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Research article

Nexus between digital trade development level and sustainable social development in Sub-Saharan Africa

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Abstract: This research explored the relationship between digital trade development and sustainable social development in Sub-Saharan Africa (SSA). We first defined these two concepts and then constructed the Sustainable Social Development Index (SSDI) and the Digital Trade Development Index (DTDI) using the entropy weighting method and panel data of 26 Sub-Saharan African countries from 2000 to 2020. We also analyzed the relationship between these indices using the Granger non-causality test and the instrumental variables two-stage least squares estimation method. Our findings show a statistically significant bidirectional causal relationship between DTDI and SSDI. Moreover, our estimation result shows that a 1% increase in DTDI is linked to a 0.33% improvement in SSDI. This provides evidence of the potential for digital trade to promote sustainable social progress in SSA. The study concludes that improving the financial infrastructure and promoting gender equality are crucial strategies for advancing both digital trade and social sustainability. This research enhances our understanding of the link between economic and social development and offers valuable insights for policymakers in emerging economies.

Keywords: sustainable social development; SDGs; 2030 Agenda; digital trade; Sub-Saharan Africa; Granger causality test; IV-2SLS

1. Introduction

In recent years, advances in digitalization and information technology have fundamentally transformed global economic structures, opening new avenues for commerce and interaction. Digital trade (DT)—which includes e-commerce, digital services, and the exchange of information and communication technology (ICT) goods—has become the fastest-growing segment of international trade, attracting an expanding base of participants [1,2]. Additionally, DT in Africa is expected to constitute a growing share of trade towards the intra-African trade agreement [3]. As digitalization progresses, its potential to drive development has drawn considerable attention, particularly within the context of sustainable development, where it presents both opportunities and challenges [4,5].

Historically, since the "Brundtland Report" [6], discussions on sustainable development in the economic literature have primarily focused on environmental sustainability [7], and social sustainability has been the least examined [8]. However, a concerted effort has been made to broaden the concept to include the social and economic dimensions, as emphasized in the United Nations' 2030 Agenda [9]. Despite the establishment of 17 Sustainable Development Goals (SDGs)[1], Sachs et al. [10] points out that "at the midpoint of the 2030 Agenda, the SDGs are far off track. At the global level, averaging across countries, not a single SDG is currently projected to be met by 2030, with the poorest countries struggling the most." Furthermore, while a social dimension to sustainability is widely accepted, precisely what this means has not been clearly defined or agreed upon [11,12]. Social sustainability is critiqued as a vague and potentially ineffective concept within the broader discourse on sustainability. It is viewed as a catch-all term that lacks precise definitions, making it challenging to analyze social issues and goals effectively [13]. Recent research has also highlighted the need for a transdisciplinary approach to redefine social sustainability and drive meaningful societal change [14]. Jankiewicz [15] argues that achieving social sustainability is crucial for overall sustainable development, particularly in African countries where economic development is currently lagging. This motivates our investigation into the societal dimension of sustainable development. Herutomo et al. [16] also noted a significant gap in studies linking digital technology to the SDGs. To our knowledge, limited research has explored how DT influences social sustainability. This study aimed to address that gap by examining the intersection of DT and sustainable social development (SSD), offering insights into how DT can help tackle challenges in achieving sustainable social progress.

The key contributions of this paper are threefold: first, we discuss the ongoing debate about the definition of both SSD and DT; second, we employ the systems approach to sustainability of Barbier and Burgess [16] to construct an SSD index (SSDI); we also build a DT development index (DTDI) based on the "eTrade for all" initiative [17]; third, we empirically investigate the relationship between these indices using data from Sub-Saharan African countries, assessing the role of DT development in promoting social sustainability. The findings will offer policy recommendations for developing countries to leverage the opportunities and address the challenges posed by rapid technological advancements such as DT.

Figure 1 displays this study's analytical framework. The rest of the paper is organized as follows: Below, we present a brief literature review, followed by our research hypothesis; Section 2 presents the data and methodology; Section 3 presents the results; Section 4 presents the discussion; and we conclude the paper in Section 5.

