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Modelling the Asymmetrical Relationships between Digitalisation and Sustainable Competitiveness: A Cross-Country Configurational Analysis

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Abstract

Sustainable competitiveness (SC) encourages nations not only to meet the needs of the current generation but also to sustain or even expand national wealth in the future without depleting natural and social capital. Drawing on complexity theory, we used a configurational approach to identify under what necessary and sufficient conditions, digitalisation contributes to achieve higher SC. Shifting attention from net effects to configuration analysis improves our understanding of cross-national differences in sustainability by exploring how the digitalisation factors combine to strengthen SC power across countries. To address the complexity of this configuration, we have incorporated fsQCA and NCA techniques in the modelling of high and low levels of sustainable competitiveness recipes. Analysis of data from 127 countries advanced our perception of how access to ICT infrastructures and capabilities, combined with the adoption and usage of ICT could result in different degrees of sustainable competitiveness. Theoretically, this study contributes to the literature on digitalisation and national sustainability; and it can practically act as a guideline for policymakers to understand the complex interactions and causal configurations of digitalisation factors on sustainability.

Keywords Digitalisation · Sustainable competitiveness · Configurational analysis · fsQCA · NCA

1 Introduction

It has been argued that the Gross Domestic Product (GDP) is not in line with the standard of living of ordinary people (Stockhammer et al. 1997), and cannot reflect the reality of the current state or the outlook for nations' competitiveness. While some countries have a high level of GDP, this economic growth does not inevitably translate into the quality of life of average citizens and the opportunities for future generations. Since overlooking non-economic or sustainable factors, GDP and its derivatives do not represent national development in a comprehensive manner. Development that is not sustainable, by its nature, is not competitive. To fill this backdrop, the Global Sustainable Competitiveness (GSC) Index has been proposed as a holistic measure of national competitiveness. Sustainable competitiveness encourages nations not only to meet the needs of the current generation, but also to sustain or even expand national wealth in the future without depleting natural and social capital (SolAbility 2017). The ultimate goal of sustainable competitiveness is thus to develop a set of mechanisms and policies to improve the level of nations' productivity, while ensuring that the future generation can meet their own needs (Thore and Tarverdyan 2016).

During the past decades, the digital revolution has dramatically changed the societies and economies and offered new possibilities and pathways that significantly altered the human lives. Previous studies suggest that digital transformation might be a significant driver to achieve sustainability (Maffei et al. 2019), and has generated entirely new mechanisms to maintain and promote natural resources, national wealth, and well-being (Akande et al. 2019). Accordingly, several IS researchers suggest that nations should set

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programs and undertake initiatives towards digitalisation in order to achieve sustainability objectives (Bednar and Welch 2019; Kar et al. 2019). However, understanding the digitalisation as a complex phenomenon (Park and Saraf 2016), which consists of several factors, such as infrastructure, capabilities, usage, and change (Hanna 2016) is a challenging problem. In a similar vein, the complex and non-linear interactions between the antecedents of sustainable competitiveness has increased the occurrence of heterogeneous patterns at both micro and macro levels (Balkyte et al. 2010). Due to such complexity, researchers have called for identifying and examining key drivers of sustainable competitiveness (Balkytė and Peleckis 2010; Despotovic et al. 2016), and also to design novel methodological approaches to detect the complex interactions of its antecedents (Balkyte et al. 2010; Cunjun and Yu-de 2011; Zhang and Zhu 2012). Accordingly, an important question is that how digitalisation as a multidimensional phenomenon is be able to drive sustainable competitiveness as a complex construct. As per Pappas et al. (2018) state in their 'Digital Transformation and Sustainability Model', increasing our understanding of the interactions and interrelations of factors that lead to digital transformation and sustainable societies is a vital step. In this respect, our study attempts to build a middle-range theory of digitalisation-sustainability relationships that explains the role that information and communication technologies play in achieving sustainable competitiveness across nations with different social and environmental contexts.

The purpose of this study, therefore, is to develop a conceptual model through the lens of configuration and complexity theories to identify the relationships between sustainable competitiveness and digitalisation. This motivation directly leads to our main research question: what configurations of digitalisation factors lead countries to high or low levels of sustainable competitiveness? By answering this research inquiry, our study contributes to existing knowledge of sustainable competitiveness and digitalisation in three ways. First, in this study, we conceptualise digitalisation as a complex, multifaceted notion comprising two main categories ('ICT capability and infrastructure' and 'ICT usage and adoption') and eight key interdependent dimensions (ICT access, affordability, ICT skills, business and innovation environment, ICT usage, digital business adoption, e-participation, and online services) that conjointly affect achieving sustainable competitiveness. To explore and empirically analyse the combinatorial contingency effects of digitalization dimensions on SC, we used a cross-national dataset of 127 countries that contains scores of digitalisation dimensions and SC measured by several well-known international institutions. Second, drawing on complexity theory and configurational analysis, this study proposes a novel way of thinking about theory building in the context of digitalisation and sustainability. By focusing on complex, asymmetrical, non-linear relationships between these two phenomena, we identify clusters of interconnected elements of digitalisation as holistic integrated patterns that must be simultaneously investigated (El Sawy et al. 2010) for explaining SC. Thereby conceptualising the countries' digitalisation as consisting of systematically interdependent rather than isolated attributes, this research employs a novel and powerful analytical approach to explore how combinatorial impacts of digitalisation form sustainable competitiveness. Third, we use fuzzy set qualitative comparative analysis (fsQCA) and necessary condition analysis (NCA) driven by theoretical expectations about causal relations, underlying a phenomenon of interest to handle the complexity of our configurational perspective (Fiss 2011; Misangyi et al. 2017). Further, whereas previous studies have used fsQCA and NCA to explain the various complex issues (e.g. Liu et al. 2017; Park and Saraf 2016; Prentice and Loureiro 2017), this study utilizes NCA proposed by Dul (2016) as a new data analytical tool to examine both in kind and in degree necessity analysis. By employing this analysis method, we seek to quantitatively formulate the degree of variable conditions (here digitalisation dimension) that are necessary for realizing the different levels of the outcome of interest (here SC). We further compare the NCA results with necessity analysis incorporated in fsQCA method.

The paper proceeds as follows. In the next section, we propose our conceptual framework and theoretical background of our study. Section 3 sets out the methodology and section 4 describes the analysis and results of the study. Section 5 discusses the findings and finishes the paper with implications, limitations, and conclusions.

2 Theoretical Background and Conceptual Framework

2.1 Digitalisation

Digitalisation is defined as the ways in which different areas of enterprise, government, and social life are generally restructured around digital technologies (Brennen and Kreiss 2016). International initiatives have developed series of indexes with the purpose of measuring the pattern of digitalisation across countries such as the World Bank's Digital Adoption Index (DAI), the International Telecommunications Union's ICT Development Index (IDI), and the World Economic Forum's Networked Readiness Index (WEF). The goal of such indexes is to elucidate the trajectory of national development and the pace of digitalisation across countries by comparing the level and evolution of ICT growth over time in both developed and developing countries, thereby assessing the digital divide and ICT technology promises.

There is a diversity of optimistic and pessimistic perspectives concerning ICT's heterogeneous and complex interactions with national growth, social welfare or government development, results in conflicting academic debates. For instance, while several studies note the beneficial effects of ICT on social welfare, such as reduction of corruption (Bhattacherjee and Shrivastava 2018) or increase of the happiness (Gelot et al. 2015); some other reports did not find any significant link between ICT and public value (Mimbi and Bankole 2016), or found partial effects of ICT factors on social welfare (Lee et al. 2017; Richmond and Triplett 2018). Regarding the impacts of ICT on government development, while some studies argue that different levels of ICT infrastructure do not correspond to providing e-service (Nguyen 2014); several other findings link the e-government maturity with ICT infrastructure growth (Das et al. 2017). Notwithstanding variations, the majority of research indicate a positive impact of digital technologies on national economic growth; the consensus, however, revolves around the fact that the significance of impact varies across economies (Bahrini et al. 2019; Niebel 2018; Stanley et al. 2018).

There is no commonly accepted model for analysis of various dimensions of digitalisation, given that current models only reflect part of its aspects (Katz et al. 2014). Therefore, through a review of international digitalisation and ICT indexes, as well as scholarly works proposing digitalisation indexes, we have identified the main components of digitalisation. We selected the indicators identified in prior digitalisation literature as the most important factors affecting the transformation of countries to digitally advanced societies. These metrics were then classified and mapped into the general categories of ICT demand and supply model. The supply side provides *ICT capabilities and infrastructure* (Galperin et al. 2013; Hanafizadeh et al. 2009), and the demand side implies *ICT Usage and Adoption* (Dutta and Bilbao-Osorio 2012; Katz et al. 2014; Park and Choi 2019). These two general categories are in line with various international studies such as IDI or WEF models. Accordingly, we use *ICT capabilities and infrastructure* and *ICT usage and adoption* as the main facets of digitalisation and categorise the key dimensions mentioned in the extant literature and international indexes into these dual facets.

2.1.1 ICT Capabilities and Infrastructure

Multiple studies point out that ICT infrastructure is one of the most critical aspects of digitalisation (e.g. Galperin et al. 2013; Hanafizadeh et al. 2009). According to the Measuring the Information Society Report, ICT infrastructure is a crucial factor that societies and economies rely on (Sanou 2018). It has been argued that compared to other factors, the discrepancy in ICT infrastructure between developed and developing countries has had a significant impact on the digital divide among countries (Dewan and Kraemer 2000; Hanafizadeh et al. 2009). Galperin et al. (2013) designed an index highlighting the *ICT capabilities and infrastructure* to evaluate Latin American countries' progress towards a digitally advanced society. Katz et al. (2014) also developed an index composed of ICT infrastructure and capability. All of these scholarly endeavours have emphasised on the importance of *ICT capabilities and infrastructure* for promoting the digitalisation of countries and subsequently improving the life and well-being of their citizens.

