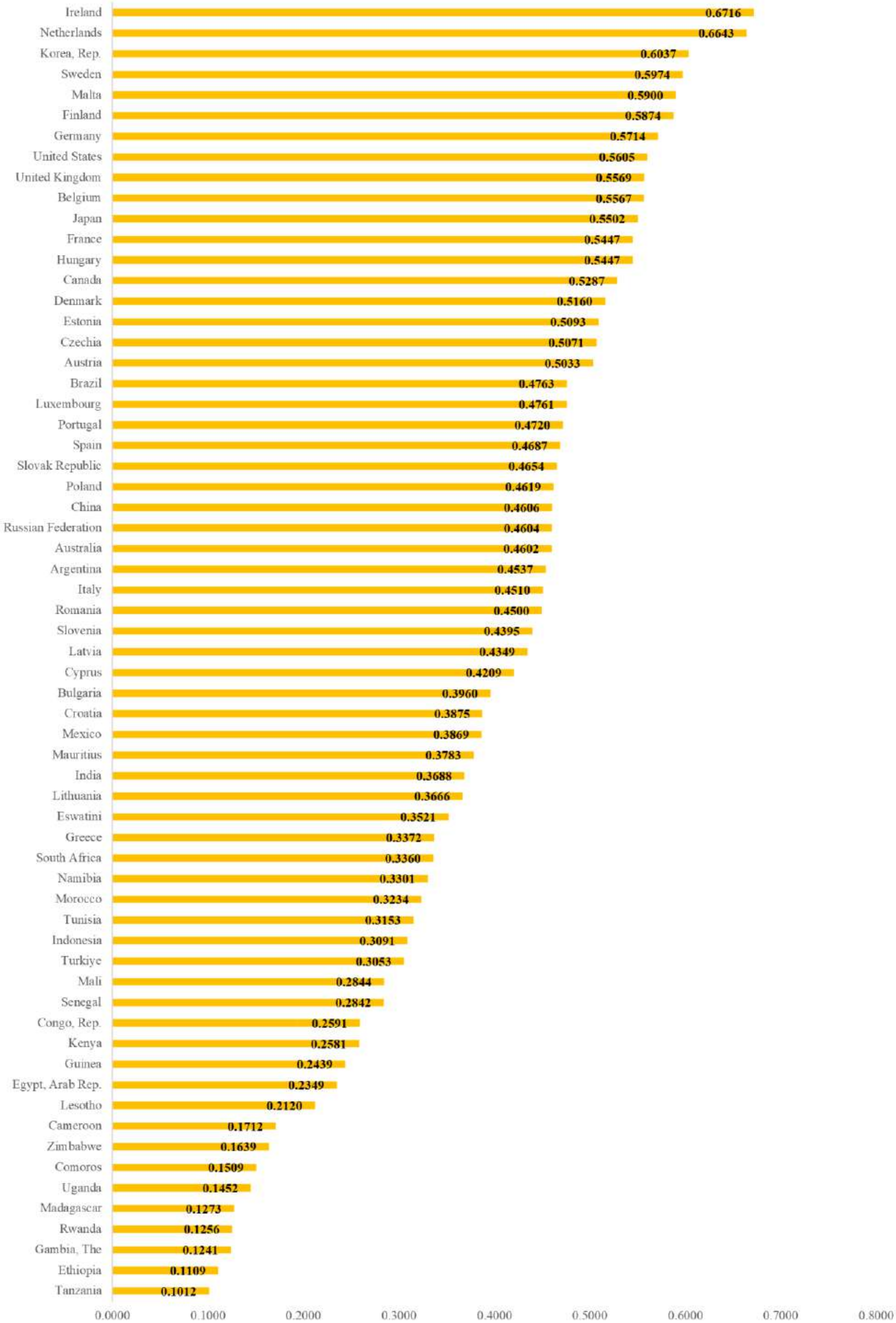

Figure 6. Cross-comparison of countries in *DII* based on their mean values during 2010-2022.

