

Scientific research, governance, and sustainable development: Evidence from AI and digitalization research in the MENA region

Ahmed El Oubani

a.eloubani@umi.ac.ma

Université Moulay Ismail de Meknes

Bouteina Elgharbaoui

Université Moulay Ismail de Meknes

Sara Chelh

Université Moulay Ismail de Meknes

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Abstract

The 2030 Agenda for Sustainable Development calls for translating science and innovation into action rather than remaining at the theoretical level. However, evidence on whether scientific research translates into measurable sustainability outcomes remains limited, particularly for AI and digitalization research and in developing regions such as the Middle East and North Africa (MENA). This study examines whether scientific output in ‘AI and digitalization for sustainability’ is associated with improvements in the Sustainable Development Index (SDI) across 22 MENA countries. We employ a two-stage approach, a bibliometric analysis of publications indexed in Scopus and Web of Science over the period 2010-2025, followed by a dynamic panel model estimated using difference GMM linking these publications to SDI. The bibliometric results reveal a rapidly expanding but unevenly distributed research landscape, concentrated in a few leading countries and organized around three complementary themes: predictive climate analytics, AI and digitalization applications tied to energy and sustainability, and the managerial frameworks guiding their implementation. Econometrically, publications are positively associated with SDI performance, with the effect emerging only after a three-year lag, consistent with a knowledge-diffusion process. Governance plays a decisive moderating role, substantially amplifying this effect in well-governed countries while it becomes negligible in weakly governed ones. The study provides new empirical evidence on how AI and digitalization research contributes to sustainability outcomes in a rapidly digitalizing yet climate-vulnerable developing region.

Keywords: Bibliometric Analysis; Difference GMM; Dynamic Panel Data; Sustainable Development Goals

1. Introduction

The 2030 Agenda for Sustainable Development positions science and innovation at the core of global efforts to tackle pressing environmental, social, and economic challenges, calling for science to contribute to inclusive and sustainable development through action rather than theory. The UN’s 2016 *Science for Sustainable Development* policy brief reinforces this by advocating for closer alignment between science and the Sustainable Development Goals (SDGs) and encouraging partnerships across science, policy, business, and civil society. Among the most transformative forces shaping contemporary societies, digitalization and artificial

intelligence (AI) have emerged as powerful enablers of sustainable development, offering unprecedented opportunities to optimize resource use, enhance productivity, and foster inclusive growth (Bhattacharya et al., 2025; Gupta & Kumar, 2024). The rapid proliferation of academic publications in these fields reflects a growing recognition that technological innovation, when harnessed effectively, can accelerate progress toward the SDGs (Siddik et al., 2026, Mihai et al., 2025; Ologeanu-Taddei et al., 2025; Valencia-Arias et al., 2025).

However, despite this surge in scientific output, it remains unclear to what extent research findings translate into measurable improvements in economic development and sustainability outcomes. While some studies show that the volume of scientific publications is associated with higher economic performance (Pinto et al., 2020), how scientific publication translates into tangible gains in sustainable development remains poorly understood, particularly in developing regions (Valencia-Arias et al., 2025). A recent study by Springer Nature and Overton (2025), drawing on over 12 million policy documents, finds that SDG-aligned research receives more policy citations than non-SDG research, highlighting a strong link between scientific output and policy engagement. However, policy citation captures visibility and uptake in discourse, not verified improvement in sustainability performance; a study can be widely cited by policymakers without any corresponding change in outcomes such as resource efficiency, emissions, or overall development trajectories. This distinction is particularly relevant for the fast-growing field of ‘AI and digitalization for sustainability’, where the assumption that research output drives real-world progress remains largely untested against composite, outcome-based measures such as the Sustainable Development Index (SDI). The gap is more pronounced in developing regions, where weaker research-to-policy pipelines, data infrastructure limitations, and implementation capacity constraints might further widen the distance between scientific activity and measurable sustainability gains. The MENA region illustrates this tension clearly. It has seen growing scientific engagement with AI and digitalization, yet it simultaneously faces acute and worsening sustainability pressures, particularly from climate change, raising the question of whether this research activity is translating into tangible development progress.

This issue is further highlighted by a growing body of scientometric research that questions whether scientific output, however abundant, corresponds to the sustainable development priorities it is supposed to serve. Confraria et al. (2024) show that countries’ research specializations often diverge from their most pressing SDG-related challenges; less than 10% of global SDG-related research is produced in low-income and lower-middle-income countries,

even though these countries face disproportionately greater SDG-related challenges, and positive alignment between research priorities and SDG-related needs applies to only a handful of goals. This raises a crucial question in the current context: even when scientific output is substantial, it does not necessarily target the sustainable development challenges most relevant to the region, and its translation into measurable results cannot be simply assumed based solely on the volume of publications.

To date, no study has empirically examined this relationship using a composite sustainability performance, leaving policymakers and research funders in the region without empirical grounding for the assumption that investment in this research area yields sustainability dividends. This study addresses this gap by examining whether scientific publications in ‘AI and digitalization for sustainability’ contribute to improvements in the Sustainable Development Index (SDI) across MENA countries.

This study draws on several complementary theoretical perspectives, namely, endogenous growth theory and its recent extension to environmentally sustainable growth (Romer, 1990; Lucas, 1988; Aghion et al., 2025), National Innovation Systems and Triple Helix theory, including their recent extension to SDG attainment (Freeman, 1987; Lundvall, 1992; Nelson, 1993; Etzkowitz and Leydesdorff, 2000; Carayannis et al., 2022; Zadegan and Ghazinoory, 2025), knowledge spillover and technology diffusion theory, recently revisited for AI and digital technologies (Acs et al., 1994; Audretsch and Keilbach, 2007; Rogers, 2003; Audretsch et al., 2025; UNCTAD, 2025), and institutional theory, recently extended to AI adoption specifically (North, 1990; Reis and Junior, 2025). Together, these perspectives explain how scientific research can function as knowledge capital that drives sustainable development, and how this translation depends on institutional interactions, knowledge diffusion, and governance quality.

Empirically, we employ a two-stage analytical approach. First, a bibliometric analysis identifies publication trends, leading countries, collaboration patterns, and dominant research themes linking digital technologies and sustainability in the MENA region. Second, we estimate a dynamic panel data model using the difference GMM estimator (Arellano and Bond, 1991) to assess the impact of these publications on SDI.

The bibliometric analysis reveals a rapidly expanding research landscape in the MENA region, with publications on digital technologies and sustainability surging after 2015 and reaching unprecedented levels by 2025. Iran, Saudi Arabia, and Morocco emerge as the most productive countries, while the keyword network reveals three complementary thematic clusters: predictive climate analytics, AI and digitalization applications tied to energy and sustainability,

and the managerial frameworks guiding their implementation. While research in MENA countries remains largely domestically concentrated, international collaboration characterizes the research community in certain countries, particularly between North Africa and Europe, as well as among Asian research hubs. The econometric analysis, based on the dynamic panel model, provides evidence that scientific publications are associated with sustainable development outcomes, with the effect materializing after a three-year lag. Notably, governance plays a crucial moderating role. The impact of publications is amplified in well-governed countries, while becoming negligible in weakly governed contexts.

This study makes several contributions to literature. First, it bridges bibliometric analysis and econometric measurement, linking scientific research activity to measurable sustainability by testing the relationship between research output and a direct, outcome-based sustainability measure, the SDI. Second, it extends the theoretical literature on knowledge diffusion and institutional absorptive capacity by testing not only whether scientific output predicts sustainability outcomes, but whether this relationship is conditional on governance quality, thereby providing an empirical account of the institutional mechanism through which research findings do or do not translate into measurable development gains. Third, it provides the first empirical test of this relationship in the MENA region, a setting that combines rapidly growing AI and digitalization research activity with acute and mounting sustainability pressures. Consistent with these theoretical mechanisms, the findings carry important policy implications for governments seeking to leverage research investments for sustainable development.