[1] See https://sdgs.un.org/goals

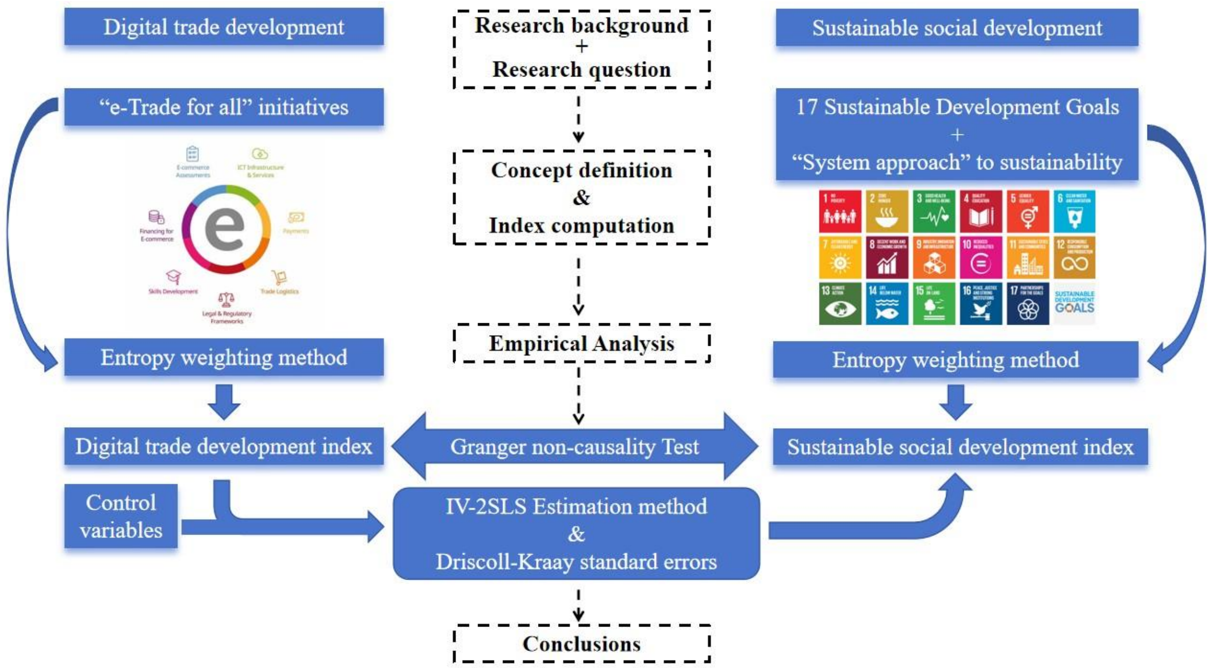

Figure 1. A framework of the analysis.

1.1. Literature review

1.1.1. Theoretical background

Several economic theories offer foundational insights for analyzing the relationship between DT and SSD. Endogenous Growth Theory, developed by Romer [18], emphasizes that technology, human capital, and innovation drive economic growth internally within economies. This theory highlights how DT can stimulate productivity, create economic opportunities, and promote social development by enhancing access to information and technology. Another relevant perspective, in line with Endogenous Growth Theory, is Human Capital Theory, as articulated by Becker [19], which posits that investment in skills and education boosts economic performance. DT can enhance access to education and skill-building resources, reducing inequalities by empowering a broader base of participants in the digital economy. Additionally, New Economic Geography, introduced by Krugman [20], can explain how digital infrastructure influences spatial economic distributions, potentially widening or reducing inequalities based on digital access. These theories collectively provide a framework for understanding how DT spurs growth and contributes to SSD by promoting inclusivity and reducing disparities in resource access.

1.1.2. Empirical literature review

Within the framework of the UN's 2030 Agenda for Sustainable Development [9], limited literature explores the relationship between DT and its 17 SDGs. For instance, Baker and Le [21] explored how DT policy can support sustainable development, focusing on how digital transformation, trade, and investment contribute to achieving the SDGs, especially for developing countries and the least developed countries. The findings highlight key policy measures, including DT facilitation to reduce environmental impacts and expand DT opportunities for women and micro, small, and medium enterprises, thereby fostering more inclusive and sustainable growth. Anukoonwattaka et al. [22] investigated the impact of DT and related policies on sustainable development by examining the relationship between DT variables and SDGs across economic, social, environmental, and governance areas. These findings indicated a strong positive impact of DT on social and environmental SDGs, with mixed results for economic and governance goals, highlighting the importance of regional DT policies and bridging the digital divide to fully realize DT's benefits for sustainable development. However, studies that focus on the relationship between DT development and SSD are still scarce, especially within the SSA region.

Focusing on the literature that analyses emerging economies, specifically African countries, a strand of study highlights the impact of digitalization on various SSD indicators. For instance, Bankole et al. [23] emphasized the importance of telecommunication infrastructure in fostering socio-economic development across Africa, where ICT-enabled trade flows contribute to employment generation, revenue increases, and poverty reduction. Moreover, the proliferation of mobile and internet access supports gender-related economic inclusion by enabling women to participate in the labor force, with evidence showing that increased ICT accessibility improves female employment rates in Sub-Saharan Africa (SSA) [24]. Overall, these studies indicate that technological advancements can be pivotal in reducing social vulnerabilities. Another strand of the literature argues that digitalization has been identified as an essential driver for enhancing access to modern services and economic opportunities, particularly for marginalized populations. Abukari et al. [25] noted that while digital tools can create avenues for economic growth, they may also perpetuate existing inequalities. The interaction between ICT adoption and income distribution further illustrates this complexity, revealing that governance quality can mediate the impacts of technology on social inequality inequality [26]. The intersection of digitalization and governance is vital in shaping social development outcomes. Ncube and De Beer [27] assert that effective regulatory frameworks governing DT can enhance innovation and support sustainable economic development. Additionally, Akinola and Evans [28] provided empirical evidence linking higher levels of ICT to enhanced social and political engagement, reinforcing the role of technology in fostering inclusivity and active citizenship.

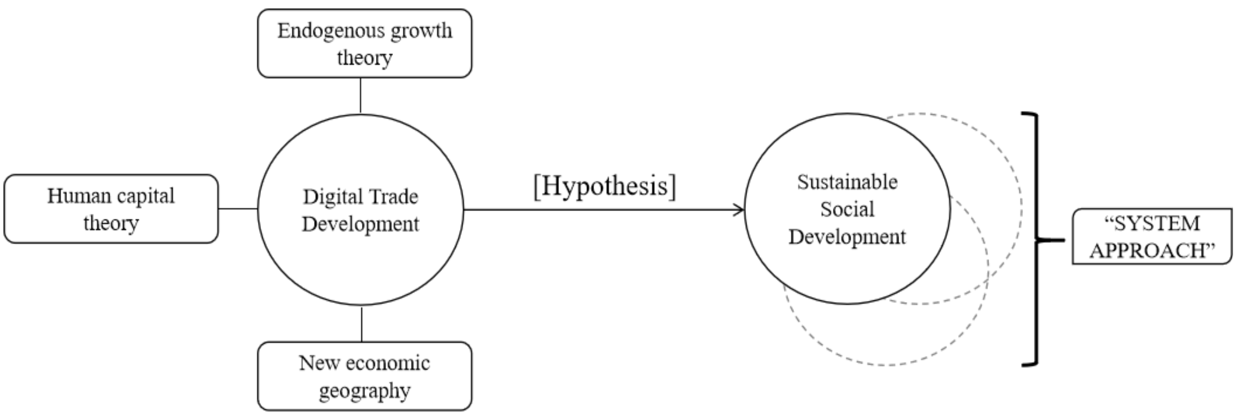

Figure 2. Conceptual model of the study.