Different international institutions evaluate *ICT capabilities and infrastructure* based on four dimensions, including ICT access, affordability, ICT skills, and business environment (Deloitte 2019; ITU 2018; Baller et al. 2016; O'connor et al. 2002). Almost all of international reports acknowledge these four dimensions as key components of digitalisation influencing the sustainable growth of nations. For instance, International Telecommunication Union (ITU) for monitoring and comparing ICT development between countries and over time uses ICT access and ICT skills as core dimensions of digitalisation in its IDI report (ITU 2018). Karnitis et al. (2019) in their study found that digital skills is a major digital element for EU economic growth. Sousa and Rocha (2019) substantiate this assumption by reasoning that the digital skills variable is a major element of digitalisation.

The other dimension of ICT capability is affordability, endorsed by other studies (e.g. Latapu et al. 2018; Martin and Goggin 2016). As an example, WEF uses affordability as one of the indicators of countries' readiness to exploit the opportunities offered by ICT (Baller et al. 2016). Relatedly, in their research, Latapu et al. (2018) address Tango's path in digital transformation from the standpoint of reliability, security, and affordability. Their studies indicate that the Tango government should enhance the affordability of digital technologies to citizens in order to achieve digitalisation goals. In terms of innovation and the business environment, some studies mention a range of business antecedents essential for digital transformation (Alkhatib et al. 2019; Basole and Patel 2018; Bouwman et al. 2019; Pradhan et al. 2019a, 2019b). Arora and Rathi (2019) assert that in India, business environment factors such as diversification, profitability, level of competition, and managerial factors have immense influence on the adoption of digitalisation. Rieti and Motohashi (2019) also emphasise that the essence of Japanese SMEs is shifting as a consequence of associations between digitalisation and the innovation environment of SMEs.

2.1.2 ICT Usage and Adoption

Past studies suggest that ICT adoption is a salient driver for digitalisation and plays a key role in the national digitalisation journey (Dutta and Bilbao-Osorio 2012; Katz et al. 2014; Park and Choi 2019). According to the Executive Opinion Survey of the World Economic Forum, ICT adoption and usage is an important aspect of enabling environment for digitalisation.

This survey is conducted annually by more than 15,000 business leaders in all economies (Dutta and Bilbao-Osorio 2012). A number of international institutions and organizations also affirm that online services (Oecd 2017), ICT usage (ITU 2018; Oecd 2015), e-participation (United Nations 2018; WEF 2016), and business adoption (WEF 2016) are key dimensions of *ICT Usage and Adoption* category.

As Katz et al. (2014) point out for transition to digitally intensive societies and achievement of significant impacts, ICT must be widely used and adopted in different sectors of a country. The recent analysis by Park and Choi (2019) also verifies that the usage of digital technologies is a significantly important factor in countries' journey to socio-economic growth. E-participation is another salient dimension of *ICT adoption and usage* suggested by previous research. For instance, Bernhard et al. (2018) contend that the level of digitalisation in a municipality is associated with the perceived satisfaction of e-government services among the citizens. Some other scholarly endeavours consider e-participation as a key digitalisation dimension for fostering civic engagement and strengthen collaboration between governments and citizens (Bailey and Ngwenyama 2011; Lindgren et al. 2019). Likewise, several studies underline the important impacts of online services in achieving digitalisation (e.g. Borangiu et al. 2019; Hänninen et al. 2019; Scupola 2018). In addition, the World Bank's Digital Business Adoption Index outlines digital business adoption required to improve digitalisation and increase productivity and business growth. Further, under the rubric of connected businesses, the Index notes that in most developing countries, the rate of adoption of sophisticated technologies is different from developed ones (World Bank Group 2016).

2.2 Sustainable Competitiveness

World Economic Forum defined sustainable competitiveness as 'the set of institutions, policies, and factors that make a nation productive over the longer term while ensuring social and environmental sustainability' (WEF, 2020). Sustainable competitiveness is a complex notion that goes beyond economic well-being. It involves factors that drive societies into sustainable prosperity and high-quality growth, while covers both the microeconomic and macro-economic areas of national competitiveness and complex interactions of competitiveness and sustainability (Bilbao-Osorio et al. 2013). Sustainable competitiveness objective is not only to protect the productivity of firms and nations but also to ensure the ability of future generations to meet their own needs (Schwab and Sala-i-Martin 2010; Weiss 1993).

Previous studies accentuate the complex interactions of interrelated and dependent factors inside sustainable competitiveness (Balkyte et al. 2010; Bilbao-Osorio et al. 2013; Doyle and Perez-Alaniz 2017; Balkytt and Tvaronavičienn 2014). They highlight the interrelationships of economic growth, sustainable development, wellbeing, international globalization, and competitiveness (Balkyte et al. 2010; Bilbao-Osorio et al. 2013). In particular, the complex nature of sustainable competitiveness in emerging economies is intensified, because unlike more developed economies, their sustainability and competitiveness do not have a clear relationship (Belyaeva 2013; Dobers and Halme 2009). Some international efforts are undertaken to measure the global sustainable competitiveness of nations by considering various combinations of factors. The GSC index has been introduced as an alternative to the competitiveness index and comprehensive measurement of the nation-states' competitiveness by an international think-thank (Schwab and Sala-i-Martin 2010; SolAbility 2017). This index comprises of 111 indicators which grouped into five domains of natural capital, resource efficiency and intensity, intellectual capital, governance efficiency, and social cohesion. The main superiority of GSC index is its objectivity, since it encompasses purely quantitative indicators and excluding any subjective data (SolAbility 2017).

Research on the interaction of digitalisation and sustainable competitiveness is evaluated at various organizational, regional, national and global levels. At the firm and organizational level, researchers have explored the interaction of business intelligence (Ahmed 2015), big data (Pu et al. 2018; Ren et al. 2019), or digitalisation (Chen et al. 2018) on sustainable competitiveness. However, some studies have adopted regional or national perspectives. The previous works on the relationship between ICT and sustainability at a national and global level have been summarised in Table 1 of Appendix. The table compares the methods, identified factors and the results of the prior research.

2.3 Complexity Theory and Configurational Analysis

The theory of complexity has been used in different fields of sustainability such as health inequalities (Gatrell 2005), sustainable education (Szekely and Mason 2019), or sustainability transitions (Peter and Swilling 2014). The complexity theory stemmed from the system theory to addresses non-linearity and heterogeneity of interactions, as well as feedback loops in dynamic networks that trigger continuous system changes (Grobman 2006). According to this theory, cases under study can be considered as constellations of interconnected elements that have complex causal relations with three features: *conjunction* (i.e. outcomes mostly result from interactions of multiple causes); *equifinality* (i.e. multiple alternative pathways lead to a given outcome); and *asymmetry* (i.e. elements in one path may be irrelevant or even inversely related to other paths) (Misangyi et al. 2017).

Recently, IS researchers argue that conventional regression or correlation methods are not appropriate for modelling complex phenomena and question these methods assumption on additive, unifinal, and symmetrical causality (Liu et al. 2017; El Sawy et al. 2010; Misangyi et al. 2017). Applying

Table 1 Sources of digitalisation condition variables and their focus

Condition Variables and Outcome of Interest	*Focus*	*Mean*	*SD*	*Min*	*Max*	*Source*
ICT Capabilities & Infrastructure						
ICT Access	The development of ICT infrastructure	5.9	2.04	2	9.54	IDI[a]
Affordability	The cost of accessing ICT	5.06	1.26	1	6.9	NRI[b]
ICT Skills	The important capabilities or skills for ICT	6.16	2.13	1.4	9.28	IDI[c]
Business and Innovation Environment	The quality of the business framework conditions to boost entrepreneurship	4.33	0.7	2.6	6	NRI[d]
ICT Usage and Adoption						
ICT Usage	The ICT intensity and diffusion	4.2	1.57	1.3	6.9	IDI[e]
Digital Business Adoption	The extent of business efforts for using ICT	0.62	0.19	0.1	0.97	DAI[f]
E-Participation	The use of online services by citizens	0.68	0.24	0.08	1	EGDI[g]
Online Services	The quality of government's delivery of online services	0.67	0.23	0.1	1	EGDI
Outcome of Interest						
Sustainable Competitiveness	The power of national competitiveness	45.08	5.8	32	60.5	SolAbility

conventional regression-based methods (CRBM) may lead to misleading results due to issues such as multicollinearity, non-normality of datasets, or ignorance of contrarian cases (Olya and Mehran 2017). Conversely, configurational analysis views 'phenomena as clusters of interconnected elements that must be understood as a holistic integrated pattern' (El Sawy et al. 2010, p.838), characterised by conjunctural, equifinal, and asymmetric relations. The configurational perspective offers IS scholars a new set of data analysis tools, a novel ground for theorising, and a fresh holistic view to enrich and extend understanding of IS concepts. The fundamental principle underlying this perception is that the outcome of interest is better identified and examined as configurations of interdependent condition variables. Examining the mutual impacts of variables allows researchers to explore asymmetrical relationships between causes and outcomes. Recent past, a number of studies have employed complexity theory and configurational analysis via fsQCA to understand complex phenomena such as mobile learning (Pappas et al. 2019), personalised e-commerce (Pappas et al. 2017), adoption of e-government services (Kourouthanassis et al. 2016), tourism expenditure (Olya and Mehran 2017), and corporate bankruptcy (Boratyńska 2016). In this manner, we believe using complexity theory and following configurational approach enable us to uncover the complex relationships between digitalisation and sustainability. More specifically, configurational analysis through NCA and fsQCA assists us to pinpoint not only critical factors for different levels of the outcome but also various sets of sufficient conditions ensure the realization of high or low/medium levels of it. Figure 1 presents our configurational illustrating two sets of causal conditions of *ICT capabilities and infrastructure* and *ICT usage and adoption* predicting the outcome of interest (here *sustainable competitiveness*).

