How to Measure Knowledge Economy

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Abstract: The paper's primary goal is to analyse the development of Knowledge Economy (KE) measurement methods ranging from those based on national income to indices identifying and combining the relevant indicators. The paper focuses on four current global and European KE level indices: Global Innovation Index (GII), Global Knowledge Index (GKI), European Innovation Scoreboard (EIS), and Digital Economy and Society Index (DESI), highlighting persistent significant differences in the perception of the very essence of KE, as there is no clear interdisciplinary definition of the initial concept of knowledge, leading to further problems with ambiguous and insufficiently specific definitions and measurement of KE. Tacit aspects of knowledge are rarely part of KE definitions or measurements, excluding a large part of the knowledge system from KE measurements. The results of the analysis show that the set of KE indicators used by the individual KE indices is heterogeneous, with the set of intersecting indicators having different weights in terms of importance. Frequent interventions in the indices by their authors were observed, such as changes in index methodology, the indicators used, main pillars (subindices), etc. Despite the high heterogeneity in the approach to measuring KE, we identified the pillars, which can be viewed as the core pillars of KE. These include, for example the level of ICT, R&D, human resources, innovation, patents, and education.

Keywords: Knowledge economy, Measurement, Knowledge index, Tacit knowledge

1. Introduction

The 1960s represent the initial phase of significant socioeconomic changes related to the massive deployment of automation and scientific discoveries. While 1915-1965 was a period of stability and continuity with the smallest changes over the last 300 years, the 1960s started a period of discontinuity in the context of the world economy. A period of changes in technology, in the economy, in the structure of industry, in the necessary knowledge, and in the knowledge to manage these changes has begun. With the arrival of computers, we realised that information is a form of energy. While electricity has been perceived as the cheapest form of energy for mechanical work, information began to be perceived as energy for the work of the mind. In the 1960s, energy for the work of the mind became more and more readily available (Drucker, 1992). The emergence of the so-called information society was discussed in the mid-1960s in the Japanese magazine Hoso Asahi focused on broadcasting, published by the television network and newspaper publisher Asahi, where the emergence of the information society and television culture was a frequent topic of discussion (Steinberg and Zahlen, 2017). Several authors such as Tadao Umesao, Yondji Masuda, and Jiro Kamishima published articles about the information society in the journal, (Duff et al., 1996). However, at the same time, we can assume that back then could have already been influenced by the publication of the economist F. Machlup (1962), who decided to analyse the American economy in terms of production and distribution of knowledge. Naturally, the forthcoming changes also began to be discussed among sociologists (Bell, 1973; Toffler, 1980). The transition from the industrial to the post-industrial economy has also been interpreted in social sciences using a wave model when an older wave is not yet exhausted as a new wave is arriving. Individual countries of the world may sense the impact of both waves combined, and thus the industrial and knowledge economy operate side by side (Toffler et al., 1995). Giving the new incoming society a common name has been a great challenge so far. In social sciences, terms such as information society, post-industrial society, white collar revolution, connected society, telematic society, information revolution, digital revolution, or information era were used at that time. We decided to conduct a short informetric survey in the Web of Science (WoS) Core Collection bibliographic database with the aim of identifying the most relevant designation of the new economy in our paper and to determine the most frequently identified names of the new economy (information economy/information economics; knowledge-based economy; knowledge economy) being the most preferred in the current expert discourse. For this purpose, we formulated four queries, TOPIC: ("information economy"/"information economics"), TOPIC ("knowledge economy") and TOPIC ("knowledge-based economy"). All queries were refined by time span 1900-2022, and indices SCI-EXPANDED, SSCI, A & HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC. It turned out that the first records of scientific papers using the phrase "information economy" appeared already in the early 1970s, but later their use weakened. We also observe that the actual

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professional interest in the topic of knowledge economy began in the late 1990s, with the frequency of occurrence of the terms Knowledge Economy (KE) and Knowledge-Based Economy (KBE) having increased significantly, while the designation KE is currently used in professional literature approximately twice as often as KBE. These results are shown in Figure 1. For this reason, we decided to use the term Knowledge Economy (KE) in our paper.