Despite an expanding body of literature examining the impact of digitalization and DT on social sustainability, research specifically addressing the influence of the level of DT development on SSD remains notably scarce. This study aimed to bridge this gap, thereby significantly contributing to the existing body of knowledge. Based on the theoretical background and review of the existing literature highlighted above, we propose a conceptual model (Figure 2) to evaluate the relationship between the development of DT and SSD in SSA. We suggest the following hypothesis:

Hypothesis: The development of digital trade positively affects sustainable social development in SSA.

2. Methods and data sources

2.1. Conceptual frameworks

2.1.1. Defining SSD

Social sustainability is a key dimension of sustainable development that focuses on creating inclusive, equitable, and high-quality living conditions within communities. It is defined as "a life-enhancing condition within communities and a process within communities that can achieve that condition" [29]. A valuable framework for understanding social sustainability was provided by Vallance et al. [30], who described it with a three-part model: Development sustainability, which addresses basic needs and social equity; bridge sustainability, which promotes behaviors that support environmental goals; and maintenance sustainability, which seeks to preserve cultural identities during change. This multi-dimensional concept aims to achieve social goals within sustainable development by fostering equitable and cohesive communities [11,31]. Similarly, Murphy [32] argued that social sustainability requires the establishment of societal structures that encourage participation and align with environmental objectives, thus ensuring long-term sustainability. The authors of [33] also emphasized integrating social, economic, and ecological strategies to manage risks, especially climate change-related ones. Additionally, Sen [7] connected social sustainability to human development by focusing on enhancing the quality of life through access to resources and opportunities for participation in governance. Woodcraft [34] defended a similar argument. This focus is particularly significant in developing countries, where ensuring equitable access to resources and opportunities is crucial [15]. Moreover, social sustainability considers various factors that contribute to community welfare [35] and incorporates corporate social responsibility within regional economic frameworks, as seen in initiatives like the African Continental Free Trade Area [36].

Ultimately, social sustainability can be defined as the ability of a social system to foster trust, shared meaning, diversity, and self-organization, enabling resilience and collaboration in addressing the challenges of sustainability [37]. In other words, SSD is the ability of a community or system to maintain and enhance social values over time, ensuring that these values promote well-being, inclusivity, and equity for all individuals [12]. It recognizes the importance of social values in achieving long-term sustainability while considering their relationship with other dimensions, such as environmental and economic sustainability. Consequently, in our research, we define SSD as part of a system (see Figure 3). This approach was first proposed by [38], who argued that to be truly sustainable, economic development must be both "socially" and "ecologically" sustainable. Therefore, social development is also sustainable when it is "economically" and "environmentally" sustainable.

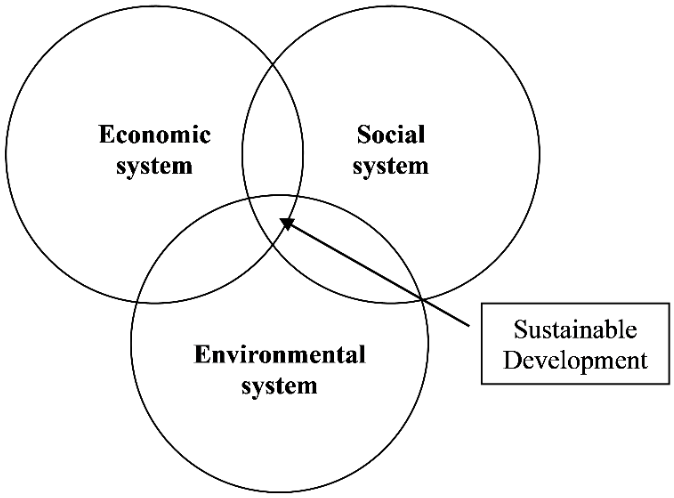

Figure 3. The system approach to sustainability [38].

To enable an analysis of progress toward sustainability, and on the basis of the United Nations 2030 Agenda's 17 SDGs [9], Barbier and Burgess [39] classified five out of the seventeen goals as part of the social system[2], namely: Goal 4 (Quality Education), Goal 5 (Gender Equality), Goal 10 (Reduced Inequalities), Goal 16 (Peace, Justice, and Strong Institutions), and Goal 17 (Partnerships for the Goals). We will discuss this in more detail in Section 2.2.

2.1.2. Defining DT

The "Work Programme on Electronic Commerce" adopted by the General Council of the World Trade Organization in 1998 describes e-commerce as producing, distributing, marketing, selling, or delivering goods and services using electronic means [40]. Many believe that DT can be understood similarly [41]. What is new in DT is the scale of transactions and the rise of disruptive players transforming production processes and industries, including those previously less impacted by globalization [42]. We list the existing literature that tried to define "digital trade" in Table 1 below.

According to WTO et al. in Table 1 [43], this last definition of DT is now widely accepted and has proven feasible and practicable for statistical compilers[3]. Kouty distinguished several types of DT models by considering the actors involved in the transaction, namely business to business (B2B), business to consumer (B2C), consumer to consumer (C2C), consumer to business (C2B), consumer to government (C2G), business to government (B2G), government to business (G2B), and government to consumer (G2C). Numerous studies have already used this definition and the dataset from the official UN Trade and Development[4] website [44–46]. Others consider exports of ICT goods (as a

[2] "Choice of system goals should take place through informed policy debate, which should include a democratic process of stakeholder interaction and public involvement" [16].