3 Methodology

3.1 Data Collection Procedure

As noted above, the aim of this research is to identify configurations of digitalisation dimensions assist countries to achieve national sustainable competitiveness. Data on sustainable competitiveness collected from the 'Global Competitiveness Report 2017'. In the *ICT capability and infrastructure* category, we used data from IDI provided by the ITU and the Network Readiness Index (NRI) developed by the WEF. We collected data from the IDI, the Digital Adoption Index (DAI) developed by the World Bank, and the E-Government Development Index (EGDI) measured by the United Nations to investigate the category of *ICT usage and adoption*. Table 1 presents the focus and data sources of the condition variables for digitalisation in this study. Our dataset included data from 127 countries, considering the full data availability of the eight condition variables matched by the GSC outcome measure.

[a]Retrieved from https://www.itu.int/net4/ITU-D/idi/2017/index.html

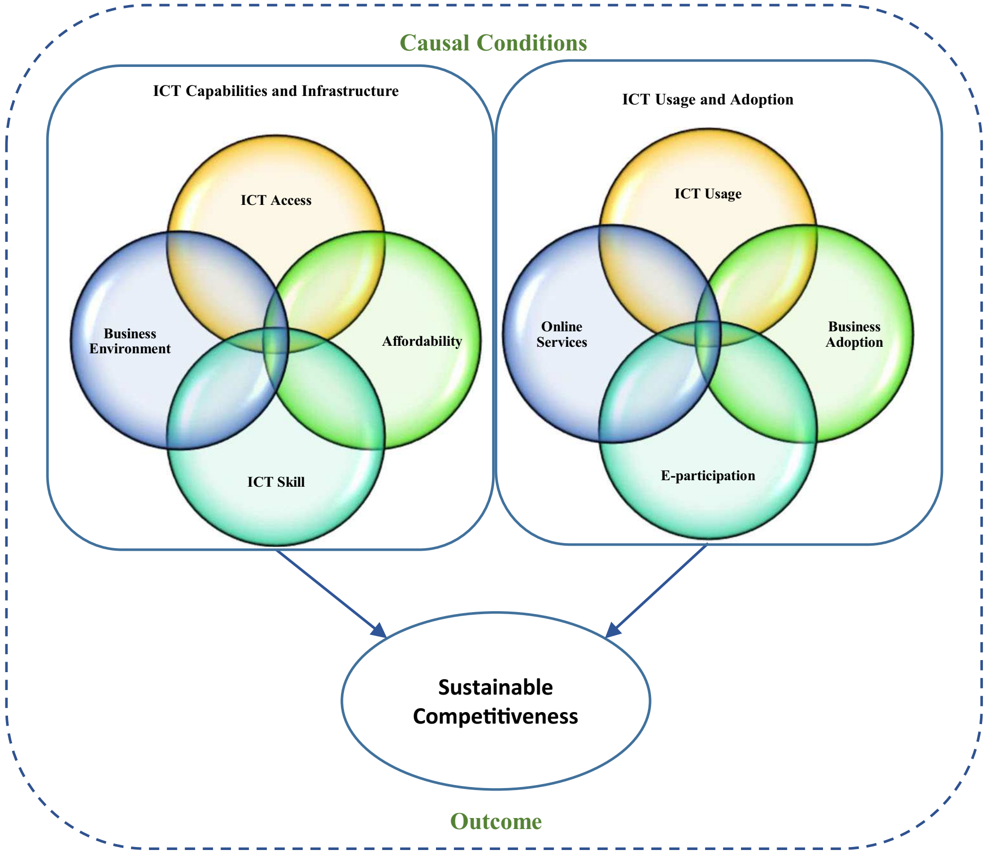
[b]Retrieved from https://reports.weforum.org/global-information-technology-report-2016/networked-readiness-index/

[c]Retrieved from https://www.itu.int/net4/ITU-D/idi/2017/index.html

[d]Retrieved from https://reports.weforum.org/global-information-technology-report-2016/networked-readiness-index/

[e]Retrieved from https://www.itu.int/net4/ITU-D/idi/2017/index.html

Fig. 1 Conceptual Framework: Outcome of interest and causual conditions



[f]Retrieved from https://www.worldbank.org/en/publication/wdr2016/Digital-Adoption-Index

[g]Retrieved from https://publicadministration.un.org/en/research/un-e-government-surveys

3.2 Analysis Methods: fsQCA and NCA

In this study, we followed the neo-configurational perspective developed by Misangyi et al. (2017); and investigated the digitalisation configuration framework using fsQCA. This technique is capable of bridging the gap between qualitative and quantitative analysis (Rihoux and Ragin 2009). fsQCA is a set-theoretic method that empirically examines the relationships between the outcome of interest (GSC in our study) and all possible combinations of membership states (i.e., full, none or crossover) of theoretically relevant predictors (here digitalisation dimensions). This technique assists researchers to go beyond CRBM, as fsQCA offers an opportunity to identify multiple configurations that explain the same outcome (Pappas 2018). CRBMs take a net effect approach whereby factors are examined in a competing environment to explain the variance in the outcomes, rather than to show how they cooperate or combine to create outcomes (Fiss et al. 2013). In contrast, fsQCA assumes that there is always more than one combination of conditions cause a given outcome. fsQCA, as a configurational comparative approach, offers unique values and new capabilities for scholars aiming to 'describe combinatorial complexities assuming asymmetrical relationships between variables, rather than symmetrical net effects that CRBMs usually estimate'(Skarmeas et al. 2014, p. 1796). In this study, we conducted the configurational analysis using fsQCA 3.0, and R 3.6.1 software with the QCA package version 3.5.

In order to explore the extent to which the conditions for digitalisation are important at different levels of sustainable competitiveness, we performed the NCA method (Dul 2016). NCA can satisfactorily complement fsQCA results, and unlike CRBMs that examine probabilistic relationships between variables, NCA as a new statistical method allows to identify variables that are necessary but do not guarantee realising the outcome. Complementing fsQCA with NCA yields solutions that are more precise or complete and can offer actionable knowledge that has very powerful policy implications (Ragin, 2009). We ran a continuous NCA for our condition and outcome variables, using R 3.6.1 software with NCA package version 3.0.1(Dul 2018).

3.3 Data Calibration

After determining relevant causal conditions and the outcome in question, initial step in the configurational analysis is to convert values of model variables into fuzzy set membership scores. In the fsQCA terminology, this process is called data calibration (Ragin, 2009). Direct or indirect data calibration can be used to transform ordinal or interval-scale measurements. In the direct method, researchers choose three qualitative anchors called full membership (i.e. value 1), crossover point (i.e. value 0.5), and full non-membership (i.e. value 0). The crossover point reflects the most ambiguity regarding fuzzy set membership. In the indirect method, researchers allocate cases to groups based on their degree of membership in the target set. Either method may be used depending on the data, the underlying theory, and the experience of researchers (Ragin, 2009).

In this study, we employed the direct method for data calibration as we used three qualitative anchors to structure calibration. For calibrating variables, we followed Beynon, Jones, and Pickernell (2016), using the Probability Density Function (PDF) to compute the membership thresholds (Greckhamer et al. 2018). The PDF enabled us to estimate the necessary anchors (Beynon et al. 2018; Greckhamer et al., 2018) for computing fuzzy membership scores via the log-odds transform (Ragin, 2009). The qualitative anchors evaluation process drew on the calculation of the respective 5th percentile (lower-threshold), 95th percentile (upper-threshold) and 50th percentile (crossover point) values. For instance, in the outcome variable (GSC), the 50th percentile was computed 44.4 as the crossover point anchor. The GSC cut-off points for full membership (95th percentile = 55.15) and non-membership (5th percentile = 37.1) were also calculated. The associated variable values of 127 countries with marked lower and upper thresholds are presented over PDF graphs in Fig. 2. In addition, given that fsQCA has difficulty to analyse the cases with exact 0.5 score membership (Ragin, 2009), we followed Fiss's (2011) recommendation and added a constant of 0.001 to variable conditions below full membership scores of 1 to avoid this issue (Pappas et al., 2020). This change does not affect the results but guarantees that none of the cases is dropped in fsQCA.

4 Analysis and Results

The configurational approach explicates necessary or sufficient subset relations for outcome by using set theory and Boolean algebra (Rihoux and Ragin 2009). Conditions may be considered necessary if they must be present for an outcome to occur, and sufficient if they can produce an outcome by themselves. To examine the relations, we first conducted a necessity analysis of all conditions and their negation and then performed a sufficiency analysis using a truth table algorithm to identify combinations of conditions consistently linked to the outcome.