The remainder of this paper is structured as follows. Section 2 presents a review of the relevant literature. Section 3 describes the data and methods. Section 4 reports and discusses the empirical results. Section 5 examines the study's implications for SDG-related policy. Section 6 concludes with a summary of the findings and limitations of the study.

2. Literature review

2.1. Digitalization, AI, and sustainable development

In recent years, technological advancements related to digitalization and artificial intelligence (AI) have profoundly altered economic dynamics and nations' development trajectories. At the same time, the SDGs have emerged as a global framework aimed at reconciling economic growth, social inclusion, and environmental preservation. Against this backdrop, the role of digital technologies in improving sustainability performance has attracted growing academic interest.

Recent research presents AI as a general-purpose technology capable of simultaneously

influencing productive, environmental, and institutional systems. Vinuesa et al. (2020) demonstrate that AI can positively impact most SDGs, particularly in energy, natural resource management, and public health. Bhattacharya et al. (2025) analyze the interaction between AI, digitalization, and global disruptions, highlighting the foundational role of digital technologies in the resilience of economic systems facing exogenous shocks. Rashid et al. (2025) find that AI-powered big data analytics significantly improves green supply chain collaboration, sustainable manufacturing, and environmental process integration, while also flagging risks tied to digital inequalities and environmental rebound effects.

Bibliometric evidence confirms the growing prominence of this field. Mihai et al. (2025) identify a significant increase in publications on digitalization and sustainability-oriented innovation, while Valencia-Arias et al. (2025) show that AI research is increasingly concentrated in the energy transition and circular economy. Zejjari and Benhayoun (2024) show, in the context of sustainable supply chains, that AI improves traceability, logistical efficiency, and waste reduction.

At the institutional level, digitalization also improves governance and SDG implementation. ElMassah and Mohieldin (2020) show that digital transformation facilitates SDG localization by enhancing transparency, while also promoting financial inclusion and administrative efficiency. Ologeanu-Taddei et al. (2025) similarly find that the digital transformation of firms generates synergies with corporate sustainability, while also creating tensions related to the costs of organizational adaptation. Gupta and Kumar (2024) highlight AI's strategic role in achieving SDGs through smart infrastructure and urban management. Finally, in the North African context, El Oubani (2024a, 2024b, 2024c) shows that digital information dynamics, including investor sentiment on social media and online attention, influence sustainable investment performance, underscoring the growing interconnection between digitalization, finance, and sustainability.

Taken together, this literature establishes that digitalization and AI are consistently associated with sustainability gains across environmental, institutional, and financial dimensions. What remains far less clear is whether the scientific research underpinning these technologies, as opposed to their deployment, itself translates into measurable sustainability performance. This question is addressed in the next section, which reviews the theoretical mechanisms and empirical evidence linking scientific output to economic and sustainable development.

2.2. Scientific research output, economic development, and sustainability: theoretical foundations and empirical evidence

The relationship between scientific output and economic performance is rooted in endogenous growth theory. Lucas (1988) and Romer (1990) show that the accumulation of human capital and knowledge generates increasing returns and sustains long-term growth, placing scientific output at the heart of the development process. This framework has recently been extended to explicitly incorporate environmental constraints, with Aghion et al. (2025) modeling how innovation-driven growth can be reconciled with environmental sustainability objectives, a direct theoretical bridge between knowledge production and sustainable outcomes that motivates this study's first hypothesis. Empirically, Pinto et al. (2020) demonstrate that research output exerts a positive and significant effect on economic growth, and Furman et al. (2002) introduce the concept of national innovation capacity, linking scientific infrastructure, institutions, and competitiveness.

Theories of national innovation systems developed by Freeman (1987), Lundvall (1992), and Nelson (1993) posit that economic performance depends on the interaction between universities, industry, and public institutions. This dynamic is formalized in the Triple Helix model of Etzkowitz and Leydesdorff (2000), which underscores the role of universities in generating and disseminating knowledge. The model has since been extended toward Quadruple and Quintuple Helix formulations that explicitly incorporate environmental and societal actors as additional helices (Carayannis et al., 2022), and has been applied directly to SDG attainment. In fact, Zadegan and Ghazinoory (2025) show that university-industry-government interactions are a recurring driver of innovation outcomes aligned with the SDGs. This strand of theory is particularly relevant to governance-related mechanisms, discussed further below.

Research spillovers are a key mechanism linking scientific output to economic growth. Acs et al. (1994) show that R&D externalities particularly benefit small innovative firms, while Audretsch and Keilbach (2007) develop the knowledge spillover theory of entrepreneurship, whereby academic research stimulates the creation of innovative firms. A recent 30-year retrospective of this theory (Audretsch et al., 2025) extends it to account for digital transformation and AI as general-purpose technologies that accelerate knowledge diffusion across regions and industries, suggesting that spillover mechanisms now operate faster and at greater scale than the original theory anticipated, a dynamic particularly relevant to fast-moving fields like AI-for-sustainability research. Complementing this, technology diffusion theory (Rogers, 2003) emphasizes that the spread of innovations depends on social and institutional adoption mechanisms; recent work on AI diffusion in low- and middle-income countries

(UNCTAD, 2025; World Intellectual Property Organization (WIPO), 2026) reframes this dependency around absorptive capacity, digital infrastructure, and policy design, which is especially relevant to the MENA context examined in this study.

Institutions also play a decisive role in translating research into economic and sustainability outcomes. North (1990) argues that institutional quality determines the effectiveness of R&D investment; this claim has recently been extended to AI specifically, with Reis and Junior (2025) integrating institutional theory with diffusion of innovation theory to show that macro-level institutional pressures and micro-level adoption behaviors jointly shape whether AI-related knowledge is effectively absorbed by organizations. Dong and Hwang (2021) find that institutional quality critically determines the benefits of knowledge spillovers for sustainable development. This moderating role of institutional quality is corroborated specifically in the MENA context by Azmeh (2025), who finds, using a dynamic panel GMM approach, that the effect of research output on economic growth is significantly conditional on government effectiveness and the rule of law. Collectively, this body of theoretical and empirical work suggests that scientific output generates macroeconomic and sustainability effects only in favorable institutional environments, a conditionality that motivates this study's second hypothesis, on the moderating role of governance quality.

In the context of sustainability, extending these theories suggests that scientific output in AI focused on the ecological transition could influence not only economic growth but also the sustainable performance of nations. Yet, although the literature extensively documents the link between scientific research and economic growth, its direct impact on sustainable development indicators remains insufficiently analyzed.

This gap is illustrated by recent evidence from Springer Nature and Overton (2025), which examines research impact, proxied by citation counts in SDG-related policy documents, across more than 12 million policy documents, finding that SDG-related research receives more policy citations than non-SDG research. This highlights a clear connection between scientific output and policy engagement, yet policy citations do not constitute a definitive measure of research impact. Research may be cited for contextual, dissenting, or methodological reasons rather than because it directly shaped a policy decision, and impact can also arise through uncited channels such as oral evidence. Policy citations should therefore be treated as one signal among several reflecting how research informs policymaking, not as confirmation that research translates into measurable outcomes (Springer Nature and Overton, 2025).

No study to date has addressed a more specific and consequential question: how research output

on ‘AI and digitalization for sustainability’ translates into economic development through the achievement of the SDGs. This study addresses this gap by empirically examining the relationship between scientific output in ‘AI and digitalization for sustainability’ and countries’ sustainable development performance, as measured by the Sustainable Development Index (SDI). Using a rigorous econometric approach, this study contributes empirical evidence to the existing literature by testing the following hypotheses:

H1: Scientific publications in ‘AI and digitalization for sustainability’ have a positive effect on SDI.

H2: Governance quality positively moderates the relationship between scientific publications in ‘AI and digitalization for sustainability’ and SDI.