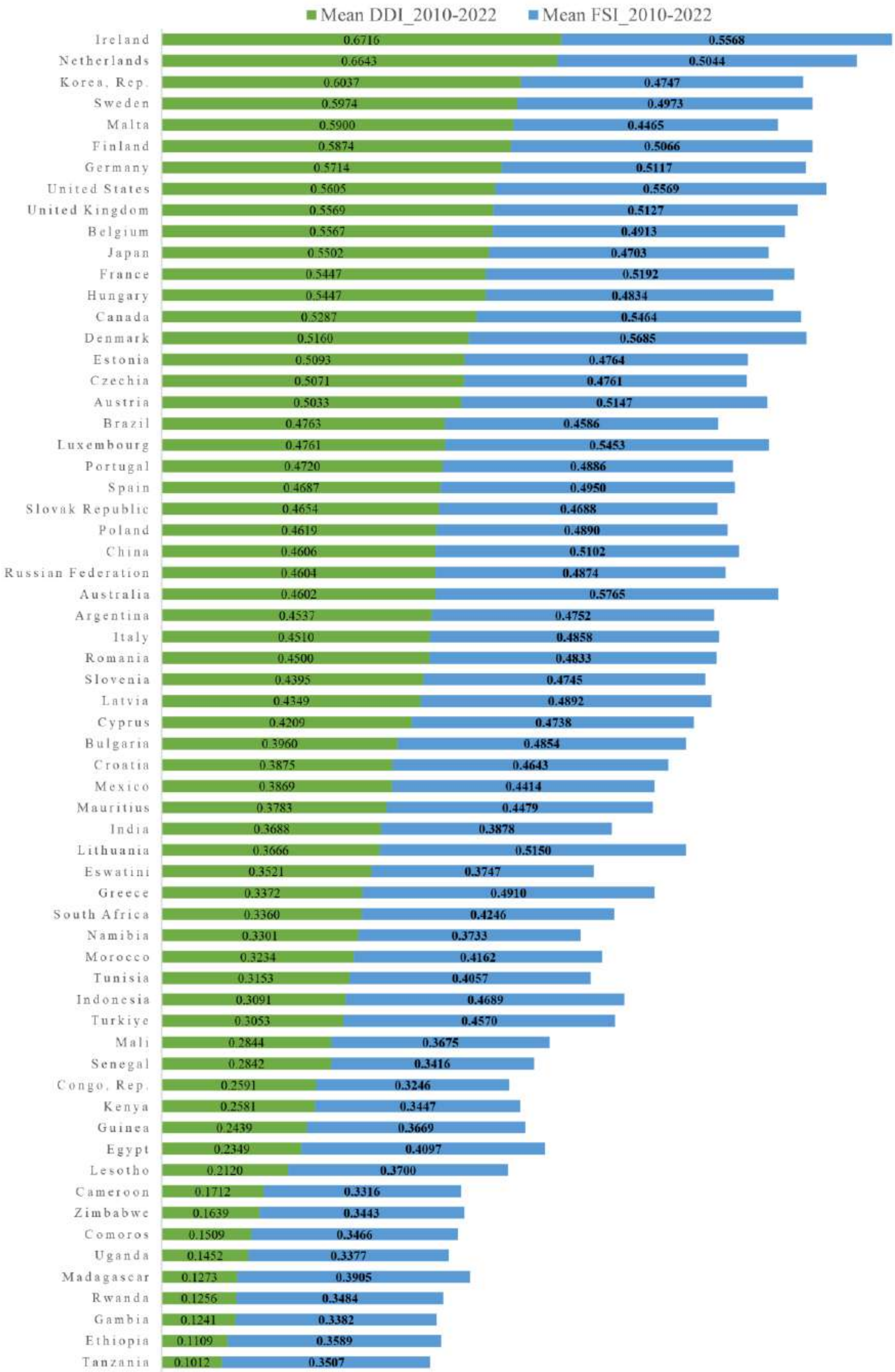

Figure 7. Progress of G20 countries in DII and FSI as per their mean value during 2010-2022.

Table 5. Ranking of countries in various indexes.

Country name	Mean ACFI		Mean AVFI		Mean STFI		Mean UTFI		Mean FSI		Mean DDI	
	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank
Ireland	0.597	2	0.536	1	0.477	39	0.617	19	0.557	4	0.672	1
Netherlands	0.563	6	0.379	32	0.451	49	0.624	18	0.504	14	0.664	2
Korea, Rep.	0.484	18	0.324	50	0.480	37	0.611	22	0.475	30	0.604	3
Sweden	0.580	3	0.285	57	0.483	36	0.641	11	0.497	15	0.597	4
Malta	0.535	13	0.261	61	0.333	63	0.657	9	0.446	40	0.590	5
Finland	0.538	12	0.323	52	0.497	24	0.668	5	0.507	13	0.587	6
Germany	0.547	10	0.397	25	0.487	31	0.616	20	0.512	11	0.571	7
United States	0.553	8	0.440	10	0.565	5	0.669	4	0.557	3	0.561	8
United Kingdom	0.543	11	0.425	14	0.475	40	0.609	25	0.513	10	0.557	9
Belgium	0.502	17	0.379	31	0.470	43	0.614	21	0.491	17	0.557	10
Japan	0.529	14	0.329	49	0.434	52	0.589	30	0.470	33	0.550	11
France	0.506	16	0.442	8	0.499	23	0.629	17	0.519	7	0.545	12
Hungary	0.410	31	0.462	6	0.486	33	0.576	35	0.483	25	0.545	13
Canada	0.554	7	0.376	33	0.578	2	0.677	2	0.546	5	0.529	14
Denmark	0.574	4	0.511	2	0.525	10	0.664	7	0.569	2	0.516	15
Estonia	0.470	21	0.355	41	0.472	41	0.609	23	0.476	27	0.509	16
Czechia	0.443	26	0.397	24	0.484	35	0.580	34	0.476	28	0.507	17
Austria	0.549	9	0.369	37	0.505	21	0.635	13	0.515	9	0.503	18
Brazil	0.356	40	0.371	35	0.519	13	0.589	31	0.459	37	0.476	19
Luxembourg	0.714	1	0.348	44	0.485	34	0.635	14	0.545	6	0.476	20
Portugal	0.470	20	0.385	29	0.439	51	0.661	8	0.489	21	0.472	21
Spain	0.476	19	0.424	15	0.415	58	0.665	6	0.495	16	0.469	22
Slovak Republic	0.435	29	0.401	22	0.492	28	0.548	40	0.469	35	0.465	23
Poland	0.401	33	0.446	7	0.516	16	0.593	28	0.489	20	0.462	24
China	0.404	32	0.436	11	0.569	4	0.631	15	0.510	12	0.461	25
Russian federation	0.441	27	0.343	47	0.574	3	0.592	29	0.487	22	0.460	26
Australia	0.568	5	0.441	9	0.613	1	0.684	1	0.576	1	0.460	27
Argentina	0.310	51	0.436	12	0.526	8	0.630	16	0.475	29	0.454	28
Italy	0.436	28	0.405	19	0.453	48	0.649	10	0.486	23	0.451	29
Romania	0.356	39	0.483	4	0.510	18	0.584	32	0.483	26	0.450	30
Slovenia	0.452	25	0.361	38	0.490	29	0.594	27	0.475	31	0.440	31
Latvia	0.458	23	0.419	16	0.497	25	0.583	33	0.489	19	0.435	32
Cyprus	0.510	15	0.316	54	0.429	55	0.640	12	0.474	32	0.421	33
Bulgaria	0.389	37	0.489	3	0.525	9	0.538	42	0.485	24	0.396	34
Croatia	0.393	36	0.403	21	0.494	26	0.568	36	0.464	36	0.387	35
Mexico	0.352	41	0.370	36	0.492	27	0.551	39	0.441	41	0.387	36
Mauritius	0.422	30	0.371	34	0.453	47	0.545	41	0.448	39	0.378	37
India	0.206	62	0.399	23	0.503	22	0.443	46	0.388	47	0.369	38
Lithuania	0.455	24	0.483	5	0.518	14	0.604	26	0.515	8	0.367	39
Eswatini	0.335	44	0.404	20	0.413	60	0.348	51	0.375	48	0.352	40
Greece	0.400	34	0.428	13	0.459	45	0.677	3	0.491	18	0.337	41