4.1 Necessity Analysis

Prevention of guaranteed failure and increased probability of success are core constituents of the 'necessary but not sufficient' (Dul 2016) logic of necessity analysis. Some scholars recommend conducting a necessity analysis before performing the core analysis of fsQCA, which identifies sufficient configurations (Schneider and Wagemann 2010). A necessary condition is defined as a condition that must be present for the outcome to occur (no outcome without a condition), but its presence does not guarantee the outcome (Ragin, 2009). A necessary cause can be considered as a constraint and a bottleneck that must be managed to allow the desired outcome to be realised (Dul 2016). Typically, scholars use two methods for identifying relationships of necessity between condition variables and the outcome of interest. One that is incorporated in fsQCA which is based on set theory and the other is a dedicated NCA method rooted in calculus (Vis and Dul 2018). While both methods examine causality relationships in terms of necessity and sufficiency analysis, they may yield different results (Dul 2016). The main difference between these two approaches is that fsQCA only analyse in kind necessary conditions (e.g., a condition variable or a configuration of conditions is necessary for the outcome), whereas NCA can analyse both in kind and in degree necessary conditions (e.g., a specific level of a condition variable is necessary for a specific level of the outcome). Another difference is that fsQCA uses bisectional diagonal line for evaluating the necessary conditions,[1] while NCA applies ceiling line as a reference line. fsQCA bisectional diagonal line is a static line, but the ceiling line in NCA can move to identify different levels of conditions necessary for different levels of the outcome. Further, the measures for evaluating the importance or criticality of a necessary condition are different in these two methods. For computing importance, fsQCA uses coverage score as the extent to which a necessary condition is also present in sufficient conditions for realizing the outcome. Wherein NCA, the effect size is used to evaluate the importance of a necessary condition based on the empty zone above the ceiling line (Dul 2016).

In fsQCA, for a condition to be necessary, its consistency should exceed the threshold of 0.9 (Schneider and Wagemann 2010). The consistency of the fuzzy subset relation indicating necessity can be assessed using the formula: Consistency $(Y_i \le X_i) = \sum(\min(X_i, Y_i)) / \sum(Y_i)$, where X$i$ is the case i's membership score in set X and Yi is the case i's membership score in the outcome. The analysis of necessary condition through fsQCA software indicated that while no conditions are necessary for high GSC, lack of ICT skills is a critical condition for low/medium GSC.

[1] For more discussion on bisectional diagonal analysis in fsQCA, please refer to Ragin (2008)

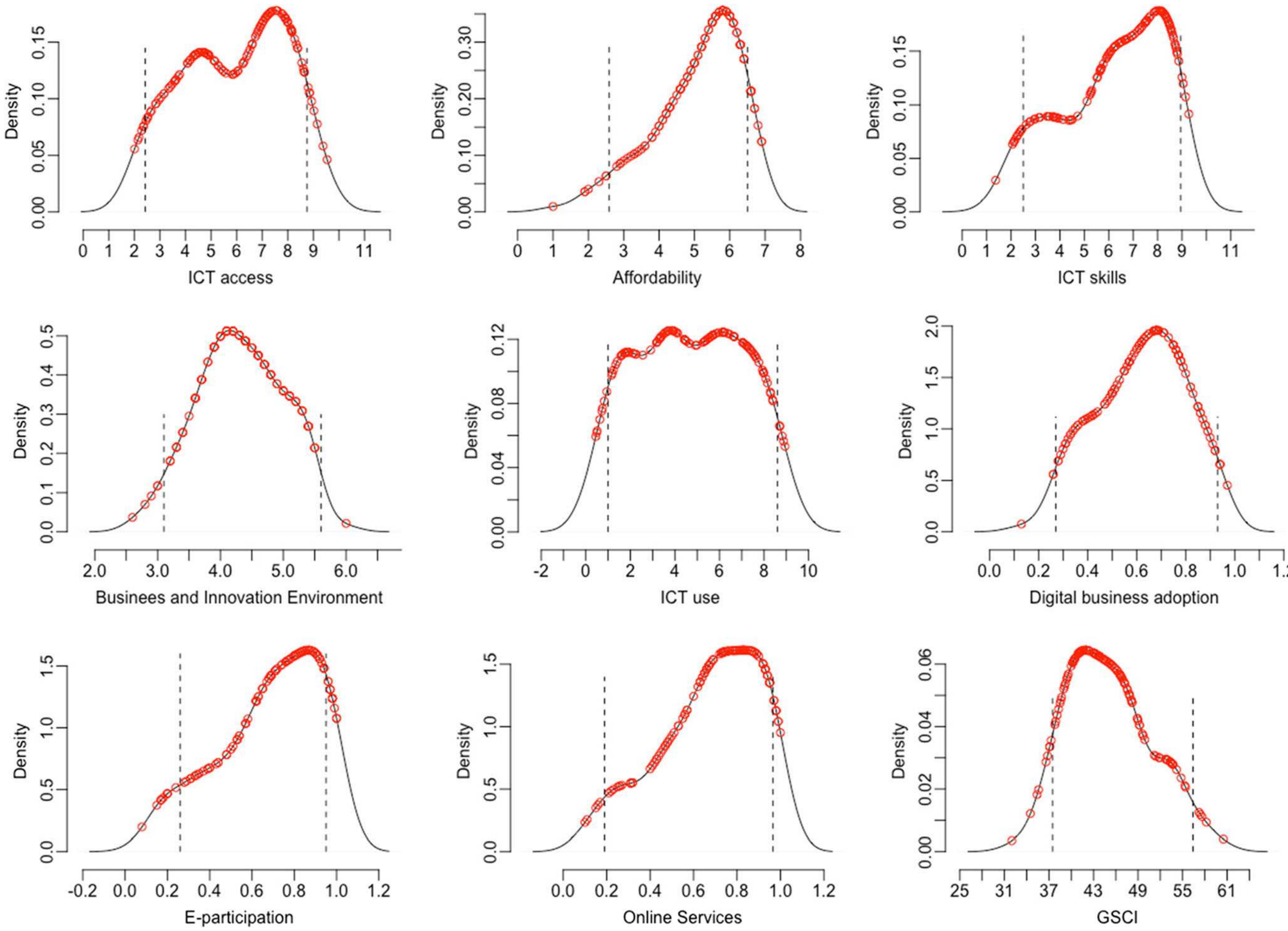


Fig. 2 Probability Density Functions and spreads of membership values for the eight conditions and the outcome

In addition, we conducted NCA to identify what specific levels of digitalisation factors may be needed for a specific level of sustainable competitiveness. By applying the NCA, the qualitative statement of 'X is necessary for Y' can be extended to the quantitative statement of degrees as follows: 'a specific level of X is necessary for a specific level of Y' (Dul 2018). The NCA technique starts by drawing a ceiling line above the cases in the space of cases. The ceiling line Y = f(X) separates the 'empty space' and the 'full space' of the data set and indicates what level of condition (*x*-axis) is necessary for what level of outcome (*y*-axis). The lower the ceiling line, the more necessary the condition; therefore, the higher constraint is imposed on the outcome. (Vis and Dul 2018).

Visual inspection of *XY* plots (Fig. 3) of the eight conditional variables and the high GSC indicates the extent to which conditions are necessary at various degrees of sustainable competitiveness. The XY plots in Fig. 3 suggest that all success factors are necessary for high GSC, but their criticality is quantitatively different. As shown in the plots, the empty space above the ceiling is wider for some conditions such as ICT access, affordability, ICT skills, ICT usage, or digital business adoption; they are thus more crucial for achieving sustainable competitiveness.

To answer the question, to what extent the condition is a bottleneck for occurring the outcome, NCA defines the 'effect size' as the size of the constraint that the condition forces to the outcome. The effect size (d), indeed, is 'the size of the ceiling zone (the upper-left zone of the *XY* plane that is [almost] without observations) as a fraction of the total size of the area where cases can be expected, given the X values and Y values that are empirically observed (the empirical scope) or theoretically assumed (the theoretical scope)'(Dul 2018. p. 881). Dul (2016) proposes a general guideline for the magnitude of an effect size: $0 < d < 0.1$ as 'small effect', $0.1 \leq d < 0.3$ as 'medium effect', $0.3 \leq d < 0.5$ as 'large effect', and $d \geq 0.5$ as 'very large effect'.

Table 2 shows the results of the bivariate NCA analysis. Bivariate NCA finds that online service is the only condition moderately essential for High GSC, and the other seven conditions individually have a major impact on the outcome. However, the effect sizes of these conditions are not the same. ICT skills and business digital adoption have a higher impact size; hence, sustainable competitiveness is more sensitive to the absence of these conditions (Table 3).