2. Methods

This study examines whether scientific research outputs in ‘AI and digitalization for sustainability’ contribute to measurable improvements in sustainable development performance in the MENA region. To capture both the evolution of this research field and its downstream empirical effects, the analysis proceeds in two complementary stages. First, a bibliometric analysis maps the structure and evolution of this research field, identifying publication trends, leading countries, collaboration patterns, and dominant research themes linking digital technologies and sustainability, and providing the empirical basis for constructing the scientific output variable used in the second stage. Second, a dynamic panel data model is estimated using the difference GMM estimator - which addresses the potential endogeneity of research output and accounts for the dynamic, persistent nature of sustainable development performance - to test whether this research output translates into measurable improvements in the Sustainable Development Index (SDI), and whether this relationship is moderated by governance quality. This two-stage design allows the study to move beyond simple bibliometric description toward a rigorous test of the causal relevance of scientific output for sustainability outcomes, a link that, as shown in the literature review, remains largely untested empirically.

3.1. Bibliometric analysis

The first part of this study uses a bibliometric approach to systematically analyze scientific literature on the intersection of digital technologies and sustainability in MENA countries. Bibliometric analysis enables the quantitative assessment of research output, underlying intellectual structures, and collaboration patterns within a scientific discipline, helping identify current trends, authorship, and the conceptual framework shaping a specific field (Donthu et

al., 2021). The analysis proceeds in four steps.

The first step consists of the literature search. A comprehensive search is performed using two major multidisciplinary scientific databases, Scopus and Web of Science (WoS Core Collection), chosen for their wide disciplinary coverage, high-quality indexing standards, and common use in bibliometric studies; combining multiple databases increases coverage and reduces potential database bias relative to single-source searches (Parmentola et al., 2022). The search strategy combines keywords associated with digital transformation (e.g., digital transformation, artificial intelligence, machine learning, big data, Internet of Things, blockchain, Industry 4.0) with sustainability-related terms (e.g., sustainable development, circular economy, green transition, ESG, climate, carbon emissions), using Boolean operators to ensure conceptual intersection between the two domains. The search is restricted to publications affiliated with the 22 MENA countries¹. The time window spans 2010-2025, covering the period since digital transformation and AI-related research began gaining sustained traction in scientific literature. Only peer-reviewed articles and conference publications are retained to ensure scientific relevance.

The second step involves data collection and pre-processing. All available metadata are exported from Scopus in BibTeX format and from WoS in plain text format, including authors, affiliations, keywords, abstracts, references, publication year, source titles, and digital object identifiers (DOIs). Raw files are converted into structured data frames using the `convert2df()` function from the *bibliometrix* R package, and datasets from Scopus and WoS are merged into a unified database. Duplicate records are then removed using a hierarchical procedure: publications sharing identical DOIs are treated as duplicates and retained only once; where DOIs are missing, duplicates are identified using title and publication year combinations. This procedure results in a final harmonized bibliographic corpus of 15,231 publications on digital technologies and sustainability in the MENA region.

The third step consists of the bibliometric analysis itself, conducted in R using the *bibliometrix* package, which offers standardized tools for science mapping. This step examines the growth of scientific production over time, identifies leading contributing countries, and computes productivity metrics to evaluate research performance across countries. Scientific collaboration patterns are further investigated through country-level co-authorship networks, constructed

¹ Algeria, Bahrain, Djibouti, Egypt, Iran, Iraq, Jordan, Kuwait, Lebanon, Libya, Mauritania, Morocco, Oman, Qatar, Saudi Arabia, Somalia, Sudan, Syria, Tunisia, Turkey, United Arab Emirates, and Yemen

using bibliometric network techniques and visualized using graph-based methods.

The final step involves keyword and thematic analysis. Prior to this analysis, orthographic variants of the same keyword arising from indexing differences (e.g., “machine learning”/” machine-learning,” “climate change”/” climate-change,” “artificial intelligence”/” artificial-intelligence”) are identified and merged to avoid artificially splitting the frequency and network centrality of a single concept across two nodes. To map the conceptual structure of the research area, a keyword co-occurrence network is constructed using the 50 most frequent keywords (author and index keywords combined), with edge weights based on co-occurrence frequency; the weakest 50% of co-occurrence links are filtered out to improve network readability, and thematic clusters are identified using the Walktrap community detection algorithm (Pons and Latapy, 2005), implemented via the *igraph* R package. The resulting network graph visualizes keyword clusters and their interconnections, helping identify dominant research themes and patterns not immediately apparent from raw publication counts.

This bibliometric analysis provides the descriptive foundation for the study’s second stage. Publication counts on ‘AI and digitalization for sustainability’ derived from this analysis serve as the scientific output variable in the subsequent dynamic panel model, which assesses whether this research activity translates into measurable improvements in sustainable development performance.

3.2. Methods for econometric analysis

3.2.1. Data, sample and variables

This study uses an unbalanced panel dataset covering 22 MENA countries over the period 2010-2024. The start year is set to 2010, as few or no publications on AI and digitalization for sustainability existed for many countries prior to this period; 2025 is excluded due to missing data on the dependent variable.

The dependent variable is the Sustainable Development Index (SDI), sourced from the World Bank database, which captures countries’ progress toward the SDGs. The independent variable of interest is scientific publications (*Pub*), measured as the number of publications in ‘AI and digitalization for sustainability’ extracted from Scopus and WoS using a structured keyword search strategy, a proxy for research output widely used in prior literature (Lee et al., 2011; Solarin and Yen, 2016; Pinto et al., 2020). Following standard practice, we apply a logarithmic transformation to reduce skewness and facilitate elasticity interpretation; since the variable includes zero values, we use $\ln(Pub + 1)$ (Feng et al., 2019).

Control variables include Gross Domestic Product (GDP, in logarithm), digital infrastructure (proxied by Internet penetration rate), and governance (captured by government effectiveness), all obtained from the World Bank database. GDP plays a dual and often contradictory role in sustainable development. Economic growth can generate the financial resources needed to invest in cleaner technologies and renewable energy, yet the Environmental Kuznets Curve (EKC) hypothesis suggests that environmental pressure rises during early development before declining beyond a certain income threshold (Grossman and Krueger, 1995). Empirical evidence reflects this complexity. Ozcan et al. (2026) find that GDP positively affects SDG performance, while Güler et al. (2025) show that the EKC does not hold in China, where GDP growth increases ecological footprints, and Groner and Moradi (2024) identify a negative bidirectional relationship between SDG scores and GDP growth rates. Given this ambiguity in the literature, GDP is included as a control variable to isolate the effect of scientific output from broader economic dynamics.

Institutional quality is likewise widely recognized as a key driver of sustainable development. Ozcan et al. (2026) find that weak governance substantially reduces SDG performance, while Durczak et al. (2026) argue that governance can either promote or hinder environmental progress, with stronger transparency, accountability, and regulatory quality accelerating SDG achievement. Bisogno et al. (2025) show that countries with stable, effective governance and robust anti-corruption measures make greater progress, particularly on social and economic goals, and Massuga et al. (2024) demonstrate that voice and accountability, together with government effectiveness, positively influence overall sustainability performance. Governance is therefore included both as a control variable and, as outlined in *H2*, as a moderator of the relationship between scientific output and SDI.

Digital technologies support SDG achievement by enhancing the efficiency, accessibility, and transparency of public services, particularly in healthcare, education, and infrastructure. Evidence on this link is nonetheless conditional; Amri (2026) shows that the net effect of information and communication technologies on sustainability depends on context, with cleaner energy and reliable access yielding positive outcomes while carbon-intensive networks and exclusionary constraints erode these gains. Bayar et al. (2024) confirm that internet usage significantly drives sustainable development in both the short and long term across African countries, and GeSI and Deloitte (2019) similarly establish a strong positive link between digital access and SDG achievement. Digital infrastructure is therefore included as a control variable to account for this parallel channel through which digitalization affects sustainability outcomes.