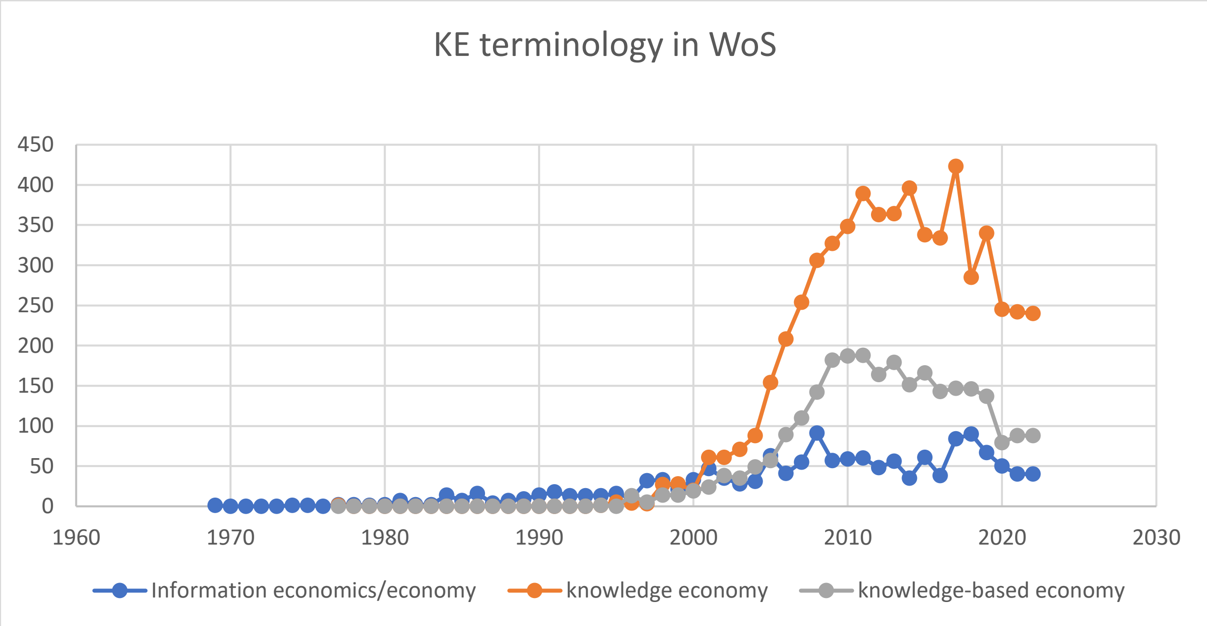

Figure 1: The Evolution of KE Terminology in the WoS Database

2. The Advent of KE

Some authors trace the origins of the KE's first wave back to the work of J. Schumpeter on the importance of innovation within the concept of development (Schumpeter, 1934) or Hayek's theory of knowledge (1937; 1945), which made a significant contribution to economics and to social sciences. Hayek (1945) tried to capture the relationship between knowledge and economics, perceiving knowledge more as subjective cognitive processes. He pointed out that social knowledge is more like incomplete and often mutually exclusive knowledge owned by individuals. In fact, in real life, no one has perfect information, but we have the skills and abilities to find it. However, such a kind of knowledge is largely subjective and is difficult to cover by statistics. In 1949, philosopher G. Ryle formulated the idea of subjective knowledge, adding the know-how type of knowledge to the traditional know-what notion, defined as disposition, skill, and a matter of competence (Ryle, 1949), followed by the philosopher M. Polanyi (1962), who came up with a theory of (subjective) inexpressible, tacit knowledge.

Probably the most frequently mentioned milestone on the path to KE is the work by F. Machlup (1962), who pointed out the increasing share of knowledge in the national budget, that knowledge is closely related to the increase in productivity, and that we are witnessing a shift of requirements from physical labour to "brain workers". He therefore decided to define the concept of knowledge and, consequently, based on the definition, to be the first to measure the production and distribution of all types of knowledge in the USA. When defining knowledge, he continued the established trend of G. Ryle and F. A. Hayek and expanded focus to subjective types of knowledge. Thus, in his understanding, knowledge is not only traditional "true" knowledge, breaking out of a purely positivist perception of knowledge. His take on knowledge also included statements, assumptions, hypotheses, regardless of the degree of their verification. He divided the set into 5 subsets of knowledge: practical, intellectual, small-talk, spiritual, and "unwanted" (Godin, 2010). In addition, while other measurements at that time were devoted to measuring the production of exclusively scientific knowledge, without measuring the distribution of this knowledge in society, Machlup decided to take a broader view of the context of knowledge in society and extended the scope of interest from creation to distribution of knowledge as another economically significant stage of the knowledge process in society.