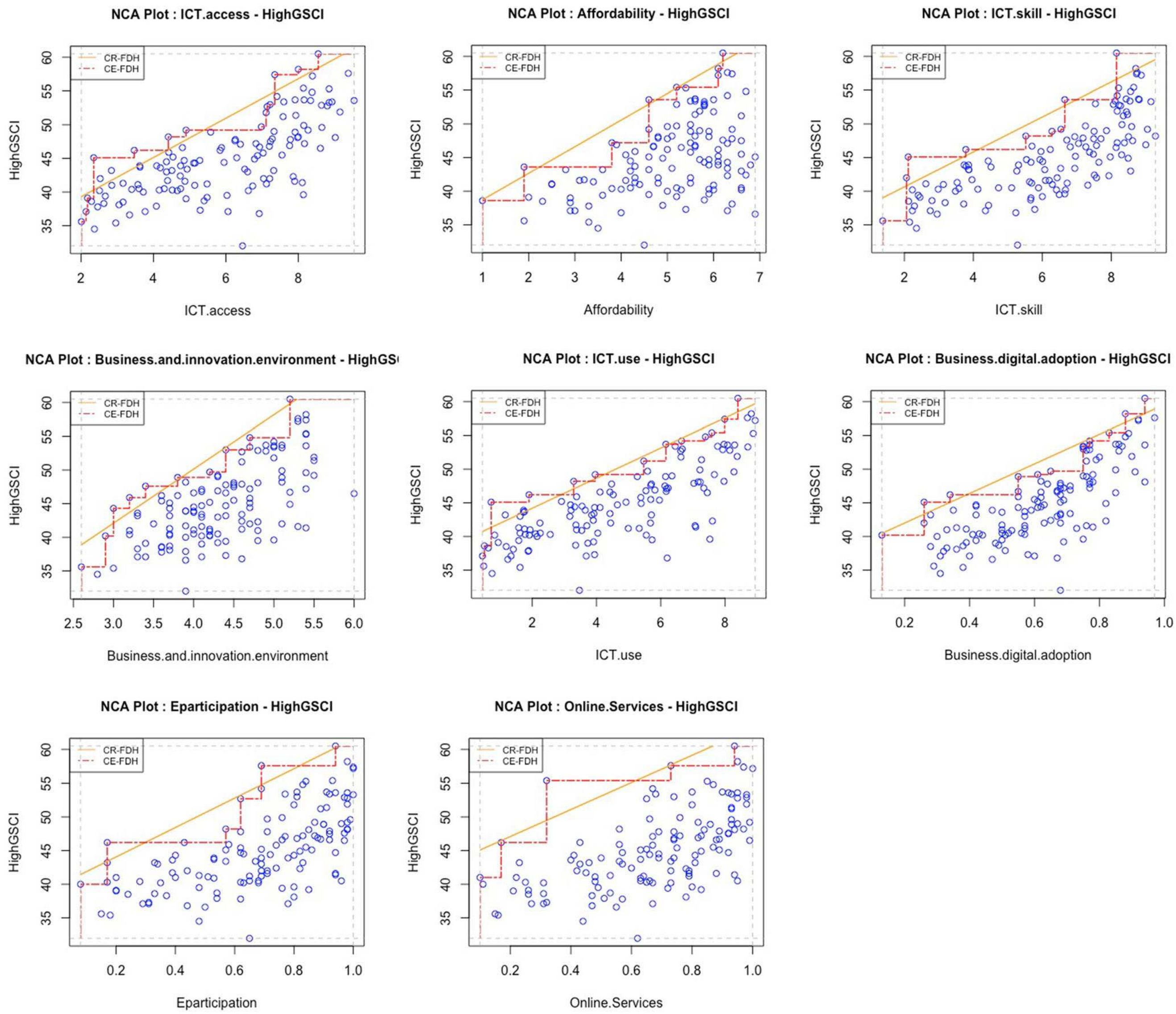


Fig. 3 NCA plots of digitalisation factors

The last column of Table 2 illustrates the regression equations of ceiling lines for digitalisation conditions. Using these ceiling line equations ($y = f(x)$), the presence of conditions is compared to the high level of the outcome. In the multivariate NCA analysis, the configurations of the necessary conditions are examined for the different levels of the outcome. Such that individual necessary conditions are combined into necessary And-configurations and their ceiling lines joints together to comprise a ceiling surface (Vis and Dul 2018). In multivariate analysis, bottleneck Table (BT) (see Table 4) examines levels of combination of conditions that are necessary for various levels of desired outcome (Dul 2018). BT indicates levels of conditions and the outcome as a percentage ranging from the lowest to the highest observed values. By using the BT, we identified the order in which digitalisation factors are necessary for achieving sustainable competitiveness. Since NN stands for not necessary, BT illustrates that very low levels of GSC (up to 40%) can be realised without digitalisation

Table 2 Bivariate necessity analysis with NCA

Conditions	*Effect size*	*Ceiling line*
ICT access	0.358	$Y_c = 2.9X_c + 33.46$
Affordability	0.357	$Y_c = 3.9X_c + 34.78$
ICT skill	0.394	$Y_c = 2.6X_c + 33.46$
Business and innovation environment	0.3	$Y_c = 8.04X_c + 17.97$
ICT usage	0.361	$Y_c = 2.2X_c + 39.73$
Business digital adoption	0.38	$Y_c = 22X_c + 37.60$
E-participation	0.317	$Y_c = 21.8X_c + 39.69$
Online services	0.231	$Y_c = 20X_c + 43.1$

Table 3 Bottleneck table of the eight digitalisation factors for sustainable competitiveness

GSC	ICT infrastructures and capabilities				ICT engagement and adoption			
	IAC	AFF	ISK	BIE	IUS	DBA	EPA	OLS
0	NN	NN	NN	NN	NN	NN	NN	NN
10	NN	NN	NN	NN	NN	NN	NN	NN
20	NN	NN	NN	NN	NN	NN	NN	NN
30	NN	NN	NN	NN	NN	NN	NN	NN
40	5.2	NN	NN	NN	0.4	NN	NN	NN
50	18.8	1.7	12.1	9.2	16	NN	NN	NN
60	32.4	16.8	26.1	23.2	31.6	13.6	11.6	NN
70	46	31.9	40.2	37.2	47.2	33	27.3	15.2
80	59.6	47	54.2	51.3	62.8	52.4	42.9	36.9
90	73.2	62	68.2	65.3	78.4	71.8	58.5	58.6
100	86.8	77.1	82.2	79.3	94	91.2	74.2	80.4

Note: IAC = ICT Access; AFF = Affordability; ISK = ICT Skills; BIE = Business and Innovation Environment; IUS = ICT Usage; DBA = Digital Business Adoption; EPA = E-Participation; OLS = Online Services; NN = not necessary

endeavours (see Table 4). Digitalisation is present from a 40% level onwards, meaning that in this set of cases, reaching a certain level of GSC is possible by the presence of some digitalisation conditions.

The BT results point out that the digitalisation conditions are criticality different for various degrees of sustainable competitiveness. In order to analyse BT results, we classified the outcome (first column of the BT) into three categories (low, <25th percentile; medium, 25th–75th percentile; high, >75th percentile) (Dul 2016). At the low range of GSC (≤40%), digitalisation conditions are not salient. Only at the 40% level, some preliminary access to ICT technologies and limited usage are important. At the mid-range of GSC (≤70%), seven digitalisation conditions are required and providing online services to citizens is needed merely in level 70%. From the 80% level (high range GSC), BT suggests that the full presence of digitalisation factors is important, such that to increase sustainable competitiveness, countries need to advance their digitalisation readiness. It is worth noting that, while fsQCA necessity analysis reveals that none of the conditions are necessary for high levels of the outcome (all consistency scores are less than 0.9), BT results indicate that eight digitalisation conditions need to be in place for achieving very high levels (≤70%) of sustainable competitiveness.

Table 4 Configurations for high GSC

Conditional variables	*Solutions*			
	S1H	S2H	S3H	S4H
ICT access	•	•	•	⊗
Affordability	•	⊗	•	•
ICT skill	•		•	⊗
Business & innovation environment		•	•	⊗
ICT use	•	•	•	
Business digital adoption	•	•	•	⊗
E-participation	•	•	⊗	•
Online Services	•	•	⊗	•
Consistency	0.93	0.91	0.83	0.92
Raw coverage	0.62	0.35	0.25	0.25
Unique coverage	0.21	0.05	0.02	0.01
Overall Solution consistency	0.88			
Overall Solution Coverage	0.70			

Note: Black circles (•) indicate the presence of a causal condition, and (⊗) circles represent the absence of a causal condition; big circles = core conditions; small circles = complementary conditions; Blank spaces indicate 'don't care'

4.2 Sufficiency Analysis

In fsQCA, the truth table is a key tool for studying the sufficiency of different configurations to achieve the outcome. After calibrating the data, we built a *2 k* row truth table, with *k* representing the number of conditions, and each row representing a logically possible configuration of the condition variables. The truth table is refined on the basis of two criteria of frequency and consistency (Ragin, 2009). In order to ensure that the minimum number of empirical cases exist for configuration assessment, a frequency cut-off point is established. For samples with less than 150 cases, Fiss (2011) proposed the frequency cut-off point of 2. Thus, considering our sample size (127 countries) minimum cases in each configuration set to be 2, and all combinations with smaller cases were removed from the table. Further, we set the lowest acceptable consistency to 0.8, following Rihoux and Ragin's (2009) recommendation.

The truth table analysis detects any relationship between the combination of potentially causal variables and the outcome of interest (Wang et al. 2019). fsQCA uses the Quine-McCluskey algorithm as a minimisation procedure to identify patterns of multiple conjunctural causation and simplify the complex combination of conditions in a logical and holistic manner (Rihoux and Ragin 2009). By using this minimisation tool on truth table results, three sets of consistent and sufficient configurational paths are produced for each fsQCA analysis: complex, parsimonious, and intermediate solutions leading to the outcome. Complex solutions include all possible configurations without applying simplifying assumptions according to logical remainders (i.e., combinations of conditions without strong case membership in the sample). Generally, interpretation of complex solutions is difficult, since their combinations are a lot, researchers use clarifying assumptions to produce more simplified solutions, i.e. parsimonious and intermediate solutions (Ragin, 2009; Pappas et al. 2019). Parsimonious solutions are generated by applying all simplifying conditions without any evaluation of their plausibility (Rihoux and Ragin 2009) and offer the most important conditions, which are present in all of the configurations. In developing intermediate solutions, researchers use simplifying assumptions consistent with empirical evidence and their theoretical knowledge (Greckhamer et al., 2018; Rihoux and Ragin 2009).