Country name	Mean ACFI		Mean AVFI		Mean STFI		Mean UTFI		Mean FSI		Mean DDI	
	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank
South Africa	0.306	52	0.410	18	0.509	20	0.474	45	0.425	42	0.336	42
Namibia	0.339	43	0.322	53	0.467	44	0.365	48	0.373	49	0.330	43
Morocco	0.253	60	0.390	27	0.490	30	0.531	43	0.416	43	0.323	44
Tunisia	0.280	58	0.357	40	0.429	54	0.556	37	0.406	45	0.315	45
Indonesia	0.461	22	0.396	26	0.540	6	0.478	44	0.469	34	0.309	46
Türkiye	0.321	46	0.386	28	0.511	17	0.609	24	0.457	38	0.305	47
Mali	0.295	55	0.302	55	0.510	19	0.363	50	0.367	51	0.284	48
Senegal	0.192	63	0.349	43	0.405	61	0.420	47	0.342	59	0.284	49
Congo, Rep.	0.317	49	0.244	62	0.415	57	0.322	54	0.325	63	0.259	50
Kenya	0.318	48	0.324	51	0.429	53	0.308	58	0.345	57	0.258	51
Guinea	0.300	53	0.339	48	0.522	11	0.306	59	0.367	52	0.244	52
Egypt	0.269	59	0.297	56	0.522	12	0.551	38	0.410	44	0.235	53
Lesotho	0.350	42	0.410	17	0.449	50	0.271	62	0.370	50	0.212	54
Cameroon	0.318	47	0.206	63	0.470	42	0.332	52	0.332	62	0.171	55
Zimbabwe	0.223	61	0.355	42	0.479	38	0.321	55	0.344	58	0.164	56
Comoros	0.297	54	0.360	39	0.404	62	0.325	53	0.347	56	0.151	57
Uganda	0.315	50	0.346	45	0.456	46	0.233	63	0.338	61	0.145	58
Madagascar	0.393	35	0.346	46	0.530	7	0.293	61	0.391	46	0.127	59
Rwanda	0.284	57	0.381	30	0.415	59	0.314	57	0.348	55	0.126	60
Gambia	0.289	56	0.284	58	0.416	56	0.364	49	0.338	60	0.124	61
Ethiopia	0.326	45	0.273	59	0.518	15	0.319	56	0.359	53	0.111	62
Tanzania	0.358	38	0.261	60	0.487	32	0.297	60	0.351	54	0.101	63

Table 6. Correlation coefficients among the estimated indexes and *IVs*.