[3] The OECD Working Party on International Trade in Goods and Services Statistics widely discussed and endorsed this handbook in their 2020, 2021, and 2022 annual meetings. This handbook was also extensively discussed at the UNCTAD Working Group on Measuring E-commerce and the Digital Economy [43].

[4] https://unctadstat.unctad.org/datacentre/reportInfo/US.DigitallyDeliverableServices

percentage of total goods exports) and ICT goods imports (% of total goods imports) to be a proxy for DT [47,48]. However, due to data limitations within our sample, this study emphasizes the development and progression of DT as a proxy, rather than focusing solely on DT in its current state.

Table 1. Definition of digital trade (DT).

Sources	Definitions
Weber (2010) [49]	DT involves electronic products or services, highlighting its convenience and digital characteristics.
USITC (2013) [50]	DT is defined as international trade and domestic business activities conducted over the internet, including digital products, services, social media, search engines, etc.
Meltzer (2014) [51]	DT refers to the exchange of goods and services facilitated by digital technologies. It includes cross-border data flows that enable trade either through the movement of data itself as a tradeable asset or through productivity gains achieved by utilizing digital services, enhancing firms' competitiveness both domestically and internationally.
López-González and Jouanjean (2017) [42]	All digitally enabled transactions are considered to be within the scope of DT.
USTR (2017) [52]	DT should be a broad concept that captures not only the sale of consumer products on the internet and the supply of online services but also the data flows that enable global value chains, services that enable smart manufacturing, and a myriad of other platforms and applications.
Ma et al. (2018) [53]	DT refers to a new type of trade that takes a modern information network as the carrier and realizes the efficient exchange of physical goods, digital products, and services, as well as digital knowledge and information through the effective use of information and communication technologies (ICTs), thus promoting transformation from a consumer-oriented internet to an industry-oriented internet and ultimately realizing intelligent manufacturing.
Fayyaz (2019) [54]	DT encompasses digitally ordered, facilitated, or delivered transactions involving digital products and a diverse range of participants, including consumers and digital intermediaries.
OECD et al. (2021) [55]	All trade that is digitally ordered and/or digitally delivered. Digitally ordered trade: The international sale or purchase of a good or service conducted over computer networks using methods specifically designed to receive or place orders. Digitally delivered trade: International transactions that are delivered remotely in an electronic format, using computer networks specifically designed for the purpose.
Huang et al. (2021) [56]	In essence, almost any product or service that contains or uses information technologies constitutes DT.
Wang et al. (2023) [57]	DT is known as a process of transferring products and services online through different technological instruments and devices.
WTO et al. (2023) [43]	All international trade that is digitally ordered and/or digitally delivered.

2.2. Model specification and variable selection

We conducted an empirical analysis to test our hypothesis, utilizing a dataset from 26 Sub-Saharan African countries spanning the period of 2000 to 2020 (see Table S1). We employed a baseline theoretical model for this analysis as specified in Eq (1) below.

$$SSDI = f(DTDI, CONTROLS), \tag{1}$$

where *SSDI* is the measure of the Sustainable Social Development Index (SSDI), and *DTDI* denotes the digital trade development index (DTDI), and *CONTROLS* indicates the control variables. We first built a unique composite indicator for our two core dependent and independent variables: The SSDI and the DTDI.

2.2.1. The Sustainable Social Development Index

A sound theoretical framework is the starting point in constructing composite indicators [58]. As discussed earlier, our theoretical framework is the system approach of Barbier [38], which was then adopted by Barbier and Burgess [16]; this framework defines what SSD is and its components, based on the 17 SDGs. We then chose various indicators from the framework of the 2030 Agenda and its 17 SDGs, combined with the work of [21,59–62]; five out of seventeen goals are considered to reflect socially Sustainable Development Goals (Table 2).

Table 2. The socially Sustainable Development Goals' indicators.

Goal	Name	Indicators	Attributes	Source
4	Quality Education	Children out of school (% of primary school age)	−	WDI*
5	Gender Equality	The proportion of seats held by women in national parliaments (%)	+	WDI
10	Reduced Inequalities	GINI index	−	WDI
16	Peace, Justice, and Strong Institutions	Completeness of birth registration (%)	+	WDI
17	Partnerships for the Goals	Exports of goods and services (% of GDP)	+	WDI

*Note: WDI: World Development Indicators from the World Bank database).

The unique composite indicator was constructed using the entropy weighting method, a widely adopted approach in the literature [63,64], which applies principles of information entropy to measure the uncertainty and variability of each indicator. By quantifying the informational contribution of each indicator, entropy values objectively determine the weights, thereby reducing subjective bias and minimizing informational redundancy among indicators [65]. An enhanced version of the entropy method improves precision by standardizing raw data, effectively addressing extreme or negative values that might otherwise skew the measurements. This refinement allows the composite indicator to provide a more accurate and credible assessment of the evaluated variables, establishing the entropy method as a dependable tool for synthesizing diverse data sources into an integrated evaluation framework [66]. The specific steps are as follows.

First, we organized the data into a panel matrix structure, capturing observations across multiple countries *i* over time *t*. Each row in the matrix represents a unique observation value of a goal indicator for country *i* at time *t*, and each column corresponds to a specific variable *n* (goal indicators) measured across different times *t* and countries.

$$\text{Let } X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix},$$

where $m = 1, \ldots, k$ (26 countries × 21 years) and $n = 1, \ldots, 5$ (Goal 4, Goal 5, Goal 10, Goal 16, and Goal 17).