Tables 5 and 6 present the results of fsQCA analysis examined the condition configurations, which led to high and low/medium scores of GSC. In each configuration, the combination of two kinds of conditions (core and complementary) results in achieving the outcome. Following Greckhamer et al. (2018), we used a combination of parsimonious and intermediate solutions. For each configuration result in the outcome, we differentiated between the core conditions that have a strong causal link to the outcome (part of both parsimonious and intermediate solutions) and the complementary conditions that have a weaker causal relationship to the outcome (only in intermediate solutions but not in parsimonious solutions) (Fiss 2011; Pappas et al. 2019). The results offer four solutions to reach a high level of GSC. Solutions are a combination of eight condition variables with consistency scores above the suggested cut-off value of 0.8. Configurations are expressed using the notation system set up by Fiss (2011). The solution table includes values of coverage and consistency for each configuration and the overall solution. The overall coverage value assesses the proportion of cases covered by all solutions, while the overall solution consistency roughly corresponds to the degree to which these configurations consistently lead to the outcome (Wang et al. 2019). The formula used to calculate the consistency is $(X_i \leq Y_i) = \sum(\min(X_i, Y_i))/\sum(X_i)$, and the formula for assessing the coverage is $(X_i \leq Y_i) = \sum(\min(X_i, Y_i))/\sum(Y_i)$ (Ragin 2009). The results indicate an overall solution coverage of 0.70 at a high level of GSC, and 0.74 at a low GSC, both suggesting that a substantial proportion of the outcome is covered by the four high solutions and four low solutions. The relatively lower coverage of solutions of high GSC may be due to the lower proportion of cases included in the sample with high GSC scores (58 cases out of 127 countries have a higher GSC score than average). Overall, the consistency of the four high solutions indicates that 88% of the high GSC can be explained by the resulting configurations in Table 5, while the four low/medium solutions listed in Table 6 justify 87% of the low/medium GSC.

Sufficiency analysis for a high level of GSC yielded in solutions S1H-S4H, specifying different configurations in which condition variables may be present or absent. These different solutions implicate three features of complex causality, i.e. equifinality, asymmetry, and conjunctional causation in the relationships. To give an example of how to interpret the resulted configurations, the first solution (S1H) with the highest unique coverage score (0.21) combines the presence of e-participation and ICT skills as core conditions, along with complementary conditions of Affordability, ICT access, online services, and business digital adoption. The countries in this group are those with high membership at the high level of sustainability competitiveness. For instance, Sweden, Norway, Finland, Denmark, Austria, and Estonia are among the top countries leading sustainable competitiveness. This path, in some respects, represents the ideal scenario for high

Table 5 Configurations for low GSC

Conditional variables	*Solutions*			
	S1L	S2L	S3L	S4L
ICT access	⊗	•	⊗	⊗
Affordability		⊗	•	⊗
ICT Skill	⊗	⊗	⊗	⊗
Business & innovation environment	⊗	•	⊗	
ICT use	⊗	•	⊗	⊗
Business digital adoption	⊗	•	⊗	⊗
E-participation	⊗	•	•	⊗
Online Services	⊗	•	•	⊗
Consistency	0.92	0.96	0.97	0.92
Raw coverage	0.58	0.25	0.32	0.51
Unique coverage	0.05	0.04	0.04	0.02
Overall Solution consistency	0.87			
Overall Solution Coverage	0.74			

Note: Black circles (•) indicate the presence of a causal condition, and (⊗) circles represent the absence of a causal condition; big circles = core conditions; small circles = complementary conditions; Blank spaces indicate 'don't care'

Table 6 Configurations of test subsample for high GSC

configurations	raw coverage	unique coverage	consistency
IAC*AFF*ISK*IUS*DBA*EPA*OLS	0.70	0.26	0.95
IAC* ~ AFF*BIE*IUS*DBA*EPA*OLS	0.39	0.01	0.90
~IAC*AFF* ~ ISK* ~ BIE* ~ DBA*EPA*OLS	0.17	0.02	0.86
IAC*AFF*ISK*BIE*IUS*DBA* ~ EPA* ~ OLS	0.23	0.01	0.91
Overall Solution Consistency	0.90		
Overall Solution Coverage	0.73		

Note: IAC = ICT Access; AFF = Affordability; ISK = ICT Skills; BIE = Business and Innovation Environment; IUS = ICT Usage; DBA = Digital Business Adoption; EPA = E-Participation; OLS = Online Services

digitalisation and its impacts on sustainability. Solution S2H is identical to S1H and indicates that countries with similar conditions to the previous group, but with a lack of affordability, can reach a high level of sustainable competitiveness by having an appropriate business and innovation environment. The ICT conditions in Singapore, Malta, Chile, Bulgaria, Hungary, and Uruguay are under this configuration. The S3H path (Czech Republic, Latvia, and Armenia) highlights that, in the absence of e-participation and online services, it is possible to improve sustainable competitiveness, in case the other six conditions are present. Particularly, business environment, affordability, and ICT skills are salient conditions in this configuration. Cases in the solution S4H (Tunisia, Nepal, Vietnam, Bhutan) show that countries with a high level of e-participation (as a core condition), online services and affordability (as complementary conditions) can reach a moderate level of sustainable competitiveness even with lack of business environment, ICT skills, ICT access, and business digital adoption.

Table 4 shows four configurations that led to the low/medium level of sustainable competitiveness. Solutions S1L and S4L are similar and typical pathways to low/medium GSC. The only difference is that in S1L, affordability, and in the S4L, the business environment are irrelevant conditions. In these two solutions, the lack of ICT skills, e-participation, and online service are the core conditions and the absence of the rest of the conditions are complementary conditions. Countries with the lowest level of sustainable competitiveness are placed in these two configurations, such as Chad, Mali, Burundi, Mauritania, Malawi, Gambia, and Haiti. The S2L configuration highlights that countries such as Qatar, the UAE, and Oman have had a low GSC due to poor ICT skills (the core condition) and affordability (the complimentary condition), even the other six conditions present. In addition, the S3L path (countries such as India, Bangladesh or Morocco) reveals that lack of business environment, ICT skills, ICT access, ICT use, and digital business adoption conditions, besides the presence of affordability, e-participation, and online services, countries are likely to lead to a low GSC. Overall, in all four paths, lack of ICT skills is a salient condition for low/medium sustainable competitiveness.

5 Testing for Predictive Validity

In order to evaluate the configurational model predictability in different samples, we tested its predictive validity following the procedure proposed by Pappas et al. (2019). It is important to test the predictive validity of the model, because even a good fitted model may not always yield the results that predict the outcome of interest as well as we expect (Pappas et al., 2020). To assess the predictive validity, we first randomly divided the sample into two parts of test subsample and holdout subsample. Then, we conducted analysis on the test subsample and checked its results against the holdout subsample. Table 6 indicates that the complex solutions are consistent with an overall consistency score of 0.90 for high levels of GSC. After that, we entered each of the configurations as a new variable in the holdout subsample and plotted it against the outcome variable (here GSC).

Figure 4 demonstrates the plots of the configurations in Table 6 as new variables and the outcome variable (GSC) based on the data in holdout subsample. Overall, the predictive validity test results of all configurations demonstrate that these solutions have high consistency (0.85–0.93) in the holdout subsample, thereby have high predictive ability.

6 Discussion

While previous research has explored the association between digitalisation and sustainability (Dima et al. 2018; Gouvea et al., 2018; Jetzek et al., 2019), understanding how digitalisation conditions produce cross-national variations in sustainable competitiveness has remained an important gap in sustainability literature (Higón, Dolores, and Shirazi 2017; Pradhan et al., 2019a, b). To fill this theoretical gap, we developed a conceptual model representing key digitalisation dimensions as interdependent conditions to explore configurations result in high and low sustainable competitiveness. Examining the results of the NCA indicates that, although digitalisation factors are not critical to low levels of GSC, their presence is important to reach moderate and high levels of sustainable competitiveness.

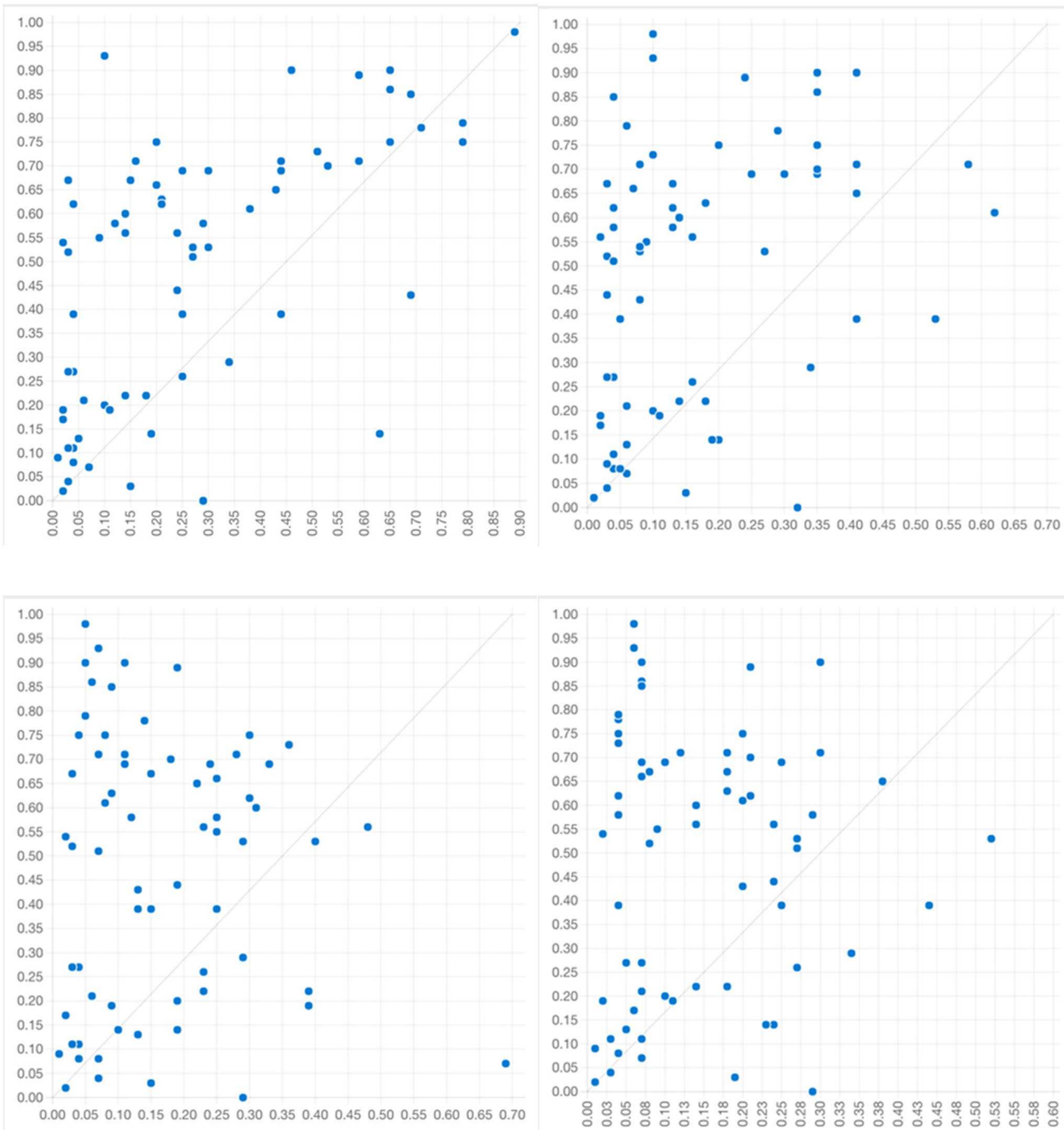


Fig. 4 plots of configurations from test subsample with data in holdout subsample.