Indicators	ACFI	AVFI	STFI	UTFI	FSI	DDI	DERTPAT	DERTIPC	FCEPGDP	FDINIPGDP	FAPLA	GDSPGDP
ACFI	1	0.137[a]	0.174[a]	0.674[a]	0.791[a]	0.731[a]	-0.059[b]	0.574[a]	-0.492[a]	0.245[a]	0.229[a]	0.511[a]
AVFI	0.137[a]	1	0.245[a]	0.299[a]	0.575[a]	0.279[a]	0.00	-0.009	-0.052	-0.024	-0.137[a]	0.086[a]
STFI	0.174[a]	0.245[a]	1	0.235[a]	0.446[a]	0.129[a]	0.013	0.031	-0.187[a]	-0.128[a]	0.107[a]	0.151[a]
UTFI	0.674[a]	0.299[a]	0.235[a]	1	0.879[a]	0.833[a]	-0.060[b]	0.404[a]	-0.459[a]	0.130[a]	0.195[a]	0.366[a]
FSI	0.791[a]	0.575[a]	0.446[a]	0.879[a]	1	0.798[a]	-0.049	0.420[a]	-0.462[a]	0.127[a]	0.156[a]	0.431[a]
DDI	0.731[a]	0.279[a]	0.129[a]	0.833[a]	0.798[a]	1	-0.031	0.563[a]	-0.511[a]	0.113[a]	0.223[a]	0.476[a]
DERTPAT	-0.059[b]	0	0.013	-0.060[b]	-0.049	-0.031	1	0.002	-0.008	-0.019	0.045	-0.020
DERTIPC	0.574[a]	-0.009	0.031	0.404[a]	0.420[a]	0.563[a]	0.002	1	-0.285[a]	0.016	0.398[a]	0.285[a]
FCEPGDP	-0.492[a]	-0.052	-0.187[a]	-0.459[a]	-0.462[a]	-0.511[a]	-0.008	-0.285[a]	1	-0.167[a]	-0.333[a]	-0.866[a]
FDINIPGDP	0.245[a]	-0.024	-0.128[a]	0.130[a]	0.127[a]	0.113[a]	-0.019	0.016	-0.167[a]	1	-0.086[a]	0.174[a]
FAPLA	0.229[a]	-0.137[a]	0.107[a]	0.195[a]	0.156[a]	0.223[a]	0.045	0.398[a]	-0.333[a]	-0.086[a]	1	0.277[a]
GDSPGDP	0.510[a]	0.086[a]	0.151[a]	0.366[a]	0.431[a]	0.476[a]	-0.020	0.285[a]	-0.866[a]	0.174[a]	0.277[a]	1

Note: [a] indicates that correlation is significant at 1% significance level and [b] indicates that correlation is significant at 5% significance level.

Moreover, there is diversity in FS in the African and European Union due to variation in indicators used to create the FSI. All countries in the African Union (except Tunisia, Egypt, Morocco, South Africa, and Mauritius) have average performance in FS. As per estimated values of DDI, G20 countries are divided into best, better, good, and poorest performers in digital development (DD) (Figure 6). Korea, Republic of, Netherlands, and Ireland have 1st, 2nd, and 3rd best performing countries in digital development. Austria, Czechia, Estonia, Denmark, Canada, Hungary, France, Japan, Belgium, the United Kingdom, the United States, Germany, Finland, Malta, and Sweden are reported as better performing countries in DD. Many low-income countries have the poorest positions in DD.

Cyprus, Latvia, Slovenia, Romania, Italy, Argentina, Australia, the Russian Federation, China, Poland, the Slovak Republic, Spain, Portugal, Luxembourg, and Brazil could sustain good performance in digitalization. Tanzania, Ethiopia, Gambia, Rwanda, Madagascar, Uganda, Comoros, Zimbabwe, Cameroon, Lesotho, Egypt, Guinea, Kenya, the Congo Republic, Senegal, and Mali have less than 0.30 values of DDI. Thus, the estimates suggest that these countries should create appropriate digital infrastructure through increasing R&D investment and strengthening the intellectual property rights regime (Benfica et al., 2023). All countries in the European Union created effective digital infrastructure and platforms. While none of the countries from the African Union could improve their positions in DD. Hence, most countries in the European Union are receiving relatively greater benefits from DD as compared to other countries in the African Union. South Korea is found to be the best performing country in DD among Asian countries. Other Asian countries like Indonesia, India, and China should give high priority to creating digital infrastructure to increase their positions in DD.

FSI is positively correlated with *AVFI*, *ACFI*, *STFI* and *UTFI* in G20 countries (Table 6). FS cannot be separated from its other dimensions. *AVFI* has a positive and statistically significant link with *STFI*, *UTFI*, and *FSI*. *ACFI* also has a positive connection with other dimensions of FS. *STFI* is positively associated with *AVFI*, *ACFI*, *UTFI*, and *FSI*. The last component of FS, i.e., *UTFI*, is also positively associated with other indexes of FS. Hence, the estimates provide clarification that there is a high interdependency of FS with its other dimensions. Subsequently, G20 countries should give equal priority to all dimensions of FS to increase their positions in it. The results imply that digital development (DD) helps to enhance *AVF*, *ACF*, *STF*, *UTF*, and overall FS. Thereupon, it is not perceived as a uniform association of external variables with estimated indexes. Despite that, per capita environmental technology, FDINI, forest area, and gross domestic saving are positively associated with *AVFI*, *UTFI*, *FSI*, and *DDI*. Hence, these variables are found useful for improving AVF, UTF, FS, and DD.