Table 1 Descriptive statistics and Fisher test results

Variable	Obs	Mean	SD	Min	Max	F-Test
SDI	321	60.83	7.86	42.09	72.63	289.04 (p-value< 0.001)
GDP	321	8.71	1.36	5.39	11.59	
Digit	284	58.04	30.29	1.25	100.00	
Gov	321	-0.36	0.84	-2.21	1.42	
Pub	321	1.86	1.77	0.00	6.72	

Source : Author's own work

Table 1 presents descriptive statistics for all variables. The average SDI score is 60.83 (SD = 7.86), ranging from 42.09 to 72.63, reflecting substantial heterogeneity in sustainable development performance across the region. Internet penetration (*Digit*) averages 58.04% but exhibits high dispersion (SD = 30.29), indicating stark digital divides between countries. Governance quality (*Gov*) is generally weak, with a mean of -0.36, consistent with the region's institutional challenges. Scientific publications show considerable inequality (mean = 1.86, SD = 1.77), ranging from countries with no publications to high research producers. Missing data are limited to Internet penetration (11.5%), concentrated mainly in 2024, which is acceptable for unbalanced panel estimation.

Table 2 Correlation Matrix

	SDI	GDP	Digit	Gov	Pub
SDI	1.00				
GDP	0.33	1.00			
Digit	0.45	0.72	1.00		
Gov	0.56	0.82	0.70	1.00	
Pub	0.62	0.31	0.60	0.39	1.00

Source : Author's own work

All correlations (Table 2) are positive and statistically significant at 1% level. Notably, publications exhibit a strong correlation with SDI ($r = 0.62$), providing preliminary support for our research hypothesis. Furthermore, the Fisher test (Table 1) strongly rejects poolability, confirming the presence of significant individual effects and justifying the panel approach.

To assess multicollinearity, we compute the Variance Inflation Factor (VIF) using an auxiliary regression of SDI on all explanatory variables. The global VIF is 2.24, well below the conventional threshold of 5, indicating that multicollinearity is not a concern in our specification.

3.2.2. Econometric model: specifications and estimation method

To examine the relationship between scientific publications and sustainable development, we specify a dynamic panel model that accounts for the persistent nature of sustainable development outcomes and the potential delayed effects of research output. The baseline model is specified as follows:

$$SDI_{it} = \alpha SDI_{i,t-1} + \sum_{j=1}^k \beta_j Pub_{i,t-j} + \gamma_1 GDP_{it} + \gamma_2 Digit_{it} + \gamma_3 Gov_{it} + \mu_i + \varepsilon_{it} \quad (1)$$

where, SDI_{it} is the Sustainable Development Index for country i at time t ; $SDI_{i,t-1}$ is the lagged dependent variable, capturing persistence in sustainable development; $Pub_{i,t-j}$ represents the scientific publications with j lags ($j = 1, 2, 3$, selected as the lag structure minimizing the residual sum of squares and maximizing R^2 across a preliminary set of models with lags 1 through 4), transformed as $\ln(Pub_{it} + 1)$; GDP_{it} is the logarithm of GDP; $Digit_{it}$ is the digital infrastructure, captured by internet penetration rate; Gov_{it} is the governance effectiveness index; μ_i captures unobserved time-invariant country-specific effects; and ε_{it} is the idiosyncratic error term.

Scientific publications are included with lags to account for the time required for research to be disseminated, absorbed, and translated into policy and practice, consistent with knowledge diffusion theory (Rogers, 2003). The inclusion of the lagged dependent variable introduces endogeneity, as $SDI_{i,t-1}$ is correlated with the country-specific effects μ_i . This dynamic panel bias, known as Nickell bias (Nickell, 1981), renders standard estimators such as pooled OLS or fixed effects inconsistent, particularly when the time dimension T is moderate. This motivates the use of the Generalized Method of Moments (GMM) approach.

Variables such as education and R&D expenditure were not included as control variables in the dynamic specification due to the lack of consistent data across MENA countries over the study period and the limited temporal variation observed in the available series. Their omission does not compromise the consistency of the model, as their effects are largely captured by the lagged dependent variable and the country-specific fixed effects eliminated through differencing.

To estimate our model, we employ the difference GMM estimator developed by Arellano and

Bond (1991). This estimator addresses the endogeneity inherent in dynamic panel models through two key transformations. First, first-differencing eliminates the country-specific fixed effects μ_i :

$$\Delta SDI_{it} = \alpha \Delta SDI_{i,t-1} + \sum_{j=1}^k \beta_j \Delta Pub_{i,t-j} + \gamma_1 \Delta GDP_{it} + \gamma_2 \Delta Digit_{it} + \gamma_3 \Delta Gov_{it} + \Delta \varepsilon_{it} \quad (2)$$

Second, to address the correlation between $\Delta SDI_{i,t-1}$ and $\Delta \varepsilon_{it}$ introduced by differencing, the estimator uses lagged levels of the endogenous variables as instruments. The moment condition for the lagged dependent variable is:

$$E[SDI_{i,t-s} \Delta \varepsilon_{it}] = 0 \text{ for } s \geq 2 \quad (3)$$

This internal generation of instruments is a key advantage, as finding external valid instruments is often difficult in empirical settings. Following Roodman's (2009) recommendations to avoid instrument proliferation, we restrict the instrument set to lags 2 through 4 and apply the collapse option, which combines instruments into smaller sets. This results in 16 instruments for 22 countries, maintaining a favorable instruments-to-countries ratio.

The choice of difference GMM over system GMM is justified by three considerations. First, our dependent variable exhibits moderate persistence ($\alpha = 0.52$, see Table 3), mitigating concerns about weak instruments that typically arise with highly persistent series. Second, the unbalanced structure of our panel is better handled by the difference estimator, which requires fewer assumptions about initial conditions. Third, the empirical rule of thumb for dynamic panels, that a consistent GMM estimator should yield a coefficient for the lagged dependent variable between the OLS upper bound (0.931) and the fixed effects lower bound (0.139), is satisfied by difference GMM (0.522) but violated by system GMM.

Beyond the direct relationship between research output and sustainability outcomes, institutional theory (North, 1990) suggests that the translation of knowledge into real-world outcomes depends on institutional quality and absorptive capacity, implying that governance may moderate this relationship. This moderating role is supported empirically. For instance, Dong and Hwang (2021) show that the benefits of knowledge spillovers for sustainable development depend critically on institutional quality. To test this moderation effect, corresponding to *H2*, we augment the baseline model with an interaction term between scientific publications and governance:

$$SDI_{it} = \alpha SDI_{i,t-1} + \sum_{j=1}^k \beta_j Pub_{i,t-j} + \gamma_1 GDP_{it} + \gamma_2 Digit_{it} + \gamma_3 Gov_{it} + \sum_{j=1}^k \delta_j (Pub_{i,t-j} \times Gov_{it})$$

$$\times Gov_{it}) + \mu_i + \varepsilon_{it} \quad (4)$$

Beyond the dynamic panel bias addressed above, a broader identification concern is that countries with stronger institutions, more developed research systems, better digital infrastructure, and higher overall levels of development may simultaneously publish more and perform better on sustainability indicators, independent of any causal effect of publications themselves. Several features of the empirical strategy help address this concern. First, the difference GMM estimator accounts for time-invariant country-specific unobserved heterogeneity (e.g., persistent institutional culture, geography, or long-standing research traditions) through first-differencing, which removes these confounders from the estimated relationship. Second, the model includes GDP, digital infrastructure, and governance quality as time-varying controls, directly addressing the most plausible common drivers of both research output and SDI performance identified in the literature (Ozcan et al., 2026; Durczak et al., 2026; Bisogno et al., 2025). Third, the use of lagged publication counts (t-1 through t-3) rather than contemporaneous values reduces the likelihood that the estimated relationship reflects simultaneous determination of *Pub* and SDI by a common contemporaneous shock, since current-year SDI performance cannot plausibly cause publication output recorded up to three years earlier.

All estimations are performed using R version 4.5.

4. Results and discussions

4.1. Bibliometric analysis results

4.1.1. Publication Trends

Based on Figure 1, research on the intersection of digital technologies and sustainability in MENA countries began to gain momentum after 2015. While annual output remained relatively modest from 2010 to 2014 (fewer than 100 publications per year), a notable upward shift occurred beginning in 2015, marking the transition from an exploratory to a growth phase. Since then, publications in this field have risen steadily, particularly after 2019. Output more than tripled between 2019 and 2022, followed by a sharp acceleration between 2023 and 2025, with more than 5,000 articles published in 2025 alone.