In particular, when countries with a low GSC (less than 40%) such as Haiti, Mauritania, Pakistan or Chad attempt to reach a higher level of GSC, they should first improve access to ICT infrastructures like fixed telephone, mobile, internet, actively facilitate using of these technologies. Similarly, when countries with mid-range GSCs such as Algeria, Thailand, Nigeria, the Philippines, or Cyprus consider upgrading their sustainable competitiveness to higher next levels, they need to improve affordability, digital skills and the business environment in their countries. Our results also indicate that in order to achieve a high level of GSC (the top quartile of the list), countries need to invest heavily in ICT and advance their *ICT capabilities and infrastructure,* as well as *ICT usage and adoption*.

The findings of this study highlight the importance of digitalisation for sustainable competitiveness and show that various dimensions of digitalisation combine to constitute equifinal configurations to outcome. While, some configurations (S1H, S2H, S1L, and S4L) to high and low GSC support the conventional logic, which suggests that all digitalisation factors must be present to achieve a high level of sustainability, other found pathways dispute such perspective. For instance, S3H and S4H solutions along with the results of the bottleneck table demonstrate that in cases where a country has a lower level of digitalisation maturity can still achieve sustainable competitiveness with certain combinations of ICT access and usage conditions. Case members in S1H configuration, such as Sweden, Norway, Finland, Denmark, Ireland, Switzerland, Austria, Luxembourg or Estonia, are countries with very advanced digitalisation conditions and very high levels of GSC. Iceland, for example, ranks among those countries with top scores in ICT access, ICT skills, ICT usage, and digital business adoption, as well as good conditions in terms of affordability, innovation, e-participation, and online services. Cases in S2H configurations (e.g. Netherlands, Singapore, Malta, France, Chile, Bulgaria, Hungary, and Uruguay) are similar to S1H cases, but their affordability condition is absent and ICT skills is an irrelevant condition. For example, New Zealand holds very good situations in all digitalisation factors except affordability. S3H cases (Czech Republic, Latvia, and Armenia) show that countries can still achieve high GSC with good conditions in terms of affordability, ICT skills, and business environment as core conditions, as well as ICT access, ICT usage and business adoption as complementary conditions, even with lack of e-participation and online services. Armenia is an interesting example in this group, indicating that a country which does not have good conditions for providing online services or civic engagement in governance activities can achieve a moderate level of sustainable competitiveness by appropriately providing the other digitalisation conditions. Country cases of S4H configuration (Tunisia, Nepal, Vietnam, and Bhutan) are relatively opposite to those of S3H. Having good e-participation and online services, coupled with proper affordability enable these countries to achieve a moderate level of GSC, even when the four digitalisation factors (i.e. ICT access, ICT skills, business environment, and business adoption) are absent. For example, Tunisia has very good e-participation and online services, 8 and 8.1 scores (out of 10) respectively, and good affordability score (6.3).

As noted above, digitalisation conditions in cases of S1L and S4L paths are similar and most of the conditions are absent. The only difference between these two configurations is that in S1L, affordability and in S4L, innovation environment is a 'don't care' condition. Countries with such conditions have the lowest level of GSC. In particular, S1L countries (e.g. Haiti, Mauritania, Malawi, and Jamaica) do not possess good digitalisation situations. For example, while Pakistan has a good affordability score (6.9 out of 10), because of other weak conditions could not achieve high GSC levels. Similarly, S4L countries (e.g. Haiti, Gambia, Burundi, Chad, Uganda, and Mali), have low scores in digitalisation conditions. The case countries (Qatar, UAE, and Oman) in the S2L configuration interestingly highlight the critical role of ICT skills as a core condition and affordability as a complementary condition. Despite the heavy investment of these countries in digitalisation, due to lack of ICT skills and good affordability, these countries have not been able to achieve a high sustainable competitiveness. Lastly, the S3L configuration posits that having good affordability, e-participation and online service conditions is not enough and countries such as India, Bangladesh, or Morocco need to improve other digitalisation conditions, in particular, ICT skills as crucial core condition.

The results show that ICT skills play a salient role in developing digitalisation and creating sustainable competitiveness, which is consistent with prior literature (e.g. Kavathatzopoulos 2015; Visvizi et al. 2018). In particular, all configurations for low/medium GSC indicates that all countries with low sustainable competitiveness have weak ICT skills. In today's knowledge economy, developing educational and training programs and policies can be huge steps towards facilitating sustainable competitiveness. As noted above, the e-participation is another core element in three high and two low GSC configurations. New forms of digital participation encourage wider participation of citizens through digital technologies, which will eventually ensure high-quality governance mechanisms and e-government service platforms (Islam 2008). Ochara and Mawela (2015) posit that social sustainability is the ultimate result of larger civic engagement and participation of citizens in policy-making. However, the results show that when a country lacks e-participation, the combination of *ICT capability and infrastructure* dimensions (i.e. ICT access, affordability, ICT skills, and business environment), coupled with business digital adoption and ICT usage would still lead to high GSC.

The findings also show that countries ought to apply various improvements in their digitalisation efforts to reach a moderate level of sustainable competitiveness. Our study reveals that *ICT capabilities and infrastructures*, together with the initial usage of ICT is required conditions for moderate levels of sustainable competitiveness. To reach this level of GSC, countries should foster their ICT training and skill development plans, facilitate access to ICT infrastructure and increase ICT affordability. Moving beyond this threshold, countries should improve ICT usage and adoption and develop platforms for e-participation and policies to support digital business adoption. Finally, although fsQCA's necessity and sufficiency analysis show that none of the digitalisation conditions is prerequisite for high levels GSC, S1H and S2H configurations along with bottleneck table results suggest that substantial development of digitalisation conditions is needed to achieve higher levels of sustainable competitiveness (level 70% and onwards).

6.1 Theoretical Implications

The findings of this research extend the existing knowledge of the associations between digitalisation and sustainability in several ways. First, by using the configurational approach, we developed a holistic model that represents key digitalisation dimensions as interdependent elements to explore how national sustainable competitiveness is predicted by combinations of these conditions. We conceptualise digitalisation as a complex, multi-faceted concept that consists of interdependent eight dimensions and proposed a combinatorial model of these dimensions that conjointly contribute toward sustainable competitiveness. Our proposed configurational model of eight condition variables in two categories of 'ICT capability and affordability' and 'ICT usage and adoption' contextualizes the national digitalisation endeavours that further is corroborated with empirical data from 127 countries. The configurational view applied in this study is a useful addition to previous digital transformation models which are mainly conceptual or based on symmetrical, net effect analysis. Using this novel perspective and empirical data assist us to engage with real-world settings and thereby develop prescriptive solutions leading to enhancing the outcome of interest. The new methodological used in this study, which differentiates it from prior work in the context of digitalisation enables us to examine conjunctural relations of digitalisation conditions and identified various equifinal, asymmetrical configurations that could better explain high and low sustainable competitiveness.

Second, by using a valid quantitative dataset to test our configurational model, this study theoretically and empirically sheds light on important dimensions of digitalisation for sustainable competitiveness. Our results confirm that achieving high levels of sustainable competitiveness depends on the combination of accessing to ICT infrastructures and capabilities and actively adopting and using ICT technologies. Furthermore, findings of the current paper provide a better understanding of different recipes of digitalisation conditions required for various levels of sustainable competitiveness. More specifically, the results show that different levels of sustainable competitiveness require different threshold levels of digitalisation conditions.

Third, this study is one of the first scholarly attempts in IS literature that simultaneously uses NCA and fsQCA methods to examine the complex relationships between variables. Using the ceiling lines and bottleneck table, NCA enabled us to quantitatively investigate various levels of conditions required to obtain a particular level of the desired outcome. At the same time, fsQCA allowed us to analyse fine-grained data in order to study causal complexity with analytical rigor because of the analytical strength of the set theory and its associated tools (e.g. truth table, consistency, and coverage scores). These methods provided a deeper understanding of how complex causal patterns of digitalisation conditions affect sustainable competitiveness and what asymmetric relationships exist between them.

Finally, in order to assess the results of current study, we examined the findings of fsQCA and NCA according to the key tenets of complexity theory (Woodside 2013) as the theoretical ground of our proposed model (see Table 7).