A few years later (1969), P. Drucker's book The Age of Discontinuity is published, which provides straightforward evidence of significant socioeconomic changes and the end of a relatively lengthy period of continuity. In his publication, Drucker as a management theorist analysed changes in society, the emergence of the knowledge industry and the KE, and he considered the measurement of the so-called knowledge workers – a term coined by himself – as the basis for measuring economic potential and economic power. In the scientific community, he is considered the founder of the discipline of Knowledge Management (KM), a novel approach to managing knowledge workers as knowledge owners. He pointed out that knowledge rather than science as such became the basis of modern economics and drew his attention to practical application of knowledge. Knowledge becomes the main cost, investment, and main product of developed economies and the livelihood of the largest groups on the population (Drucker, 1992).

In 1973, sociologist Daniel Bell joined the scientific debate with his publication The Coming of Post-Industrial Society (1973). He pointed to the shift from manufacturing to services and the rise of a new technical elite, yet his perception of knowledge was limited to theoretical knowledge and new science-based industries. Two years later he pointed out in his work Social Framework of the Information Society that at that time 70% of the workforce was in the services sector, which was also too heterogeneous in terms of knowledge intensity. He therefore proposed to distinguish five sectors of the economy: primary (agriculture, mining, fishing, carpentry, etc.), secondary (goods production, construction industry, production of stable and unstable goods), tertiary (transport, shipping, utilities), quaternary (trade, finance, insurance, real estate), and quinary (health, education, research, state administration, etc.). (Bell, 1980).

In 1977, Marc Uri Porat elaborated a report for the U.S. Department of Commerce/ Office of Telecommunication titled The Information Economy (Porat, 1977) to define and measure information activity in the U.S. economy. He dedicated his work to F. Machlup and D. Bell, who had served him as the basis for his work. The Porat's report launched a series of similar analyses in various countries and international organisations.

The 'first wave' of KE also includes the publication by futurologist and sociologist Alvin Toffler – The Third Wave (Toffler, 1980), focused on technologies such as waves introduced by people throughout history. He distinguished three waves: agrarian, industrial, and postindustrial, the latter being characterised by the mass deployment of ICT that creates unlimited possibilities for the transmission of information. He discusses postindustrial economy, where information and what people can do with it with their intellect play a vital role.

The second wave of KE has been mapped since the 1990s and extends till the present day and is associated with increased interest of international organisations in KE and the possibility of its measurement, as well as with the arrival of KM as an academic discipline.

As we have indicated, against the background of several emerging problems, we see that there is a problem with a clear definition of the semantic content of the concept of knowledge and with its precise comprehensive delimitation. This problem can then be implicitly perceived in subsequent complications with the creation of a KE definition and with the possibilities of KE measurement. Smith (2002) and, similarly, Carlaw (2006) state that there is no coherent KE definition. The definitions offered by international institutions are too broad and too abstract for measurement purposes. For example, the Organisation for Economic Co-operation and Development (OECD) (1996) defined KE as an economy that is directly based on the production, distribution, and use of knowledge and information. The World Bank (Chen and Dahlman, 2006) views KE as one that utilises knowledge as the key engine of economic growth. It is an economy where knowledge is acquired, created, disseminated, and used effectively to enhance economic development. Authors of scientific papers devoted to KE are more interested in identifying the main attributes of KE rather than in its exact definition. A partial consensus was found among experts, most of whom refer to the four pillars of KE as defined by the World Bank (Chen and Dahlman, 2006): an economic incentive and institutional regime; educated and skilled workers; an effective innovation system; a modern and adequate information infrastructure. Apparently, as it turns out, there is no definition alone that can capture all aspects of KE, and as Brinkley (2006) stated in the results of his analysis, there are hardly any definitions that describe KE in such a way that would make it possible to measure and quantify it. In addition, the tacit aspects of knowledge are rarely part of KE definitions, and likewise if we try to measure KE, then in most cases we will be limited to measuring those parts of the knowledge system that can be codified (patents, investments in formal R&D, papers published and cited, etc.). Economic research was mostly constructed on codifiable knowledge, which implies that we ignore a large part of the knowledge in the economy (Ducatel, 1998).

Despite the above ambiguities, we have been monitoring the efforts to measure the level of KE for about 60 years. It is natural that due to the issues outlined the measurement methods vary, and even the present day's methods of measurement via KE indices are not uniformly consolidated.

3. The Early Approaches to KE Measurement

Measurement can be seen as a process of assigning scaled numbers to items in a manner that makes it possible to express the relationships existing among the possible states of the variable in the relationship among the numbers on the scale (Andriessen, 2003). Knowledge measurement can be studied at two levels: at the level of an individual firm or at a national (macroeconomic) level.