This growth likely reflects both rising academic interest and the structural transformations underway across the region, including ambitious national digital transformation strategies, smart city developments, large-scale renewable energy investments, and economic diversification programs aligned with long-term visions such as Saudi Arabia's and the UAE's

Vision 2030 agendas. North African countries are pursuing parallel digital and green transition pathways, illustrated by flagship initiatives such as Morocco’s Noor Solar Complex, the “Digital Morocco 2030” strategy, and Egypt’s ICT 2030 Strategy. The COVID-19 pandemic further acted as a catalyst, accelerating digital adoption across governance, education, finance, and energy systems, and likely contributing to increased scholarly production in this domain. While this publication growth signals expanding scientific engagement with the digital-sustainability nexus, it does not by itself confirm a corresponding rise in policy uptake or implementation, a distinction this study returns to in its econometric analysis.

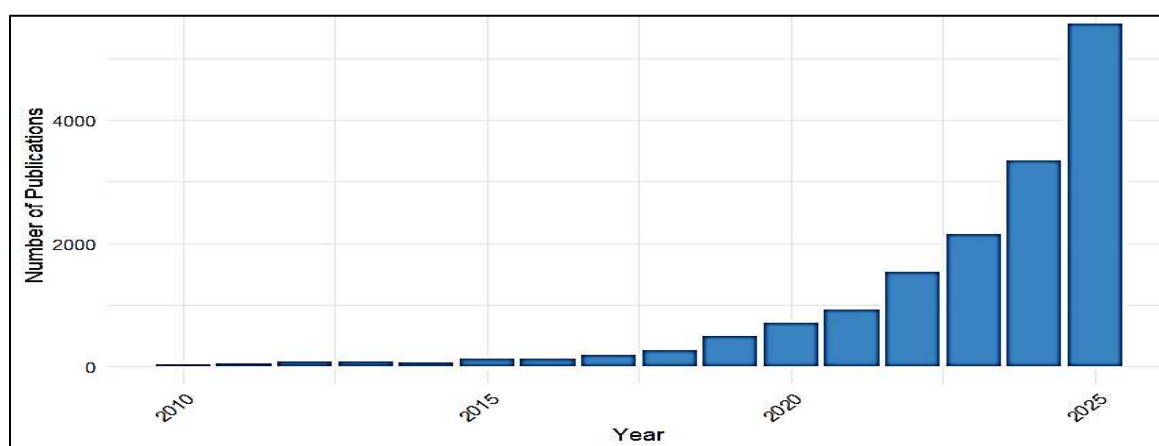


Fig. 1 The distribution over time of articles on digital technologies and sustainability in MENA countries. Source: Authors’ elaboration based on bibliometric data

4.1.2. Document types and country distribution

The distribution of document types offers additional insight into the maturity and spread of research in this field. The dataset is predominantly composed of peer-reviewed journal articles (11,827 documents), the primary channel for disseminating validated scientific knowledge. Conference publications also represent a notable share (3,404 documents), reflecting the dynamic, fast-moving nature of digital sustainability research, where initial findings are frequently presented and discussed at academic conferences before formal publication.

The analysis of corresponding authors’ countries reveals a strong concentration of scientific production among a limited number of leading nations (Figure 2). Iran ranks first with 1,796 articles (12.82%), followed closely by Saudi Arabia (1,691) and Morocco (1,158), indicating their central role in driving research activity in the field. Turkey (985) and Egypt (912) also emerge as key contributors, reflecting the growing research capacity of major MENA economies.

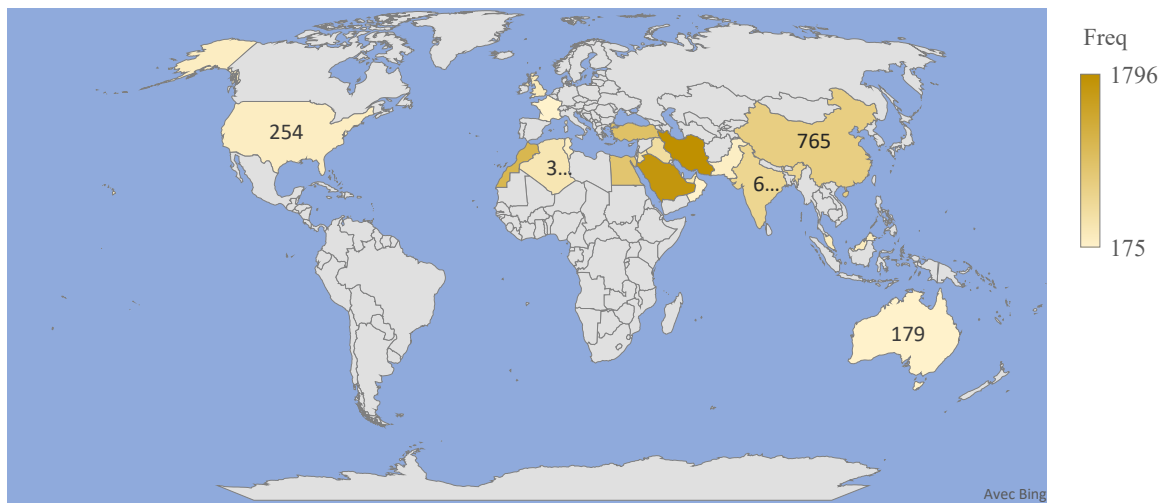


Fig. 2 Paper distribution per country. Notes: darker shades indicate higher output, while lighter shades represent lower contributions. Source: Authors' elaboration based on bibliometric data

4.1.3. International collaboration patterns

Collaboration intensity, measured by the Multiple Country Publication (MCP) ratio, varies considerably across these leading producers. Egypt (0.442) and Iran (0.316) show relatively high shares of internationally co-authored work, while Morocco (0.159) and Turkey (0.079) rely predominantly on single-country publications. Figure 3 illustrates these collaboration patterns, highlighting connections between MENA countries and their key international partners.

A more detailed view of the network highlights the particular role of MENA countries within this global structure. The clustered visualization identifies three major collaborative groups. The first, centered on Morocco and European partners such as France, Germany, Spain, Switzerland, and Italy, reflects deep historical and academic ties between North Africa and Europe, often supported through joint programs, mobility schemes, and international funding. The second, comprising mainly Asian countries such as Saudi Arabia, the UAE, China, India, Malaysia, and Pakistan, represents a rapidly expanding research hub characterized by advanced technological capabilities and active involvement in digital transformation research. The third connects Anglo-Saxon and Asian nations, including Qatar, Kuwait, the United Kingdom, the United States, Australia, and Japan, serving as bridges linking different regional research communities.

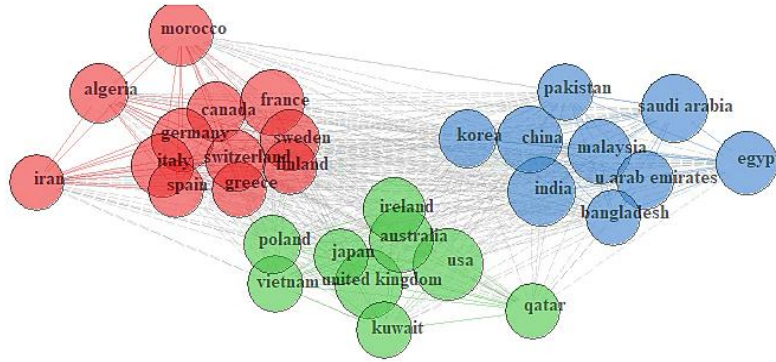


Fig. 3 Country Collaboration Network. Notes: Nodes represent countries, node size reflects the total number of publications, and edges weight indicates the strength of collaborative relationships between countries. Source: Authors' elaboration based on bibliometric data

When focusing exclusively on MENA countries, the collaboration network becomes denser but also reveals structural asymmetries (Figure 4). For instance, Saudi Arabia, Morocco, Egypt, and Iran occupy relatively central positions within the regional network, suggesting stronger institutional capacities, more developed research infrastructures, and greater integration into international scientific collaboration. In contrast, several other countries appear at the periphery of the network, reflecting lower research output or more limited integration into the regional academic ecosystem.