Step 1: Standardization of indicators. We used the two equations below to standardize the chosen goal indicators above:

$$X_{mn} = 1 - \frac{x_{mn} - x'_{min,n}}{x'_{max,n} - x'_{min,n}}, \tag{2}$$

$$X_{mn} = \frac{x_{mn} - x'_{min,n}}{x'_{max,n} - x'_{min,n}}, \tag{3}$$

where X_{mn} is the standardized value for goal indicator n measured for country i in year t; $x'_{max,n}$ and $x'_{min,n}$ are the maximum and minimum values, respectively, for goal indicator n in all countries in the whole period considered. Eq (2) is used for Goals 4 and 10 because a higher value in their observations indicates negative progress toward the SSD goal.

Step 2: Normalization of indicators. Because the entropy weighting method involves logarithms, and we have 0 values after standardization, in Eq (4), we shifted the value by adding one unit to all standardized goal indicators to avoid undefined values:

$$X'_{mn} = X_{mn} + 1. \tag{4}$$

Step 3: Computing the proportion for each country's goal indicator n observed at time t (P_{mn}). In Eq (5), we calculated the proportion relative to the sum of that goal indicator across all countries and years.

$$P_{mn} = \frac{X'_{mn}}{\sum_{m=1}^{k}(X'_{mn})}. \tag{5}$$

Step 4: Computing the information entropy value for each goal indicator n across all countries and years in Eq (6):

$$e_n = -\frac{1}{\ln(k)} \sum_{m=1}^{k} P_{mn} \times \ln(P_{mn}), \tag{6}$$

where k is the total number of observations (26 countries × 21 years) for each goal indicator n.

Step 5: Computing the redundancy d_n of the n^{th} goal indicator in Eq (7):

$$d_n = (1 - e_n). \tag{7}$$

Step 6: Weighting for each goal indicator in Eq (8):

$$W_n = \frac{d_n}{\sum_{n=1}^{5} d_n}. \quad (8)$$

Step 7: Building the composite index using the weights in Eq (8) and the following equation:

$$SSDI_{i,t} = \sum_{n=1}^{5} W_n \times X'_{mn}, \quad (9)$$

where $SSDI_{i,t}$ is the SSDI for country i in year t, W_n is the calculated weight for the indicator n, and X'_{mn} is the normalized observation of indicator n for country i at year t. Table 3 below shows the result of the weight of each goal indicator. We can see that the goal indicator assigned to Goal 16 (Peace, Justice, and Strong Institutions) contributes the most compared with all indicators included in our SSD index, followed by Goal 5 (Gender Equality).

Table 3. Results of the entropy weighting method for SSD indicators.

Goal number	Goal Name	Weight
Goal 16	Peace, Justice, and Strong Institutions	0.252
Goal 5	Gender Equality	0.235
Goal 10	Reduced Inequalities	0.183
Goal 17	Partnerships for the Goals	0.178
Goal 4	Quality Education	0.151

2.2.2. The Digital Trade Development Index

As mentioned in the introduction of this paper, we used the "eTrade for all" initiative [17] (Figure 4) as the theoretical framework to build the composite indicator for DT development. This initiative aims to enhance the ability of developing countries to leverage DT and e-commerce for their economic development. It emphasizes the importance of seven pillars, namely (1) e-commerce readiness assessment and strategy formulation, (2) ICT infrastructure and services, (3) trade logistics and trade facilitation, (4) payment solutions, (5) legal and regulatory frameworks, (6) e-commerce skills development, and (7) access to financing.

Figure 4. The seven key policy areas for "eTrade for all" initiative (https://etradeforall.org/).

On the basis of the work of [64,67–70], we chose the corresponding indicators for all seven pillars (Table 4), and for the second pillar, we first built the indicator using principal components analysis based on four sub-indicators [71] (see Table S2). We then used the same method as in the previous section to calculate the SSDI and compute the DTDI.

Table 4. The digital trade development indicators.

No.	Pillars	Indicators (Unit)	Source
1	E-commerce readiness	1. International trade in digitally deliverable services (percentage of total trade in services)	UNCTAD*
2	ICT infrastructure and ICT services	2.1. Mobile cellular subscriptions (per 100 people) 2.2. Individuals using the internet (% of the population) 2.3. Fixed broadband subscriptions (per 100 people) 2.4. ICT service exports (% of service exports, BoP)	WDI*/PCA*
3	Trade logistics and trade facilitation	3. Logistics performance index: Quality of trade and transport-related infrastructure (1 to 5)	WDI
4	Payment solutions	4. Account ownership at a financial institution or with a mobile money service provider (% of population ages 15+)	WDI
5	Legal and regulatory frameworks	5. Secure internet servers (per million people)	WDI
6	E-commerce skills development	6. Labor force with intermediate education (% of total working-age population with intermediate education)	WDI
7	Access to financing	7. Domestic credit to private sector (% of GDP)	WDI

*Note: UNCTAD: UN Trade and Development; WDI: World Development Indicators; PCA: Principal Component Analysis.

Table 5 below shows that the indicator assigned to Pillar 7 (access to financing) contributes the most to all of the indicators included in our DTDO, followed by Pillar 4 (payment solutions).

Table 5. Results of the entropy weighting method for the DTD indicators.

No.	Pillars	Weight
7	Access to financing	0.218
4	Payment solutions	0.207
1	E-commerce readiness	0.176
2	ICT infrastructure and ICT services	0.170
6	E-commerce skills development	0.087
3	Trade logistics and trade facilitation	0.076
5	Legal and regulatory frameworks	0.062

2.2.3. Control variables

To mitigate potential omitted variable bias in estimating the impact of DT development on SSD, we incorporated five control variables in our analysis. First, GDP per capita growth (GDPCG) was included to account for overall economic performance, which may independently influence social development outcomes. Population growth as the annual percentage (POPG) is considered to capture demographic changes that can impact social structures and economic demands. The unemployment rate percentage of the total labor force) (UNEMP), based on International Labour Organization (ILO) estimates, is included to reflect labor market conditions that may directly affect social stability and well-being. Finally, total natural resources rents (as a percentage of of GDP) (NAT) was added to account for the role of resource wealth in shaping development paths and economic dependencies, which can influence social development outcomes. Together, these variables allowed us to control for key economic and demographic factors, improving the accuracy and reliability of our estimates.