Measurements at the level of an organisation involve a combination of accounting and nonfinancial indicators measuring stocks of intellectual or knowledge capital and flows of changes in knowledge stocks The knowledge capacity of firms is proxied by means of instruments like Balanced Scorecards (Kaplan and Norton, 1996), Intangible Asset Monitor (Sveiby, 1997), Skandia Navigator (Edvinsson and Malone, 1997), Technology Broaker (Brooking, 1996) Citation-Weighted Patents (Bontis, 1996) Value Chain Scoreboard (Lev, 2001). However, due to the nature of knowledge, all such measurements include, in addition to direct measurements, proxies, and indirect estimates (Shapira et al., 2006). Thus, none of these assessment methods are perfect. However, organisations seek to find a measuring tool that would be the most suitable for them in the given context under the given circumstances (Bontis et al., 1999).

At the macro-level, economic models have been built that capture the creation of new knowledge and its connection with wealth in the production function. The basic Cobb-Douglas function (1928) had problems in handling innovation and endogenous technical changes and was therefore improved by Solow (1957) from 1957 onwards. The literature that followed, referred to as growth accounting, attempts to disaggregate the residual in the standard production function using increasingly sophisticated econometric methods, often embodied in technical change (Shapira et al., 2006). Similar calculation were initiated by *Machlup* (1962), whose work is a milestone on the path to KE, with an attempt to define knowledge, measure its contribution to the economy and identify policy issues. His definition of knowledge integrates all kinds of knowledge and points out that it is important both to create (discovering, inventing, designing, planning) and to distribute knowledge (disseminating and communicating). He was aware that knowledge had always played a role in economic analysis and considered the increase in technical knowledge and the resulting increase in productivity to be crucial factors in analysing economic growth. When Machlup published his work in 1962, economic analyses of science were still beginning to develop. At that time, there were two types of accounting measurement: growth accounting and national income accounting (Kuznets, 1946). Machlup chose the national accounting method for his calculations, which, unlike formalised growth accounting, relied on descriptive statistics. National accounting developed after the Second World War and allowed the National Bureau of Statistics to systematically collect data on the production of economic goods and services in the country, but without data on "knowledge". Machlup had to collect data for his calculations from various private and public sources, too. Therefore, the goal of his effort was not the statistical accuracy of calculations, but a general message that knowledge is an important entity of the economy, even if it does not correspond to economic logic.

In his work, he analysed areas such as: *education* (in the home, on the job, elementary and secondary, colleges and universities, etc.); *R&D* (basic and applied research); *printing and publishing* (books, periodicals, newspapers, etc.); *information machines* (printing trades machines, motion pictures apparatus, telephone and telegraph, typewriters, electronic computers, etc.); *personal services* (legal, engineering and architectural, accounting and auditing, medical); *financial services; photography; stage, podium* (theatres and concerts, motion pictures, etc.); *radio and television, advertising; telecommunication media* (telephone, telegraph, postal service); *conventions* (check-deposit banking, securities brokers, insurance agents, real estate agents); *wholesale agents; miscellaneous business services; government* (federal, state, and local). In his analyses, he focused on groups of professions and distinguished white- and blue-collar workers, showing that KE accounted for up to 29% of GNP in 1958 and such people as knowledge-producing workers (education, R&D, media of communication, information machines, information services) accounted for almost 27% of the national income. His message was therefore directed towards focussing more on education, R&D and information technology revolution as source of growth and productivity and structural change and unemployment by automation.

Unlike Machlup, *M. Porat* strictly follows the national income accounting framework. In the introduction, it defines information activity as one that includes specific industries and professions having their primary function to produce, process or transmit economically valuable information. Information activity includes all the resources consumed in producing, processing and distributing information goods and services. Porat describes the distinct types of "information workers" who make a significant contribution to the creation of knowledge, the communication of ideas, the processing of information, and the transformation of symbols from one form to another. These include, for example, research scientists, engineers, designers, draftsmen, managers, secretaries, clerks, advertising managers, communications officers, etc. His work contains information definition (data organised and communicated) and includes a formal set on National Income and Product Accounts for the *primary* and *secondary information sectors* (with input-output matrices for both sectors) specifying information-related occupations of both primary and secondary information sectors (Porat, 1977). He asserted that certain occupations are primarily engaged in the manipulation of symbols, either at a high intellectual content (production of new knowledge) or at a more routine level (feeding computer cards into a card reader). That means it is a division by level (of degree not of kind). In such a manner, he divided the 422 occupations reported by the U.S. Census and the Bureau of Labor Statistics into two main groups (information and noninformation). He defined the *primary* information sector that includes firms that supply the bundle of information goods and services exchanged in a market context and the *secondary* information sector that includes all the information services produced for internal consumption by government and noninformation firms. Based on the matrix created he found out that in 1967, the *primary* information sector accounted for 21.9% of final demand (GNP), the *secondary* information sector 3.4% of GNP, and the *noninformation* sector 74.6% of GNP. He further states that since 1955 the information sector had become predominant, growing from 15% of workforce in 1901 to almost 40% in 1970, with information workers earning more than 53% of all labour income in 1967. He saw this as an argument that the U.S. had emerged as an information-based economy (Porat, 1977).