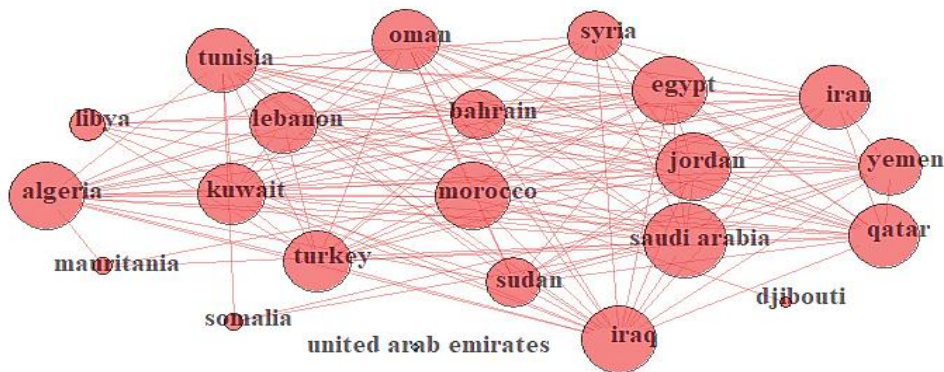


Fig. 4 Collaboration network of MENA countries. Notes: nodes represent MENA countries; node size reflects total publications; edge weight indicates the strength of collaborative relationships. The network shows collaboration patterns exclusively among MENA countries, illustrating regional research connectivity. Source: Authors' elaboration based on bibliometric data.

These findings align with broader patterns documented by Springer Nature and Overton (2025),

who examined more than 12 million policy documents and found that research from the Global South, including the MENA region, is severely underrepresented in SDG-related policy citations, with 78% of cited research originating from the Global North. Their analysis further shows that domestic research accounts for less than 10% of SDG policy citations in most countries examined, and that few Global South countries cite one another's research, pointing to a broader gap in South-South knowledge exchange. Our bibliometric findings on concentrated research output and asymmetrical collaboration patterns within the MENA region offer a complementary perspective, suggesting that the underrepresentation of MENA research in global policy discourse may be partly related to the limited regional integration and international visibility observed in this analysis.

4.1.4. Thematic Structure

To map the conceptual structure of the research area, a keyword co-occurrence network was constructed using the 50 most frequent keywords in the corpus (author and index keywords combined). Community detection using the Walktrap algorithm identifies three dominant thematic clusters, shown in Figure 5.

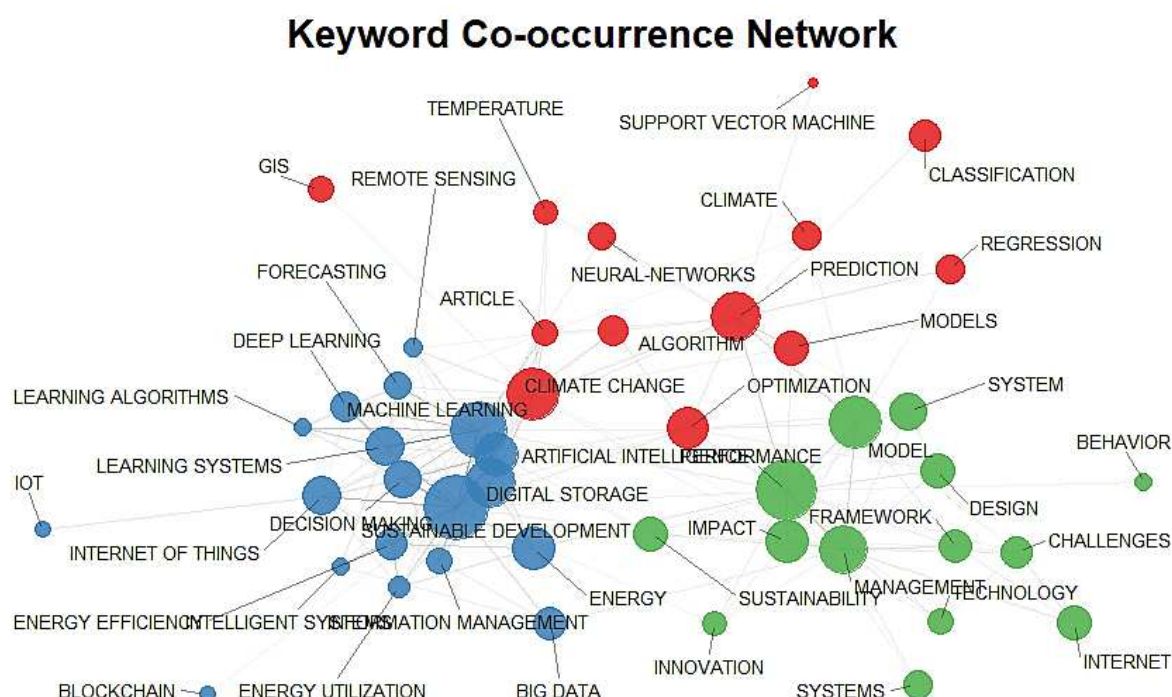


Fig. 5 Keyword co-occurrence network. Notes: node size reflects keyword frequency; node color indicates cluster membership; edge width reflects co-occurrence strength. Source: Authors' elaboration based on bibliometric data

Cluster 1 - Predictive modeling and climate analytics (red cluster). This cluster is structured

around methods and topics related to climate-focused predictive analysis, including climate change (745 occurrences), prediction (671), optimization (472), algorithm (286), regression (272), climate (260), neural networks (254), GIS (235), temperature (226), and support vector machine (164), together with models (338), classification (295), and article (232). The concentration of statistical and machine-learning modeling terms (regression, neural networks, support vector machine, algorithm) alongside climate- and geography-related terms (climate change, climate, temperature, GIS) indicates a substantial body of research applying predictive and geospatial modeling techniques specifically to climate-related phenomena, distinct from the broader AI and digitalization cluster discussed below.

Cluster 2 - AI, digitalization, and energy systems (blue cluster). This cluster brings together sustainable development (1,141 occurrences), the most frequent keyword in the corpus, with machine learning (857), digital storage (638), artificial intelligence (537), energy (499), internet of things (408), learning systems (403), decision making (385), big data (331), energy efficiency (293), deep learning (279), forecasting (251), information management (232), energy utilization (204), remote sensing (188), learning algorithms (179), intelligent systems (176), blockchain (174), and IoT (171). This is the largest and most technologically diverse cluster, integrating core AI and machine-learning terminology directly with digital-infrastructure concepts (IoT, blockchain, big data, digital storage) and energy-sector applications (energy efficiency, energy utilization). Its direct integration with “sustainable development”, the corpus’s most central keyword, indicates that, among the most frequently used terms in this literature, AI and digital technologies are consistently framed in relation to sustainability and energy outcomes rather than treated as a purely technical domain.

Cluster 3 - Management, systems, and organizational innovation (green cluster). This cluster is structured around organizational and systems-level concepts, including performance (981), model (738), management (615), impact (483), system (398), design (349), internet (345), sustainability (341), framework (329), challenges (295), systems (265), technology (236), innovation (224), and behavior (177). This cluster reflects a research stream concerned with the organizational, managerial, and systemic dimensions of technology adoption and sustainability performance (encompassing frameworks for implementation, innovation processes, and behavioral or systems-level evaluation) that is conceptually distinct from both the predictive-modeling focus of Cluster 1 and the specific AI/digital-infrastructure focus of Cluster 2.

Overall, the network reveals a research landscape organized less around a strict separation

between “computational methods,” “environmental topics,” and “digital technologies” than around three complementary orientations: predictive and climate-focused analytics (Cluster 1), AI and digitalization applications directly tied to sustainability and energy systems (Cluster 2), and the managerial and organizational frameworks through which these technologies are implemented and evaluated (Cluster 3). This structure reinforces the premise of the present study: AI and digitalization research in the MENA region is not confined to a narrow technical literature, but is embedded within a broader ecosystem connecting predictive methods, sustainability-oriented applications, and organizational implementation.