2.3. Estimation strategy

We first ran different tests for our core variables and their relationship to choose the adequate estimation techniques correctly.

2.3.1. Relationship between SSDI and DTDI

Figure 5 below shows the similar trend of our two core variables of interest (SSDI and DTDI), indicating a general growth trend across our sample countries. Figure 6 provides a scattergram to visualize the relationships between the core independent variable (DTDI) and the dependent variable (SSDI). The figure shows that the SSDI and the DTDI are positively correlated.

Figure 5. SSDI and DTDI trends over 2000-2020 across all countries.

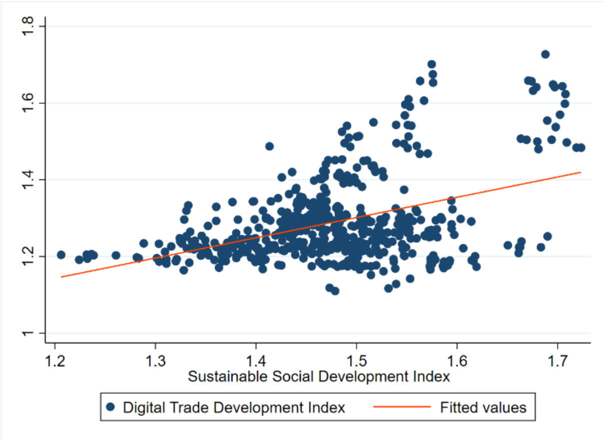

Figure 6. SSDI and DTDI scatter plot.

2.3.2. Granger noncausality test

As highlighted in our theoretical baseline model in Eq (1) and Figure 6, we can assume that SSDI hinges on DTDI. To accurately check the direction of causality between these two variables, we used the Granger causality test, a commonly used method for panel datasets [72,73]. Moreover, Weber and Lopez [74] argued that one should not use this tool to analyze nonstationary variables. Therefore, we first ran a stationary test to see if our variables of interest were unit-rooted. We adopted the second-generation testing method for panel datasets, called the cross-sectional Im–Pesaran–Shin (CIPS) unit root test [75]. The CIPS statistic is the average of the individual cross-sectionally augmented Dickey–Fuller test statistics across all cross-sectional units (i.e., it averages the test statistics from each unit's regression). Table 6 below indicates that the CIPS statistics are lower (more negative) than any critical value; thus, we can reject the null hypothesis and conclude that both SSDI and DTDI are adequate for the Granger causality test.

Table 6. Results of CIPS unit root test and Granger non-causality test.

CIPS				
Null hypothesis:	Statistic	Critical value		
SSDI is homogeneous nonstationary	−3.015	−2.07 (10%)	−2.15 (5%)	−2.30 (1%)
DTDI is homogeneous nonstationary	−2.675			
Granger noncausality test				
Null hypothesis:			HPJ Wald test	*P*-value
DTDI does not Granger-cause SSDI			4.26	0.038
SSDI does not Granger-cause DTDI			11.56	0.000

We used the Stata command "*xtgrangert*" recently developed by Xiao et al. [76], which implements the panel Granger noncausality testing approach developed by Juodis et al. [77]. The test allows for cross-sectional dependence and cross-sectional heteroskedasticity. The results show strong evidence of bidirectional Granger causality between SSDI and DTDI; the null hypothesis of noncausality can indeed be rejected at the 5% level of significance, according to Table 6.

2.3.3. Estimation methods

To address the issue of bidirectional causality, we estimated the effect of DTDI on SSDI using the instrumental variables two-stage least squares (IV-2SLS) estimation method [78,79]. This method can isolate the effect of DTDI on SSDI [80] but requires a valid instrument variable. The choice of instruments was based on previous literature, which used historical data [81,82] and the latitude of the countries [83–86]. Therefore, we chose fixed telephone subscriptions (per 100 people) from 1979 to 1999 and the latitude of the country's capital city as instruments. The rationale behind these choices is as follows. First, telecommunication infrastructure (the infrastructure level two decades earlier) is a primary driver of DT development (nowadays), enabling access to digital services and online markets. However, it may not directly affect social development (e.g., education, health, inequality) unless it increases DT. Second, latitude may affect DT development by influencing the climate, infrastructure needs, and historical trade patterns. Countries at certain latitudes may have better or worse access to resources that support digital infrastructure. It does not directly affect modern-day social development outcomes (e.g., education, health) but can indirectly influence them through DT. The validity of these choices was tested after the estimation. The model for this analysis can be expressed as follows:

$$SSDI_{it} = \alpha_0 + \alpha_1 DTDI_{it} + \sum_{k=1}^{4} \alpha_\text{k} CONTROLS_{kit} + \gamma_i + \delta_t + \varepsilon_{it}, \quad (10)$$

where $SSDI_{it}$ is the measure of SSDI for country i in period t; $DTDI_{it}$ denotes the DTDI; $CONTROLS_{it}$ is the vector of the control variables; and γ_i, δ_t, and ε_{it} are the country effects, time effects, and the error term, respectively.

2.4. Data sources

Table 7. Variables definitions and sources.