4. Indicator-Based Measurement

When the arguments about the transition to KE were quite strong and visible, international economic organisations began to discuss possible indicators of relative knowledge intensity of economies (Karahan, 2012) capturing inputs and outputs, or elements of the cause and effects of knowledge processes. A broad system of statistical indicators and metrics has been developed to describe KE. The measurement of KE was started using a set of indicators collected under the umbrella of "knowledge" as a collection of available statistics capable of capturing some dimensions of knowledge and KE. Such a method of measurement is a comprehensive and complicated process, and even the perception of the basic concept of knowledge is not unambiguous, leading to many discussions at the international level on measurements through indicators. Currently, we are witnessing the application of various approaches, both in the selection of indicators and in determining the weight of individual indicators in the calculation of the knowledge index. Gradually, it becomes clearer which indicators are more relevant and reflect the true features of KE and which are troublesome. Back in 2008, Arundel et al. pointed to the problem of the excessive importance placed on knowledge *production* (Arundel et al., 2008), especially in the initial stages of measuring KE, where the measurement of scientific articles and patents was one of the main indicators of KE's level. The need to integrate "softer" indicators of sociocultural factors as well as knowledge diffusion and knowledge impact into the measurements has been shown in the case of the so-called European paradox. Indeed, it turned out that Europe is to outperform the U.S. in the production of new knowledge when measured through scientific publications; however, the EU lags behind in the commercial exploitation or use of this knowledge base (Arundel et al., 2008). Another assumption that new start-ups automatically generate more successes proved to be problematic too, however, there is not enough empirical data for that, and excessive clinging to insufficient data may lead to risks of socially inefficient overinvestment in projects that are doomed to fail (Parker, 2005). Similarly, the traditional measurement of the *science* system may encounter a problem as in KE the science system is implicitly expected to change its traditional function of producing new knowledge through basic research and educating new scientists toward a new role as an entity cooperating with industry (OECD, 1996), which has not happened in some countries. In fact, ineffective cooperation among KE actors has been found to undermine the effects that a higher investment in education, R&D and innovation would bring. The importance of regional relationships in starting up innovation is shown by the Triple Helix as 3H (Etzkowitz and Leydesdorff, 1997) or Quadruple Helix as 4H (Carayannis and Campbell, 2010; Ivanova, 2014) and Penta/Quintuple Helix as 5H (Carayannis et al., 2012; S Halibas et al., 2017) models.

4.1 The Organisation for Economic Co-operation and Development (OECD) 1995 - 2017

Included countries: 38 OECD + Argentina, Brazil, China, India, Indonesia, Russia, Saudi Arabia, South Africa

The first crucial effort to measure KE by an international organisation dates back to 1995, when the OECD discussed KE in the context of new growth theory and innovation performance (OECD, 1995). The OECD started to conduct research on KE (KBE) with attempts to compile statistical indicators on KE based on their work of developing and publishing science and technology (S&T) indicators (OECD, 1996). They discussed the need for improved KE indicators in the context of measuring knowledge inputs, knowledge stocks and flows, knowledge outputs, knowledge networks, and learning (OECD, 1996). In 1999, the OECD launched a two-year study called the "Growth Project" to analyse the causes underlying differences in growth performance in the OECD countries and to identify factors, institutions and policies that could improve long-term growth prospects (OECD, 2000b, 2000a, 2001) where broad elements of a KE were named as: stable and open macroeconomic environment with effectively functioning markets, the diffusion of ICT, fostering innovation, investing in human capital, and stimulating firm creation.

In general, the OECD attempted to measure knowledge directly. The relevant statistics have been made comparable among nations by the OECD and Eurostat, and the focus of the efforts has been to develop indicators of the relative knowledge intensity of industrial sectors (Leydesdorff et al., 2006). The creation of KE indicators was largely a transformation of indicators from the Industry and Technology Scoreboard of Indicators, which were published by the OECD every two years and consist of 76 *indicators* grouped into five main categories: *R&D and Innovation* (15), *Human Resources in Science and Technology* (10), *Patents* (11), *ICT* (17), *Knowledge Flows and the Global Enterprise* (12), *The Impact of Knowledge on Productive Activities* (11). Basically, most of the collected indicators used by the OECD long before were subsumed under the concept of KE. For example, indicators such as "science and technology policies" and "output and impact" were changed to the category "creation and diffusion of knowledge" (Godin, 2006).