4.2. GMM estimation results

Table 3 presents the main estimation results from the difference GMM estimator. The validity of the GMM estimator relies on two key conditions: the absence of second-order serial correlation in the differenced residuals and the exogeneity of the instruments. The Arellano-Bond test (Arellano & Bond, 1991) for first-order serial correlation (AR (1)) is significant, which is expected by construction in first-differenced models, as the transformation induces correlation between the differenced error term and its first lag. More importantly, the test for second-order serial correlation (AR (2)) fails to reject the null hypothesis of no autocorrelation, satisfying a crucial condition for instrument validity. Hansen’s (1982) J-test of overidentifying indicates that we cannot reject the null hypothesis of instrument validity. This confirms that our instruments, lags 2 through 4 of the endogenous variables, are uncorrelated with the error term and are appropriately excluded from the estimated equation. Collectively, these diagnostics confirm that our model specifications satisfy the necessary conditions for consistent GMM estimation.

Table 3 Difference GMM estimation results

Variable	Model 1 (Baseline)	Model 2 (With Moderator)
<i>Pub_{t-3}</i>	0.168 (0.035)**	0.137 (0.044)**
<i>Pub_{t-2}</i>	0.114 (0.256)	0.083 (0.350)
<i>Pub_{t-1}</i>	0.022 (0.829)	-0.014 (0.878)
<i>Pub_{t-3} × Gov</i>	-	0.179 (0.022)**
<i>Pub_{t-2} × Gov</i>	-	0.140 (0.084)*
<i>Pub_{t-1} × Gov</i>	-	0.080 (0.244)

SDI_{t-1}	0.522 (<0.001) ***	0.455 (<0.001) ***
Digit	0.018 (0.048) **	0.023 (0.004)***
Gov	-0.613 (0.142)	-1.602 (0.010)***
GDP	-0.308 (0.371)	-0.312 (0.380)
Observations	174	174
Countries	22	22
Instruments	16	19
Hansen J-test (p-value)	0.594	0.696
AR (1) test (p-value)	0.018	0.057
AR (2) test (p-value)	0.665	0.568

Notes: P-values in parentheses. ***, ** and * are significance at 0.01, 0.05 and 0.1 levels.

Source: Author's own work

Scientific publications and SDI: the baseline relationship

In the baseline model (Eq. 1), the coefficient on publications at lag 3 ($\beta = 0.168$, $p < 0.05$) is positive and statistically significant, indicating that a 1% increase in scientific publications is associated with a 0.168-point improvement in the SDI three years later. This finding is consistent with our first hypothesis (H1), that research output in ‘AI and digitalization for sustainability’ is associated with improved sustainable development performance in the MENA region, with the three-year lag reflecting the time required for knowledge diffusion and implementation.

This result can be explained through several complementary mechanisms. First, endogenous growth theory (Romer, 1990; Lucas, 1988) treats research output as a form of knowledge capital that raises the productivity of subsequent innovation; applied to AI and digitalization research specifically, this mechanism operates through the diffusion of more efficient, less material-intensive technologies, echoing the structural shift toward quality-driven, resource-efficient growth described by Aghion et al. (2025), whereby innovation directed at efficiency and quality improvements gradually reduces environmental intensity while sustaining economic progress. Second, National Innovation Systems theory (Freeman, 1987; Lundvall, 1992; Nelson, 1993) and the Triple Helix model (Etzkowitz and Leydesdorff, 2000) suggest that publications do not translate into sustainability outcomes directly, but rather through the interactions between

universities, industry, and government that convert research findings into applied technologies, firm-level practices, and public policy; this mechanism has been shown to operate specifically for SDG-oriented innovation (Zadegan and Ghazinoory, 2025) and is consistent with the extended Quadruple/Quintuple Helix perspective, which incorporates environmental and societal actors directly into this knowledge-transfer process (Carayannis et al., 2022). Third, knowledge spillover theory (Acs et al., 1994; Audretsch and Keilbach, 2007) points to a further transmission channel, whereby research findings diffuse beyond their originating institutions to influence entrepreneurial activity, firm practices, and broader economic behavior; this channel is likely to operate with particular strength in AI and digitalization research, since Audretsch et al. (2025) show that digital technologies act as general-purpose accelerators of knowledge diffusion, shortening the distance between scientific discovery and downstream application relative to earlier technology waves. Together, these mechanisms suggest that the three-year lag captures the time needed for research to move from publication, through institutional intermediaries and spillover channels, to measurable sustainability improvements, rather than reflecting a direct, unmediated effect of publication counts.

This interpretation is further supported by Springer Nature and Overton (2025), whose analysis of over 12 million policy documents finds that SDG-aligned research is cited more frequently in policy documents than non-SDG research, establishing a plausible policy-engagement channel through which publications could influence sustainability outcomes; the same report also finds that open-access articles are cited nearly a year earlier than closed-access articles, underscoring the role of knowledge accessibility in accelerating this transmission channel. The findings of Pinto et al. (2020), who show that research output positively and significantly affects economic growth, provide complementary evidence of the broader developmental role of scientific research, reinforcing our results in the specific context of sustainability.

Lag structure and the diffusion mechanism

The non-significance of the shorter lags ($t-1$ and $t-2$) indicates that the translation of research into development outcomes follows a gradual diffusion pattern rather than an immediate effect. This is consistent with technology diffusion theory (Rogers, 2003), which identifies distinct stages (awareness, evaluation, adoption, and implementation) that separate the initial availability of new knowledge from its full-scale use. Recent evidence specifically on AI and digital technologies reinforces this diffusion lag; indeed, UNCTAD (2025) shows that AI-related benefits typically require complementary investments in infrastructure, data, and skills before they materialize at the country level, while WIPO (2026) finds that although knowledge

now diffuses faster across borders than in earlier technology waves, the intensity of use, as opposed to mere availability, still depends on absorptive capacity built up gradually within recipient economies. This suggests that the three-year lag observed here does not reflect a fixed constant, but rather the empirical footprint of a diffusion process whose speed is itself conditioned by a country's infrastructure and institutional readiness, a point developed further below in relation to governance.

Meanwhile, the lagged dependent variable is highly significant ($\beta = 0.522$, $p < 0.001$), confirming the dynamic nature of sustainable development and the persistence of SDI scores over time. Among control variables, internet penetration shows a positive and significant effect ($\beta = 0.018$, $p < 0.05$), indicating that digital infrastructure plays an important enabling role for sustainable development. This finding aligns with recent evidence from GeSI and Deloitte (2019) and Bayar et al. (2024), who establish a strong positive link between digital access and progress toward the SDGs across development levels. In the MENA context, where internet penetration averages 58% but exhibits high dispersion ($SD = 30.29$), digital infrastructure appears to function as a necessary complement to the diffusion mechanism discussed above, facilitating access to the information, services, and opportunities that convert research-driven technological knowledge into practical, on-the-ground sustainability gains.

Governance as a moderator: the absorptive capacity mechanism

Consistent with institutional theory (North, 1990), the results from the moderation model (Eq. 4) indicate that the translation of scientific knowledge into sustainable development outcomes is not automatic, but critically depends on the quality of governance. The significant interaction term between publications at lag 3 and governance ($\beta = 0.179$, $p < 0.05$) indicates that the effect of research output is substantially amplified in countries with stronger institutional frameworks, supporting our second hypothesis (H2). Mechanistically, this result is consistent with the absorptive-capacity channel through which institutions operate. Effective governance lowers the transaction costs of translating research into regulation, public investment, and firm-level adoption, while weak governance leaves research findings isolated from the policy and market channels needed to convert them into practice. This mechanism has recently been formalized for AI-specific contexts by Reis and Junior (2025), who show that the diffusion of AI-related knowledge within organizations depends jointly on macro-level institutional pressures and micro-level absorptive capacity, a two-level dynamic that mirrors the country-level amplification effect observed here.