5. EMPIRICAL RESULTS

The impact of digital development and explanatory variables on ACF, AVF, STF, UTF and FS are presented in Table 7. While comprehensive results which estimate the impact of DD on ACF, AVF, STF, UTF, and FS are given in Appendix B (Table B1-B5). The regression coefficients of *DDI* with *ACFI*, *AVFI*, *STFI*, *UTFI*, and *FSI* are reported as positive. The estimates demonstrate that digital development (DD) positively influences FS and its other dimensions. Per capita environmental technology and the share of environmental technologies show a positive impact on ACF, AVF, UTF, and FS. However, STF appears to decline due to increases in per capita environmental technology and the share of environmental technologies. The impact of final consumption expenditure on FS and its drivers is not consistent. Although it shows a negative impact on ACF and UTF, AVF, STF, and FS are likely to increase as final consumption expenditure rises. The impact of *FDINI* on ACF, UTF, and FS is positive and statistically significant. Conversely, AVF and STF are expected to decline as *FDINI* increases. Forest area supports ecosystem services and helps reduce temperature impacts on Earth. Therefore, it is proposed that forest area would positively influence FS. Our results also demonstrate that forest areas have a positive impact on ACF, AVF, and STF, while forest area is not found to be favorable for promoting UTF and FS.

Table 7. Impact of DD on FS and its dimensions.

Number of obs.	819	819	819	819	819
Number of groups	63	63	63	63	63
R-squared	0.6156	0.1154	0.0958	0.741	0.6888
Wald Chi^2	5214.32*	200.02*	353.84*	5932.05*	8082.29*
DVs/IVs	**log(ACFI)**	**log(AVFI)**	**log(STFI)**	**log(UTFI)**	**log(FSI)**
	Reg. Coef.	**Reg. Coef.**	**Reg. Coef.**	**Reg. Coef.**	**Reg. Coef.**
log(DDI)	0.0957*	0.1790*	0.0152**	0.3988*	0.1661*
log(DERTPAT)	0.0247*	0.006	0.0120*	0.0411*	0.0223*
log(DERTIPC)	0.0705*	0.0003	-0.0049*	0.0225*	0.0218*
log(FCEPGDP)	-0.062	0.3567*	0.0024	-0.0321	0.0496***
log(FDINIPGDP)	0.0302*	-0.0120***	-0.0129*	0.0035	0.0038***
log(FAPLA)	0.0042	0.0031	0.0111*	-0.0103*	-0.0021
log(GDSPGDP)	0.0679*	0.0680*	0.0298*	0.0105	0.0424*
Constant Coefficient	-0.8869*	-2.5969*	-0.8600*	-0.2316	-1.0381*

Note: *, ** and *** infer that coefficients are statistically significant at 1%, 5% and 10% significance level, respectively.

Table 8. Impact of FS and its dimensions on DD.

Number of obs.	819	819	819	819	819
Number of groups	63	63	63	63	63
R-squared	0.6895	0.4031	0.0906	0.0188	0.7165
Wald Chi²	3230.02*	1229.58*	24.8*	72.21*	5234.68*
DVs/IVs	**log(DDI)**	**log(DDI)**	**log(DDI)**	**log(DDI)**	**log(DDI)**
	Reg. Coef.	**Reg. Coef.**	**Reg. Coef.**	**Reg. Coef.**	**Reg. Coef.**
log(FSI)	1.4627*				
log(DERTPAT)	0.0921*				
log(DERTIPC)	0.0639*				
log(FCEPGDP)	-0.2799*				
log(FDINIPGDP)	0.0007				
log(FAPLA)	-0.0189*				
log(GDSPGDP)	0.0126				
log(ACFI)		1.0723*			
log(AVFI)			0.5282*		
log(STFI)				0.6074*	
log(UTFI)					1.4166*
Constant Coefficient	1.1689*	-0.0408	-0.4927*	-0.5849*	-0.0662*

Note: * infer that coefficient is statistically significant at 1% significance level.

The impact of *FS*, *ACF*, *AVF*, *STF* and *UTF* on digital development (DD) is included in Table 8. The impact of FS, accessibility of food, availability of food, stability of food, and utilization of food on DD are provided in Table C1,-C5, respectively, in Appendix C. The positive coefficients of FS and other components are detected as positive and statistically significant. Thus, the results indicate that DD is expected to improve as AVF, ACF, STF, UTF, and FS increase. Moreover, *FDINI* and gross domestic savings are reported as positive factors for increasing digitalization. In contrast, forest area and final consumption expenditure showed negative implications on DD.

6. CONCLUSION

This study estimated various indexes in the areas of food security (FS) and digital development (DD) for selected G20 countries. The results highlighted that G20 countries exhibit high diversity in DD and FS. The variation in DD and FS is due to significant differences in digital infrastructure and FS-enhancing factors. Additionally, there is considerable diversity in *AVF*, *ACF*, *STF*, and *UTF* across G20 countries. High diversity in FS and DD-promoting indicators could pose challenges for low-ranking countries in achieving SDGs in the near future. For example, most countries in the African Union have the poorest performance in FS and DD. A few countries in the European Union also need to implement conducive policies to improve their performance in DD and FS. Therefore, low-ranking countries should prioritize FS and its drivers equally, along with activities that promote digital infrastructure development.

The correlation results also imply that FS can be achieved by increasing AVF, ACF, STF, and UTF. Moreover, FS is reported positively to increase its other drivers. Thus, FS and its drivers have a positive and significant interconnection with each other. ACF, AVF, STF, UTF, and FS are positively associated with DD. FS cannot be sustainable without improving its other components and creating an appropriate digital infrastructure (Scanlan, 2001). Also, ACF, AVF, STF, UTF, and FS are also reported positive for further improving DD in G20 countries. Furthermore, the regression results reveal a positive impact of DD on FS and its other drivers. FS and its other components showed a positive impact on DD. FS and its drivers have a positive and bi-directional relationship with DD. Thereupon, DD also has a positive and bi-directional association with FS, AVF, ACF, STF, and UTF.