The main categories of indicators observed by the OECD would be gradually adjusted, e.g., in 1999 (OECD, 1999) they developed a scoreboard of 32 indicators where five dimensions were observed: *Knowledge-Based Economy; ICT; Science & Technology Policies; Globalization; and Output and Impact*. In 2001 (OECD, 2001) four main categories of indicators were developed: *ICT; innovation and technology diffusion; human capital; firm creation and entrepreneurship*, and in 2003 the indicators were arranged into classes: *Investment in Knowledge; Investment in ICT; Trends in Trade and Investment Flow* (OECD, 2003). The reports were published under the title until 2017 when the OECD analysed six groups of indicators: *Knowledge economies and the digital transformation; Knowledge, talent, and skills; Research excellence and collaboration; Innovation in firms; Leadership and competitiveness; Society and the digital transformation* (OECD, 2017).

4.2 World Bank Institute's Knowledge for Development Program (K4D) 1999-2012

Included countries: 128.

The World Bank (WB), more specifically the Knowledge for Development (K4D) initiative, which developed the Knowledge Assessment Methodology (KAM) in 1999, a simple KE benchmarking tool, providing a basic assessment of readiness of countries and regions for the KE, is considered a significant milestone in the measurement of KE using indicators. As Chen and Dahlman suggest, the unique strength of the KAM lay in its cross-sectoral approach that allows a holistic view of the wide spectrum of factors relevant to the KE (Chen and Dahlman, 2006). They argue that a successful transition to the KE involves elements such as investments in education, developing innovation capability, modernising the information infrastructure, and having an economic environment that is conducive to market transactions, the four KE pillars.

The KAM consists of data for 80 variables, describing the four pillars of the KE, as well as economic and social performance, governance, and gender issues. Indicators (variables) that are contained in the KAM span over different ranges of values, all indicators are normalised from 0 (weakest) to 10 (strongest), and the 128 countries are ranked on an ordinal scale. It was the first web-based user-friendly diagnostic tool that allowed individual countries to understand their strengths and weaknesses within the EC by comparing themselves with other countries analysed.

The tool offered the possibility of simplified conversion of the so-called basic scorecard, which provided an overview of countries' performance in terms of all four pillars of the EC. It included 14 standard variables: two performance variables (*%Average annual GDP growth; Human Development Index*) + 12 knowledge variables under the four pillars (see Table 1):

Table 1: KAM Pillars and Subpillars (World Bank Institute, 2004)

Economic Incentive and Institutional Regime:	*Tariff and non-tariff barriers*
	Regulatory Quality
	Rule of Law
Education:	*Adult literacy rate % age 15 and above*
	Secondary enrolment
	Tertiary enrolment

Innovation:	*Researchers in R&D/million population*
	Patent applications granted by the USPTO/million population
	Scientific and technical journal articles/million population
ICT:	*Telephones per 1,000 persons*
	Computers per 1,000 persons
	Internet users per 10,000 persons

The four KE pillars mentioned are perceived by experts as the main pillars of KE to this day. The level of KE of a given country, or a comparison of a country's progress over time, or a comparison with selected countries, offered an instrument both in the traditional tabular form and in the spider, diamond, and bar chart form of visualisation. The basic scorecard was used to create the Knowledge Economy Index (KEI), which integrated the four KE pillars, and to calculate the Knowledge Index (KI) consisting of only three pillars (without the Economic Incentive and Institutional Regime pillar). (World Bank Institute, 2004).

5. Current Global and European Indices Measuring the Level of KE

During our research conducted since 2019, we have identified several initiatives to measure the main attributes of KE. Based on the results of the content analysis of studies devoted to the main attributes of KE, we decided to conduct a detailed analysis and mutual comparison of what we see as the four most important KE indices, which allow mutual comparison of the level of KE of individual countries, which functions as a web-based tool with a data export option. We selected the Global Knowledge Index (GKI) and the Global Innovation Index (GII) from the existing global indices, and we chose the European Innovation Scoreboard (EIS) – Summary Innovation Index (SII) and The Digital Economy and Society Index (DESI) from the European indices.