Variables	Names (codes)	Definitions	Sources
Dependent	Sustainable Social Development Index (SSDI)	Based on [39]: A higher value indicates progress toward sustainable economic development goals.	WDI*, Entropy
Independent	Digital Trade Development Index (DTDI)	Based on [17]: A higher value indicates better DT development.	UNCTAD*, WDI, PCA*, Entropy
Controls	GDP per capita growth (GDPCG)	GDP per capita growth (annual %)	WDI
	Population growth (POPG)	Population growth (annual %)	WDI
	Unemployment (UNEMP)	Total unemployment (% of the total labour force) (modeled International Labour Organization estimate)	WDI
	Natural resources rents (NAT)	Total natural resources rents (% of GDP)	WDI
Instruments	Fixed telephone subscriptions from 1979–1999 (FTS)	Fixed telephone subscriptions (per 100 people)	WDI
	Latitude (LAT)	The geographical coordinates of the capital cities (decimal degrees)	CEPII*

*Note: UNCTAD: UN Trade and Development; WDI: World Development Indicators; PCA: Principal Component Analysis; CEPII: Centre d'Études Prospectives et d'Informations Internationales.

The data utilized in this study were sourced from a range of reputable international organizations and supplemented by the author's computations, as summarized in Table 7.

3. Results

3.1. Preliminary analysis

3.1.1. Descriptive analysis

The descriptive statistics for the selected variables are presented in Table 8. The dataset is well balanced, with the exception of the negative values observed for the minimum values of GDP per capita growth rate (GDPCG) and latitude (LAT). A negative value for GDPCG indicates a contraction in GDP per capita for certain observations at a given time t, reflecting an economic decline in some of the countries within the sample, which is likely attributable to significant levels of underdevelopment. Negative values for latitude (LAT) correspond to locations situated to the south of the Equator.

Table 8. Results of the entropy weighting method for DTD indicators.

Variable	Obs	Mean	Std.Dev.	Min	Max
SSDI	546	1.475	0.088	1.206	1.723
DTDI	546	1.288	0.107	1.11	1.727
GDPCG	546	1.698	4.517	−22.383	19.939
POPG	546	2.495	0.838	0.002	5.785
UNEMP	546	8.188	6.842	0.6	28.24
NAT	546	9.782	10.121	0.002	59.684
FTS	546	1.256	2.5	0.055	21.329
LAT	546	−1.698	13.287	−25.73	18.15

3.1.2. Multicollinearity test

Table 9. Multicolinearity matrix.

Variables	SSDI	DTDI	GDPCG	POPG	UNEMP	NAT	FTS	LAT
SSDI	1							
DTDI	0.432***	1						
GDPCG	−0.0120	−0.079*	1					
POPG	−0.263***	−0.578***	0.0290	1				
UNEMP	0.084*	0.253***	0.00400	−0.441***	1			
NAT	−0.0310	−0.183***	−0.0140	0.407***	0.081*	1		
FTS	0.386***	0.817***	−0.084**	−0.559***	0.200***	−0.167***	1	
LAT	−0.198***	−0.520***	0.0670	0.239***	−0.096**	−0.0310	−0.542***	1

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Before conducting our regression analysis, we first used a Pearson correlation matrix to identify multicollinearity in our independent variables. This step is essential to avoid unreliable estimates of

regression [87]. As seen in Table 9, our independent variables' coefficients are all below 0.7, a common threshold for severe multicollinearity. Moreover, the relationship between DTDI and SSDI is significant and positive. We discuss this relationship further in the regression analysis below.
Data source: Authors' calculation

3.2. Estimation result

Table 10. The impact of DTDI SSDI.

Estimation Methods	OLS	IV-2SLS
	(1)	(2)
Variables	SSDI	SSDI
DTDI	0.341***	0.332***
	(0.034)	(0.043)
GDPCG	0.000	0.000
	(0.001)	(0.001)
POPG	−0.009	−0.010
	(0.007)	(0.008)
UNEMP	−0.001	−0.001
	(0.001)	(0.001)
NAT	0.001*	0.001**
	(0.000)	(0.000)
Time effect		YES
cons	1.057***	1.033***
	(0.051)	(0.070)
N	546	546
r2	0.195	0.233
Kleibergen-Paap rk LM statistic		125.689***
Cragg-Donald Wald F statistic		298.407
Hansen J statistic		1.419
Hansen J statistic *P*-value		0.2336

Note: Standard errors in parentheses.
Stock-Yogo weak ID test critical values: 19.93 (10%); 11.59 (15%); 8.75 (20%).
***, **, * represent statistical significance at the 1%, 5%, and 10% levels, respectively.

For comparison, we first start with the Ordinary Least Squares (OLS) estimation results for Eq (10), which are reported in column (1) of Table 10. We find a statistically significant and positive estimated coefficient, suggesting that DTDI promotes SSDI. Regarding the magnitude, SSDI increased by 3.53% on average, while DTDI increased by 10%. The IV-2SLS estimation method give similar results. Specifically, for the magnitude in column (2), SSDI increased by 3.32% on average when DTDI increased by 10%. These findings lend support to our research hypothesis. Evidence of the instrumental variable's relevance is reported in column (2) of Table 10. First of all, regarding the *p*-values of Kleibergen and Paap [88], we can reject the null hypothesis that the equation is under-identified, i.e., the model is identified. Next, the failure to reject the null for the Hansen J statistic [89] indicates that the instruments are valid, i.e., there is no significant evidence against the validity of our instruments. Last but not least, the weak instrument test can be used to diagnose whether a particular endogenous regressor is "weakly identified" [90]. Our instruments are valid because we can reject the Stock-Yogo [91] weak ID test null hypothesis since the Cragg-Donald Wald F statistic is greater than the 10% critical values (19.93). The Sargan statistic tests the validity of the instruments.