6.2 Practical Implications

This study offers new insights and solutions to achieve sustainable competitiveness through various configurations of digitalisation factors. Implementation of these solutions may lead countries to the desired outcome, thereby policymakers can use these proposed configurational recipes to develop and design strategies based on the status of their home countries to ensure achieving high levels of sustainability. Results indicate that almost all countries with low sustainable competitiveness such as Chad, Haiti, Mali, and Malawi have weak digitalisation condition. In order to enhance their GSC, solutions indicate that these countries should improve access to ICT and facilitate its usage and, at more advance stages, increase affordability and encourage businesses to adopt ICT in their operations. Previous research and industrial reports suggest various ways to improve ICT access and usage such as increasing the number of fixed and mobile telephones (Lwoga and Sangeda 2019), increasing international Internet access and bandwidth besides providing new generations of mobile networks (e.g., 4G or 5G), improving affordability by enhancing the ability of individuals or households to pay for access to ICT relative to their disposable income as well as increasing the number of ICT providers to foster competition in the market (ITU 2018).

Our findings also affirm the critical role of ICT skills in sustainable competitiveness. In recipes to low/medium GSC, the lack or the inadequacy of ICT skills are major impediments for achieving higher sustainable competitiveness power. Results show that besides improving ICT skills, countries like Qatar, UAE, and Oman by promoting ICT affordability for their citizens, and countries like India, Bangladesh, or Morocco by boosting ICT access, innovation environment, ICT usage, as well as business digital adoption could reach a higher level of GSC. For example, policymakers in these nations can facilitate open innovation initiatives such as living lab projects to develop smart city or smart health innovation environments (Ruijer and Meijer 2020; Shin 2019). In addition, some businesses in these countries might still be reluctant to comprehensively use and integrate ICT particularly when the expected benefits are outweighed by costs, or if they are not confident about the security and reliability of online transactions. After making network infrastructure available and affordable, national policies thus need to concentrate on making application benefits relative to costs and reassure the security of online business transactions by making them reliable and verifiable throughout a confident legal framework.

Further, the findings highlight the importance of ICT affordability, ICT skills, business & innovation environment, and e-participation as core conditions in four different configurations

Table 7 comparing the key tenets of complexity theory with the results obtained from fsQCA and NCA

Complexity Tenet	Supportive evidence in this research
T.1: a simple antecedent condition may be necessary, but a simple antecedent condition is rarely sufficient for predicting a high or low score in an outcome condition	A simple antecedent (e.g. e-participation) is not consistently sufficient in all causal recipes. (See Tables 5,6).
T.2: a complex antecedent condition of two or more simple conditions is sufficient for a consistently high score in an outcome condition—the recipe principle	As shown in Table 5, the presence of three conditions for digitalisation is sufficient to provide a high level of GSC (affordability, e-participation and online services). While the absence of two antecedents (affordability and ICT skills) is sufficient to achieve a low level of GSC.
T.3: a model that is sufficient is not necessary for an outcome having a high score to occur—the equifinality principle	The results of the fsQCA illustrate four alternative solutions that are sufficient to achieve high GSC levels. In addition, the four proposed models demonstrate the necessary and sufficient conditions for low GSC levels (Table 6).
T.4: recipes indicating a second outcome (low GSC) are unique and not the mirror opposites of recipes of a different outcome (high GSC)— the causal asymmetry principle	A comparison of the four solutions depicted in Table 5 with the four solutions illustrated in Table 6 reveals that they are not simply the mirror opposites of each other.
T.5: an individual feature (condition) in a recipe can contribute positively or negatively to a specific outcome depending on the presence or absence of the other ingredients in the recipes	The presence of affordability and e-participation are affected by the presence or the absence of online services and other conditions and can lead to high or low levels of GSC.
T.6: for high Y scores, a given recipe is relevant for some but not all cases; coverage is less than 1.00 for any one recipe.	Some cases are not covered by the extracted configurations and the overall coverage of solutions for both high and low levels of GSC is 0.7 and 0.74 (Tables 5, 6).

to achieve high levels of sustainable competitiveness. Particularly, solutions indicate that the Czech Republic, Latvia, and Armenia by improving e-participation and providing online services to their citizens can reach higher GSC. In order to improve e-participation, nations can invest in initiatives like developing tokenizable e-Participation models to promote greater participation in public affairs (Benítez-Martínez et al., 2020).

Also, we suggest that countries like Bhutan, Nepal, Tunisia, and Vietnam could upgrade their sustainable competitiveness with improving ICT access, ICT skill, business and innovation environment, and business digital adoption. We identified various antecedents of high levels of GSC; however, findings here pinpoint that on different levels, some antecedents are more important than the others. For instance, when a country has low levels of GSC, policymakers should take initiatives for developing ICT infrastructures and especially enhancing ICT skills. Further, when a country attempts to achieve higher levels of sustainability, policymakers can develop strategies to encourage the ICT usage, create appropriate digital platforms to promote e-participation, improve citizens' access to information and public services, and assist businesses to adopt new technologies. For example, the city council of Madrid has developed an award-winning e-participation platform called 'Decide Madrid' to engage the public in decision making by participatory budgeting, proposing ideas, providing opinions, and voting (Royo et al., 2020).

7 Limitations and Future Research

The results of this research should be interpreted in light of its limitations. The present study aimed to explore the impacts of digitalisation factors on sustainability by using available data from 127 countries. Future studies may expand the analysis to include more countries. It would be also useful to test the robustness of the results by using data from other countries. fsQCA results rely on existing literature and prior knowledge to select appropriate predictors and outcomes (Wang et al. 2019). In the current study, we developed our conceptual model based on previous academic and international industrial research, thus future research could employ an exploratory approach or a mixed-method design to identify other variables and conditions that might have an impact on this field. Further, while using fsQCA enables researchers to identify multiple configurations that led to the outcome, it does not examine the distinct impacts of conditions on the outcome. Future research could combine fsQCA with CRBM to integrate insights from both approaches and create a more holistic view regarding the relationship between digitalisation and sustainable competitiveness. Additionally, further research could investigate the casual relationships of digitalisation factors with different sustainability goals in five domains of natural capital, resource efficiency and intensity, intellectual capital, governance efficiency, and social cohesion. Finally, conducting a longitudinal study to empirically examine the impacts of changes in digitalisation conditions overtime on GSC could be a fruitful research avenue.

8 Conclusion

Unlike most of the previous studies on digitalisation and sustainability, which simply have used independent, additive, symmetrical modelling/thinking, the current study has developed and examined conjectural, equifinal, and asymmetrical relations between digitalisation and sustainable competitiveness (please see Table 8 in Appendix). In response to the main inquiry of this study: 'What configurations of digitalisation factors lead countries to high or low levels of sustainable competitiveness?', we used fsQCA and NCA techniques to identify complex combinations of digitalisation conditions that result in both high and low levels of sustainable competitiveness.

Drawing on complex theory and using configurational approach through fsQCA and NCA allowed us to discover not only the influential factors but also various sets of conditions that could lead to low or high levels of sustainable competitiveness. By analysing a dataset of 127 countries, this study offers a novel theoretical framework to further understanding of the complex relationships between digitalisation factors and sustainable competitiveness. The results of fsQCA and NCA improved our understanding of how ICT capabilities and infrastructure combined with ICT usage and adoption yield varying levels of sustainable competitiveness. The results of this study expand global debates regarding the impact of digitalisation in countries with varying stages of development, as it identifies multi-factor causal recipes that create sustainable competitiveness.

Appendix

Table 8 Examples of previous studies exploring the interaction of ICT and sustainability across countries

Source	Variables	Methodology	Findings
(Matei and Savulescu 2012)	Networked readiness, global competitiveness and ICT sector share in national economies	Correlation analysis	There is a significant relationship between ICT and development of a sustainable knowledge economy.
(Yunis et al. 2012)	ICT usage, readiness, and environment and global competitiveness	Structural equation modeling (SEM)	ICT has a significant relationship with the global competitiveness of countries, while there is a stronger relationship in high readiness countries than in low readiness countries.
(Gouvea et al. 2018)	environmental sustainability, ICT, and human development	Ordinary least squares regression	ICT and human development have a positive and significant effect on environmental sustainability
(Pradhan, Arvin, Nair, and Bennett 2019)	ICT diffusion, innovation diffusion, venture capital investment, and economic growth	vector error-correction model	In the long run, there is a significant relationship between venture capital investment, ICT diffusion, and innovation diffusion with economic growth in Europe.
(Apaydin, Bayraktar, and Hossary 2018)	hyperconnectivity and socio-economic sustainability	canonical correlation analysis	Affordability of technologies and high individual ICT usage in the emerging countries did not impact socio-economic sustainability.
(Jetzek et al. 2019)	Open Government data and sustainable value	SEM	Open data, digital governance and digital infrastructure in a country have a positive effect on the country's level of sustainable value.
(Dima et al. 2018)	Global Competitiveness Index (GCI), research and development expenditure, percentage of population with tertiary education, lifelong learning, GDP per capita, and debt to equity	Pearson coefficient and panel-data regression models	Both innovation and education are crucial determinants of EU competitiveness and economic convergence.
(Park, Meng, and Baloch 2018)	Internet use, financial development, economic growth, and trade openness and carbon dioxide (CO2) emissions	Pooled mean group (PMG) estimator	Internet use has lowered the environmental quality in EU countries.
(Lee et al. 2018)	ICT use and e-government development (telecommunication infrastructure, online service, e-participation) and government corruption	A three-step analysis of the mediating effects and a Sobel test (empirical analysis)	A significant relationship between e-government user levels, governance, government regulation, and government corruption
(Añón Higón et al. 2017)	ICT readiness, ICT use, ICT intensity, GDP, Government effectiveness, rule of law, number of passenger car, population density, oil, Kyoto ratification, education, industry share and CO2 emissions	Linear OLS regression	An inverted U-shaped relationship between ICT and CO2 emissions

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