This finding aligns with recent literature documenting the moderating role of governance in the

knowledge-sustainability nexus. Dong and Hwang (2021) show that the benefits of knowledge spillovers for sustainable development depend critically on institutional quality. Azmeh (2025) reveals that the effect of research output on economic growth is likewise significantly amplified by institutional quality in certain MENA countries. Taken together with the theoretical mechanisms discussed above, research output alone is insufficient to drive sustainability improvements; its impact materializes only when supported by institutional frameworks capable of channeling scientific knowledge into policy and practice.

However, these results should be interpreted with appropriate caution. We do not interpret this finding as evidence that publications directly cause specific SDG-related policy changes, nor do we claim that increasing publication counts alone is a sufficient policy lever for improving sustainability outcomes. Rather, our results are consistent with a broader knowledge-diffusion process in which research output represents one necessary, but not independently sufficient, input into a longer chain, encompassing institutional absorption, policy translation, and implementation capacity, that ultimately determines whether scientific knowledge is converted into measurable development progress.

4.3. Robustness check

To assess the reliability of our findings, we implement two robustness checks addressing lag specification and instrument choice.

Extended lag structure

To verify that the effect of publications at lag three is not an artifact of the chosen lag structure, we re-estimate the baseline model with an additional lag, including publications at lags one through four. Table 4 presents the results.

The coefficient on $Pub(t-3)$ remains close in magnitude to the baseline estimate (0.163 vs. 0.168), and the fourth lag is not statistically significant ($p = 0.940$), confirming that the effect of publications dissipates after three years rather than extending further into the future. The significance of the lag-3 coefficient weakens slightly relative to the baseline ($p = 0.070$ vs. $p = 0.035$), which is expected given the loss of degrees of freedom associated with estimating an additional lag and the resulting increase in estimated standard errors. The coefficient's stability in magnitude, together with continued instrument validity (Hansen $p = 0.499$), supports the robustness of the three-year lag structure used in our main specification.

Table 4 Model with four lags for publications

	Coefficient	P-value	Hansen test
<i>Pub</i>_{<i>t-3</i>}	0.163	0.070	0.499
<i>Pub</i>_{<i>t-4</i>}	0.005	0.940	

Notes: The model extends the baseline specification to four lags of publications to test whether the effect persists beyond three years. Source : Author's own work

Instrument-depth sensitivity

To assess whether our results depend on a specific instrument choice, we vary the instrument lag depth from lags 2-3 to lags 2-6 and re-estimate the baseline model at each depth. Table 5 reports the results.

The coefficient on *Pub(t-3)* remains stable across instrument depths, ranging from 0.145 to 0.168, and remains statistically significant in all specifications. Hansen test p-values consistently fail to reject instrument validity across depths, indicating that the main result is not an artifact of a particular instrument choice.

Table 5 Sensitivity to instrument depth

Instrument lags	Pub(t-3) coefficient	P-value	Hansen test (p-value)
2-3	0.152	0.048	0.612
2-4 (baseline)	0.168	0.035	0.594
2-5	0.159	0.042	0.578
2-6	0.145	0.058	0.543

Source : Author's own work

Taken together, these checks indicate that the estimated relationship between AI-and-digitalization-for-sustainability publications and SDI performance is stable and not driven by a specific model specification or an arbitrary instrument choice.

5. SDG-policy implications of the study

Our findings carry several implications for policy in the MENA region. First, investments in 'AI and digitalization for sustainability' research should be treated as long-term development

strategies rather than short-term fixes. The three-year lag between research output and measurable SDI improvement suggests that patience and sustained funding are important considerations for policymakers; premature evaluation or funding discontinuation based on short-term metrics risks underestimating the developmental returns of research investment. Policies that support continuous research activity, such as stable, multi-year funding mechanisms, doctoral training programs, and research infrastructure investment, are likely to yield greater long-term development returns than short-horizon, project-based funding.

Second, the results indicate that the impact of research on SDI is not uniform across countries. It is significantly amplified in well-governed contexts and becomes negligible in weakly governed ones. This underscores that investment in ‘AI and digitalization for sustainability’ alone is unlikely to be sufficient; it needs to be accompanied by institutional reforms that strengthen transparency, accountability, and regulatory quality. For policymakers, this implies that efforts to build research capacity should be pursued in parallel with governance improvements. Without adequate institutional frameworks, the developmental returns of research investment may remain largely unrealized. Prioritizing governance reform alongside research funding can help create the enabling environment needed for scientific knowledge to be translated into policy and practice.

Third, the significant effect of internet penetration highlights the role of digital infrastructure as an enabling condition for knowledge-based development. Policies that expand internet access, particularly in underserved areas, may amplify the developmental impact of research investment by facilitating the diffusion and practical application of research findings.

Fourth, even where research output is substantial, its translation into policy influence is not automatic. Our bibliometric analysis reveals that a number of MENA countries exhibit weak regional or international research collaboration, which may limit the visibility and policy relevance of locally produced research. This is consistent with Springer Nature and Overton (2025), who find that research from the Global South is severely underrepresented in SDG-related policy citations, with 78% of cited research originating from the Global North, and domestic research accounting for less than 10% of SDG policy citations in most countries examined. To address this imbalance, policymakers should invest in open-access publishing infrastructure to ensure that locally produced research is accessible to decision-makers, and should promote South-South knowledge exchange, since few Global South countries currently cite one another’s research, a pattern that Springer Nature and Overton (2025) suggest perpetuates dependency on Global North research.

6. Conclusion

This study examines whether scientific research output in ‘AI and digitalization for sustainability’ is associated with measurable improvements in sustainable development outcomes in the MENA region. To address this question, we employed a two-stage methodological approach. First, we conducted a bibliometric analysis of publications in the field from 2010 to 2025, mapping publication trends, identifying leading countries, and characterizing the intellectual structure of the field. Second, we estimated a dynamic panel data model using the difference GMM estimator on a sample of 22 MENA countries to test the relationship between these publications and the SDI.

The bibliometric analysis reveals a rapidly expanding research landscape, with publications surging after 2015 and reaching unprecedented levels by 2025, though marked by uneven collaboration and concentration among a small number of leading countries. Econometrically, we find that scientific publications are positively associated with sustainable development performance, with the effect materializing after a three-year lag consistent with a knowledge-diffusion process rather than an immediate effect. Governance plays a crucial moderating role in this relationship. In fact, the impact of research is substantially amplified in well-governed countries and becomes negligible in weakly governed contexts, underscoring that institutional quality functions as a key absorptive-capacity mechanism. Internet penetration also exerts a significant direct effect, underscoring the enabling role of digital infrastructure. Taken together, these findings indicate that while research output matters for sustainable development, its translation into measurable outcomes depends critically on institutional quality and digital absorptive capacity, rather than occurring automatically or immediately.

Several limitations of this study should be acknowledged, and each points to a corresponding avenue for future research. First, our measure of scientific output captures research volume, proxied by counts of articles and conference papers indexed in Scopus and WoS, rather than research quality, influence, or topical alignment with specific SDG priorities. This is a meaningful and policy-relevant quantity in its own right, capturing the scale of scientific engagement with this research area, but it does not indicate whether this research is of high scientific quality or specifically targeted at a country’s most pressing sustainability challenges. Future work could extend this analysis using field-weighted citation impact, policy-citation counts, or SDG-target-level classification of publications to assess whether the relationship identified here is driven primarily by research volume, research quality, or the topical alignment between research output and specific national sustainability challenges. Second, our analysis

treats the MENA region as a relatively homogeneous sample; comparing heterogeneous subgroups within it, such as North African countries versus Gulf Cooperation Council states, which differ substantially in research capacity, governance quality, and digital infrastructure, or extending the analysis to other developing regions, could enhance the generalizability of our results and clarify whether the mechanisms identified here hold uniformly or vary systematically with regional characteristics.

Future research could also usefully disaggregate the SDI into its component goals or dimensions, testing the effect of AI and digitalization research separately on environmental, social, and economic sustainability outcomes. Such disaggregation would allow for a more nuanced understanding of whether this research area exerts a stronger influence on specific sustainability dimensions, enabling more targeted policy interventions than are possible using a single composite index.

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