7. POLICY IMPLICATIONS

The results suggested several policy proposals that can support increasing FS in G20 countries. FS cannot be attained without improving its other components. Hence, it is necessary to give priority to boosting the availability, stability, accessibility, and utilization of food. Irrigation facilities, water conservation practices, organic farming, high-yielding seeds, and appropriate technologies should be improved to increase food availability (Abdullayev et al., 2023). More creation of employment, non-farming income, and price stability of food products would be conducive to increasing food accessibility (Abdullayev et al., 2023). Thereafter, protection of arable land and sustainable yield of crops would enhance STF. Appropriate food supply management must be improved to reduce food inequality in rural and urban areas. Application of clean and green technologies, minimum quantities of fertilizer, chemicals, and pesticides in cultivation would maintain food quality and food utilization. R&D investment in this sector is necessary to make better returns (World Bank Group (WBG), 2025).

Monitoring and controlling pests and insects in cultivation would be positive for increasing food utilization. Farming communities should move towards agricultural digitalization to increase FS for the present and growing population (Lioutas et al., 2021). Thereupon, FDI, level of employment, inflation, technological change, environmental technologies, and per capita CO_2 emissions showed a significant impact on FS. The process of DD is determined by technological change, per capita income, FDI, and inflation. Hence, these indicators must be considered in policy implementation to enhance FS and to create DD. These countries should develop sustainable agricultural management policies to give more scope of digital technologies to increase FS. Land protection mechanisms must be promoted to ensure the FS of the growing population (Zou & Guo, 2015). Extensive investment in infrastructure, mobile connectivity and digital skills would cultivate a best DD (Anderson & Sandin, 2022). Use of digital technologies would enhance improvement in the food system (Wang et al., 2023). Farmers should also move towards digital agriculture to increase FS (Wang et al., 2023).

8. SIGNIFICANCE AND INNOVATION

The world's countries are growing very fast. Accordingly, per capita income and social welfare also increase at unprecedented rates in most countries. Despite that, a significant share of global countries is still unable to ensure their food security (FS). The World Food Program (WFP) reported that around 45% of the population is food insecure worldwide. Additionally, chronic poverty, income inequality, corruption, black marketing, and ineffective government policies are increasing hunger, food and health insecurity, and malnutrition in many countries. Many G20 countries also have lower positions in FS and digitalization. Therefore, this study aims to attract the attention of policymakers in G20 countries to adopt effective policies to improve their standings in FS and digital development (DD). Subsequently, the variables considered can be used in further policy implications to enhance FS and DD in G20 countries. The article also provides directions for future research with specific questions.

9. LIMITATIONS AND SCOPE OF FURTHER RESEARCH

Estimations of FSI and DDI are limited for selected G20 countries during 2010–2022. The statistical values of FSI and DDI may not remain the same when considering or excluding any variables or countries in their estimations. The ranking of the undertaken countries in FS and DD may not be comparable with existing studies that have estimated FSI and DDI using different indicators and methods. The findings of this research are feasible for selected G20 countries. These countries exhibit diversity in many indicators. Existing researchers, therefore, can include the above-mentioned issues in further studies. Further research can also examine the impact of digitalization on the availability, stability, accessibility, and utilization of food. Additional studies can replicate this research using similar empirical exercises for individual countries to verify its validity. There are many areas such as the food supply chain, exports and food, food quality, transportation of foodstuffs, and quality measures of food where DD has a significant contribution. Therefore, further studies can incorporate these aspects into empirical analysis. Additionally, future research can explore the role of DD in controlling food waste in countries worldwide (Mantravadi & Srai, 2023). Existing researchers can also examine the roles of globalization, foreign trade, technology transfer, intellectual property rights, exports and imports of high-tech products, financial development, and the green economy on DD and FS in G20 countries.

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Appendix A: Overview of regression equations.

$$log(STFI)_{ct} = \gamma_0 + \gamma_1\, log(DDI)_{ct} + \gamma_2\, log(DERTPAT)_{ct} + \gamma_3\, log(DERTIPC)_{ct} + \gamma_4\, log(FCEPGDP)_{ct} + \gamma_5\, log(FDINIPGDP)_{ct} + \gamma_6\, log(FAPLA)_{ct} + \gamma_7\, log(GDSPGDP)_{ct} + \delta_{ct} \quad (1)$$

$$log(UTFI)_{ct} = \xi_0 + \xi_1\, log(DDI)_{ct} + \xi_2\, log(DERTPAT)_{ct} + \xi_3\, log(DERTIPC)_{ct} + \xi_4\, log(FCEPGDP)_{ct} + \xi_5\, log(FDINIPGDP)_{ct} + \xi_6\, log(FAPLA)_{ct} + \xi_7\, log(GDSPGDP)_{ct} + \lambda_{ct} \quad (2)$$