3.3. Robustness check

We conduct robustness tests to validate the baseline result and avoid biased estimation results. Given the large number of countries (26) and our dataset's low period (21 years), the baseline estimation may produce a biased result. The Driscoll-Kraay standard-errors [92] estimator can address this issue; this technique is designed to address issues related to serial correlation, heteroskedasticity, and cross-sectional dependence, which is common in an $N > T$ dataset. The result of this estimation is shown in Table S3 and is similar to the baseline result.

4. Discussion

Regarding the constructed Sustainable Social Development Index (SSDI), our findings underscore the prominent influence of indicators associated with Goal 16 (Peace, Justice, and Strong Institutions) and Goal 5 (Gender Equality) on overall sustainable social development. Specifically, the completeness of birth registration (as a proxy for Goal 16) and the proportion of parliamentary seats held by women (as a proxy for Goal 5) emerge as the most substantial contributors within the SSDI framework. This result aligns with existing literature that emphasizes the foundational role of institutional integrity and inclusivity in fostering resilient, socially sustainable societies. Birth registration, an indicator of both institutional effectiveness and the safeguarding of individual rights, is crucial in enabling individuals to access essential services, exercise civic rights, and participate fully in economic and social systems. Similarly, female representation in governance structures reflects broader societal commitments to gender equality, which has positively impacted policymaking, social cohesion, and developmental outcomes. These dimensions promote equitable governance and appear to catalyze progress across various facets of social sustainability, demonstrating the interconnectedness and compounding effects of these goals within the broader sustainability agenda.

For Digital Trade Development Index (DTDI), the findings highlight the significant contributions of Pillar 7 (Access to Financing) and Pillar 4 (Payment Solutions) to the overall development of digital trade. Specifically, Domestic Credit to the Private Sector (% of GDP), representing access to financing, and account ownership at financial institutions or with mobile money service providers (% of population aged 15+), reflecting the availability and usage of payment solutions, emerge as the primary drivers within the DTDI framework. These results underscore the central role of financial inclusion and robust payment infrastructure in fostering digital trade. Access to financing, as proxied by domestic credit to the private sector, is crucial for enabling businesses—particularly small and medium-sized enterprises (SMEs)—to participate in digital trade ecosystems. Adequate financial resources facilitate the adoption of digital technologies, improve market access, and support the development of digital platforms for trade. Similarly, widespread account ownership, which reflects both formal financial inclusion and the use of mobile money services, is fundamental for facilitating cross-border transactions and enabling seamless digital payments. The expansion of accessible, secure, and costeffective payment solutions is a cornerstone for digital trade, as it reduces transaction costs, enhances market efficiency, and promotes greater participation in the global digital economy. These findings highlight the interdependence between financial infrastructure and digital trade development, reinforcing the notion that a well-developed financial sector, characterized by both traditional and digital financial services, is integral to enhancing a country's digital trade capacity. Moreover, the prominence of these pillars in our index suggests that further improvements in financing access and payment solutions may catalyze broader advancements in digital trade, particularly in emerging markets where such services remain underdeveloped.

Our empirical findings align with the prevailing theoretical and empirical literature on the interplay between digitalization, economic growth, and social development. Specifically, the results corroborate the hegemonic perspective that emphasizes the transformative role of technology and innovation in fostering economic growth. This school of thought posits that technological advancements stimulate productivity, generate economic opportunities, and enhance social welfare. The positive and statistically significant relationship observed between the Digital Trade Development Index (DTDI) and the Social Development Index (SSDI) in Sub-Saharan African (SSA) economies underscores the critical role of digitalization in shaping social outcomes. This finding is consistent with prior research (e.g., [22,25]), which highlights that the strategic integration of digital technologies into trade policies and frameworks can serve as a catalyst for social development, particularly in regions of the Global South. As such, the results provide empirical support for policy interventions aimed at leveraging digitalization to achieve broader developmental objectives in SSA, reaffirming its potential to drive inclusive growth and social progress.

5. Conclusion

This study examines the relationship between digital trade development and sustainable social development in Sub-Saharan Africa (SSA) by constructing the Sustainable Social Development Index (SSDI) and the Digital Trade Development Index (DTDI) using the entropy weighting method. Based on panel data from 2000 to 2020, the results reveal several significant findings.

First, institutional integrity and inclusivity play a critical role in sustainable social development. Within the SSDI framework, the completeness of birth registration and the proportion of parliamentary seats held by women contribute 25.2% and 23.5%, respectively, to overall social sustainability. These findings underscore the pivotal influence of Goal 16 (Peace, Justice, and Strong Institutions) and Goal 5 (Gender Equality) in fostering resilient and inclusive societies. In the context of digital trade, access to financing and payment infrastructure emerge as key drivers of development. Specifically, domestic credit to the private sector accounts for 21.8% of the DTDI, while account ownership at financial institutions or through mobile money services contributes 20.7%. These results emphasize the centrality of financial inclusion and robust payment systems in facilitating the growth of digital trade ecosystems.

Empirical analysis demonstrates a statistically significant bi-directional causality between DTDI and SSDI, and a quantifiable relationship, with a 1% increase in DTDI associated with a 0.33% improvement in SSDI. This finding highlights the transformative potential of digital trade in driving sustainable social progress in SSA. The study concludes that enhancing financial infrastructure and promoting gender equality are critical dual strategies for advancing digital trade while fostering social sustainability. These findings offer innovative insights into the interconnected dynamics of economic and social development, providing a robust foundation for integrated policy initiatives in emerging economies.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

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Conflict of interest

The authors affirm that this research was carried out without any commercial or financial affiliations that could be perceived as potential conflicts of interest.

Author contributions

Conceptualization: Rakotondrazaka, Xu; Methodology: Rakotondrazaka, Xu; Data curation: Rakotondrazaka; Writing draft: Rakotondrazaka; Supervision, review and editing: Rakotondrazaka, Xu.

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