The creators of GKI state that because global measurements of the World Bank KAM (KEI, KI) have been disconnected, they are the only index measuring knowledge at the global level (UNDP and MBRF, 2019). The EIS and GII indices are primarily perceived as innovation indices; at the same time, they can be perceived as KE indices because they capture the main drivers of KE and work with such indicators as employment in knowledge-intensive activities, etc. Our view is also supported by the statements of authors like Karahan (2012) and Leogrande (2022). We decided to choose DESI due to the fact that in 2019, when we started analysing and collecting data, the index was focused not only on the field of ICT and digital economy, but also on other areas of KE, such as research, innovation, and education.

A note related to terminology – index creators use a diverse terminology to describe the structure of indices, therefore, to improve clarity and facilitate subsequent comparison, we decided to use a uniform terminology for all indices. For global indices with four levels of hierarchy, the index is subdivided into subindices, pillars, subpillars, and indicators, and for European indices with three levels of hierarchy, the index is subdivided into pillars, subpillars, and indicators.

5.1 Global Innovation Index (GII)

Included countries: 120-132.

The Global Innovation Index (GII) project was launched by Professor Soumitra Dutta in 2007 during his tenure at INSEAD. The aim was to find and identify metrics and methods that could capture the most complete picture of innovation in society. WIPO started the association with GII in 2011 and co-published the GII jointly in 2012. In 2013, Cornell University joined INSEAD and WIPO as co-editors to publish GII until 2020. From 2021 GII is published by WIPO in liaison with the Portulans Institute, various corporate and academic network partners, and the GII Advisory Committee. The GII 2021 model includes 132 economies, representing 94.3% of the world population and 99.0% of world GDP in purchasing power parity in international dollars (WIPO, 2021).

In 2021, the GII consisted of two SUBINDICES, seven pillars (including 21 *subpillars)*. See Table 2.

Table 2: GII Subindices, Pillars and Subpillars (WIPO, 2021)

INNOVATION INPUTS		INNOVATION OUTPUTS	
Institutions:	*Political environment*	**Knowledge and technology outputs:**	*Knowledge creation*
	Regulatory environment		*Knowledge impact*
	Business environment		*Knowledge diffusion*
Human capital and research:	*Education*	**Creative outputs:**	*Intangible assets*
	Tertiary education		*Creative goods and services*
	Research and development		*Online creativity*
Infrastructure:	*ICTs*		
	General infrastructure		
	Ecological sustainability		
Market sophistication:	*Credit*		
	Investment		
	Trade, diversification, and market scale		
Business sophistication:	*Knowledge workers*		
	Innovation linkages		
	Knowledge absorption		

There are minimal changes to the GII index. Sub-index names have not changed, or only slightly. The number of indicators decreased from 84 to the current 81, in contrast, the number of hierarchy levels increased from three to four. Similarly, the number of countries analysed increased from 120 to 132.

While the innovation input sub-index includes only two pillars, it has the same weight as the innovation output sub-index for calculating the overall GII score. Each of the five input and two output pillars is divided into three subpillars, each consisting of individual indicators. The subpillars are calculated using the weighted average of their individual indicators and normalised to form a score ranging from 0 to 100. The score of a pillar is calculated using the weighted average of the scores of its subpillars (Dutta, Lanvin, and Wunsch-Vincent, 2021). The GII structure and sub-index weights are shown in Figure 2.