$$log(FSI)_{ct} = \chi_0 + \chi_1\, log(DDI)_{ct} + \chi_2\, log(DERTPAT)_{ct} + \chi_3\, log(DERTIPC)_{ct} + \chi_4\, log(FCEPGDP)_{ct} + \chi_5\, log(FDINIPGDP)_{ct} + \chi_6\, log(FAPLA)_{ct} + \chi_7\, log(GDSPGDP)_{ct} + \eta_{ct} \quad (3)$$

$$log(DDI)_{ct} = \Psi_0 + \Psi_1\, log(FSI)_{ct} + \Psi_2\, log(DERTPAT)_{ct} + \Psi_3\, log(DERTIPC)_{ct} + \Psi_4\, log(FCEPGDP)_{ct} + \Psi_5\, log(FDINIPGDP)_{ct} + \Psi_6\, log(FAPLA)_{ct} + \Psi_7\, log(GDSPGDP)_{ct} + \theta_{ct} \quad (4)$$

$$log(DDI)_{ct} = \xi_0 + \xi_1\, log(ACFI)_{ct} + £_{ct} \quad (5)$$

$$log(DDI)_{ct} = \phi_0 + \phi_1\, log(AVFI)_{ct} + ¥_{ct} \quad (6)$$

$$log(DDI)_{ct} = \Omega_0 + \Omega_1\, log(STF)_{ct} + §_{ct} \quad (7)$$

$$log(DDI)_{ct} = \varphi_0 + \varphi_1\, log(UTF)_{ct} + \Psi_{ct} \quad (8)$$

Here, *log* is natural logarithm of corresponding *DV*s and *IV*s; *c* is cross country; *t* is time; γ_0, ξ_0, χ_0, Ψ_0, ξ_0, ϕ_0, Ω_0, and φ_0 are constant-term; δ_{ct}, λ_{ct}, η_{ct}, θ_{ct}, $£_{ct}$, $¥_{ct}$, $§_{ct}$ and Ψ_{ct} are error-term; γ_0..., ξ_0..., χ_0..., Ψ_0..., ξ_1, ϕ_1, Ω_1, and φ_1 are the unknown parameter of associated variables that are estimated through regression analysis in the above-mentioned equations (1), (2), ..., (8), respectively. The detailed description of all *IV*s and *DV*s is also provided in Table 4.

Appendix B. Impact of DD on FS and its other dimensions.

Table B1. Impact of DD on accessibility of food (ACF).

Number of obs.	819					
Number of groups	63					
R-squared	0.6156					
Wald Chi²	5214.32					
log(ACFI)=[DV]	***Coef.***	***Std. Err.***	***z***	***P>|z|***	**[95% Conf. Interval]**	
log(DDI)	0.0957	0.0238	4.020	0.000	0.0490	0.1424
log(DERTPAT)	0.0247	0.0066	3.710	0.000	0.0116	0.0377
log(DERTIPC)	0.0705	0.0060	11.800	0.000	0.0588	0.0823
log(FCEPGDP)	-0.0620	0.0554	-1.120	0.263	-0.1705	0.0466
log(FDINIPGDP)	0.0302	0.0054	5.590	0.000	0.0196	0.0408
log(FAPLA)	0.0042	0.0053	0.790	0.430	-0.0063	0.0147
log(GDSPGDP)	0.0679	0.0136	5.000	0.000	0.0413	0.0945
Constant Coefficient	-0.8869	0.3008	-2.950	0.003	-1.4765	-0.2972

Table B2. Impact of DD on availability of food (AVF).

Number of obs.	819					
Number of groups	63					
R-squared	0.1154					
Wald Chi²	200.02					
log(AVFI)=[DV]	***Coef.***	***Std. Err.***	***z***	***P>|z|***	**[95% Conf. Interval]**	
log(DDI)	0.1790	0.0261	6.870	0.000	0.1280	0.2301
log(DERTPAT)	0.0060	0.0129	0.460	0.645	-0.0194	0.0313
log(DERTIPC)	0.0003	0.0099	0.030	0.978	-0.0191	0.0196
log(FCEPGDP)	0.3567	0.0588	6.060	0.000	0.2414	0.4720
log(FDINIPGDP)	-0.0120	0.0072	-1.670	0.096	-0.0262	0.0021
log(FAPLA)	0.0031	0.0110	0.280	0.778	-0.0184	0.0246
log(GDSPGDP)	0.0680	0.0200	3.400	0.001	0.0287	0.1072
Constant Coefficient	-2.5969	0.2976	-8.730	0.000	-3.1802	-2.0137

Table B3. Impact of DD on stability of food (STF).

Number of obs.	819					
Number of groups	63					
R-squared	0.0958					
Wald Chi²	353.84					
log(STFI)=[DV]	***Coef.***	***Std. Err.***	***z***	***P>|z|***	**[95% Conf. Interval]**	
log(DDI)	0.0152	0.0075	2.010	0.044	0.000	0.030
log(DERTPAT)	0.0120	0.0046	2.600	0.009	0.003	0.021
log(DERTIPC)	-0.0049*	0.0018	-2.740	0.006	-0.008	-0.001
log(FCEPGDP)	0.0024	0.0215	0.110	0.911	-0.040	0.045
log(FDINIPGDP)	-0.0129	0.0032	-4.080	0.000	-0.019	-0.007
log(FAPLA)	0.0111	0.0015	7.310	0.000	0.008	0.014
log(GDSPGDP)	0.0298	0.0086	3.450	0.001	0.013	0.047
Constant Coefficient	-0.8600	0.1113	-7.730	0.000	-1.078	-0.642

Table B4. Impact of DD on utilization of food (UTF).

Number of obs.	819					
Number of groups	63					
R-squared	0.741					
Wald Chi²	5932.05					
log(UTFI)=[DV]	***Coef.***	***Std. Err.***	***z***	***P>|z|***	**[95% Conf. Interval]**	
log(DDI)	0.3988	0.0190	20.940	0.000	0.3615	0.4362
log(DERTPAT)	0.0411	0.0127	3.230	0.001	0.0162	0.0661
log(DERTIPC)	0.0225	0.0026	8.730	0.000	0.0175	0.0276
log(FCEPGDP)	-0.0321	0.0358	-0.900	0.370	-0.1022	0.0381
log(FDINIPGDP)	0.0035	0.0034	1.040	0.298	-0.0031	0.0102
log(FAPLA)	-0.0103	0.0024	-4.200	0.000	-0.0150	-0.0055
log(GDSPGDP)	0.0105	0.0133	0.800	0.427	-0.0155	0.0365
Constant Coefficient	-0.2316	0.2000	-1.160	0.247	-0.6236	0.1605

Table B5. Impact of DD on food security (FS).

Number of obs.	819					
Number of groups	63					
R-squared	0.6888					
Wald Chi²	8082.29					
log(FSI)=[DV]	***Coef.***	***Std. Err.***	***z***	***P>|z|***	**[95% Conf. Interval]**	
log(DDI)	0.1661	0.0098	16.880	0.000	0.1468	0.1854
log(DERTPAT)	0.0223	0.0064	3.480	0.000	0.0098	0.0349
log(DERTIPC)	0.0218	0.0029	7.450	0.000	0.0161	0.0276
log(FCEPGDP)	0.0496	0.0263	1.890	0.059	-0.0019	0.1011
log(FDINIPGDP)	0.0038	0.0023	1.660	0.096	-0.0007	0.0082
log(FAPLA)	-0.0021	0.0027	-0.780	0.435	-0.0073	0.0031
log(GDSPGDP)	0.0424	0.0073	5.790	0.000	0.0281	0.0567
Constant Coefficient	-1.0381	0.1407	-7.380	0.000	-1.3139	-0.7623

Appendix C. Impact of FS and its dimensions on DD.

Table C1. Impact of food security on DD.

Number of obs.	819					
Number of groups	63					
R-squared	0.6895					
Wald Chi²	3230.02					
log(DDI)=[DV]	***Coef.***	***Std. Err.***	***z***	***P>|z|***	**[95% Conf. Interval]**	
log(FSI)	1.4627	0.0820	17.840	0.000	1.3020	1.6234
log(DERTPAT)	0.0921	0.0161	5.730	0.000	0.0606	0.1235
log(DERTIPC)	0.0639	0.0052	12.370	0.000	0.0538	0.0740
log(FCEPGDP)	-0.2799	0.0710	-3.940	0.000	-0.4190	-0.1408
log(FDINIPGDP)	0.0007	0.0061	0.110	0.911	-0.0113	0.0126
log(FAPLA)	-0.0189	0.0044	-4.320	0.000	-0.0275	-0.0103
log(GDSPGDP)	0.0126	0.0239	0.530	0.598	-0.0343	0.0595
Constant Coefficient	1.1689	0.3687	3.170	0.002	0.4463	1.8916

Table C2. Impact of accessibility of food on DD.

Number of obs.	819					
Number of groups	63					
R-squared	0.4031					
Wald Chi²	1229.58					
log(DDI)=[DV]	**Coef.**	**Std. Err.**	**z**	**P>|z|**	**[95% Conf. Interval]**	
log(ACFI)	1.0723	0.0306	35.070	0.000	1.0124	1.1323
Constant Coefficient	-0.0408	0.0286	-1.420	0.154	-0.0969	0.0153

Table C3. Impact of availability of food on DD.

Number of obs.	819					
Number of groups	63					
R-squared	0.0906					
Wald Chi²	24.8					
log(DDI)=[DV]	**Coef.**	**Std. Err.**	**z**	**P>|z|**	**[95% Conf. Interval]**	
log(AVFI)	0.5282	0.1061	4.980	0.000	0.3204	0.7361
Constant Coefficient	-0.4927	0.1095	-4.500	0.000	-0.7074	-0.2780

Table C4. Impact of stability of food on DD.

Number of obs.	819					
Number of groups	63					
R-squared	0.0188					
Wald Chi²	72.21					
log(DDI)=[DV]	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
log(STFI)	0.6074	0.0715	8.500	0.000	0.4673	0.7475
Constant Coefficient	-0.5849	0.0519	-11.280	0.000	-0.6866	-0.4833

Table C5. Impact of utilization of food on DD.

Number of obs.	819					
Number of groups	63					
R-squared	0.7165					
Wald Chi²	5234.68					
log(DDI)=DV	**Coef.**	**Std. Err.**	**z**	**P>|z|**	**[95% Conf. Interval]**	
log(UTFI)	1.4166	0.0196	72.350	0.000	1.3782	1.4549
Constant Coefficient	-0.0662	0.0155	-4.270	0.000	-0.0966	-0.0358