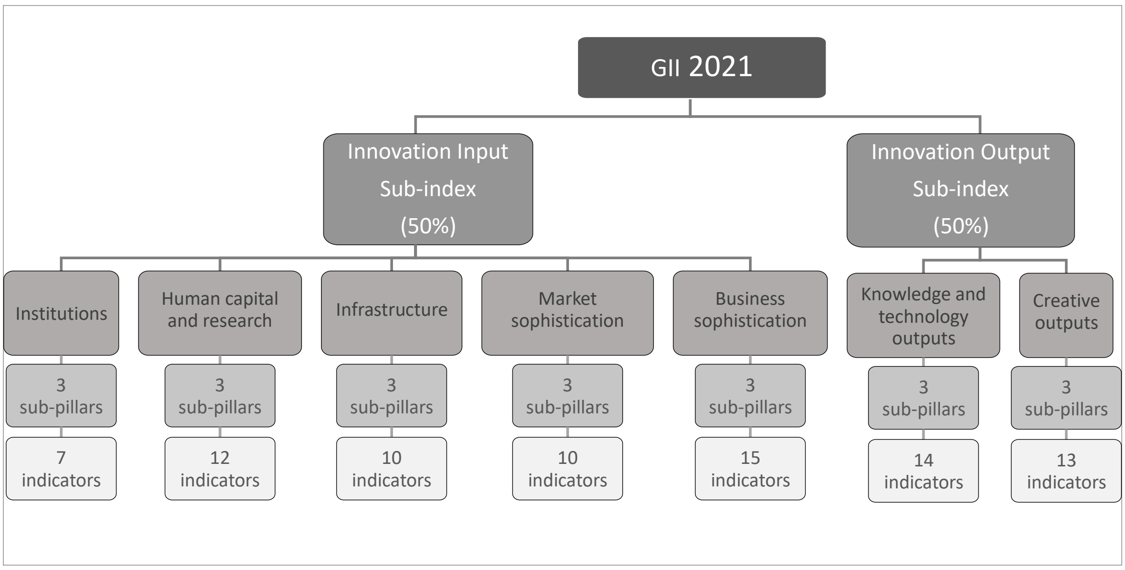

Figure 2: The Structure of GII

5.2 Global Knowledge Index (GKI)

Included countries: 140-155.

GKI was introduced in 2017 to measure the state of knowledge among 136 countries around the world. As they state, because KAM measurements (KEI, KI) have been disconnected, they are the sole index measuring knowledge at the global level. The aim of the index is to measure the multidimensional concept of knowledge in relation to the “knowledge economy” and the "knowledge society" (UNDP and MBRF, 2019). GKI sought to raise awareness of the need to create a composite index that meets the methodological conditions necessary to contribute to international efforts tracking and monitoring knowledge, and the extent to which it supports comprehensive and sustainable human development. It was built by a multidisciplinary team of academic researchers, in consultation with a broader consulting team comprising independent experts and those affiliated with specialised international bodies. GKI is a joint initiative between UNDP and the Mohammed Bin Rashid Al Maktoum Knowledge Foundation (MBRF) (UNDP and MBRF, 2021). According to them, GKI is the first of its kind in the world to establish a connection between knowledge and future technologies. This is especially relevant in the context of the Fourth Industrial Revolution, which emphasises both KE and advanced technology (UNDP and MBRF, 2022).

In 2021, the GII consisted of seven SUBINDICES, seven pillars (including 50 *subpillars*). See Table 3.

Table 3: GKI subindices, pillars and subpillars (UNDP and MBRF, 2021)

I. PRE-UNIVERSITY EDUCATION		V. INFORMATION AND COMMUNICATIONS TECHNOLOGY	
Knowledge Capital	*Enrolment*	**Infrastructure**	*Coverage*
	Completion		*Quality*
	Outcomes		*Affordability*
Educational enabling environment	*Expenditure*	**Access**	*Subscriptions*
	Resources		*Skills and employment*
	Early learning	**Usage**	*Services*
	Equity and inclusiveness		*Outcomes*
II. TECHNICAL AND VOCATIONAL EDUCATION AND TRAINING		VI. ECONOMY	
TVET Components	*Continuous training and skilling*	**Economic competitiveness**	*Infrastructure investment*
	TVET structure		*Business agility*
	TVET quality and qualifications	**Economic openness**	*Trade and diversification*
TVET labour market	*Efficiency of the labour market*		*Financial openness*
	post-TVET employment	**Financing and domestic value added**	*Financing and taxes*
	Equity and inclusiveness		*Domestic value added*
III. HIGHER EDUCATION		VII. ENABLING ENVIRONMENT	
Inputs	*Expenditure*	**Governance**	*Political environment*
	Enrolment		*Quality of institutions*
	Resources	**Socio-economic**	*Gender equity*
Learning environment	*Diversity and academic freedom*		*Social inclusion*
	Equity and inclusiveness		*Standard of living*
Outputs	*Attainment*	**Health and Environment**	*Health*
	Employment		*Standard of living*
	Impact		
IV. RESEARCH, DEVELOPMENT, AND INNOVATION			
Inputs	*Inputs of R&D institutions*		
	Inputs of R&D in business enterprises		

	Inputs of societal innovation		
Outputs	*Outputs of R&D institutions*		
	Outputs of R&D in business enterprises		
	Outputs of societal innovation		
Impact	*Quality*		
	Linkages		
	Business development		

Changes to the GKI: Sub-index names have remained almost unchanged. The number of indicators increased from 133 to 155, the number of hierarchy levels is not changed, and it has had four levels since the beginning of the measurement. The number of countries analysed increased from 140 to 154.

GKI is calculated with each of the six sub-indices having a weight of 15%, with the exception of enabling environment, which is accorded a weight of 10%. Weighting across the different components of the index (subindices, pillars and subpillars) was not unified; rather, it varied according to the nature of the components and their relative importance. The weightings identified for the seven constituent indices ranged from equal weighting and budget allocation to factor analysis (UNDP and MBRF, 2021). The GKI structure and sub-index weights are shown in Figure 3.

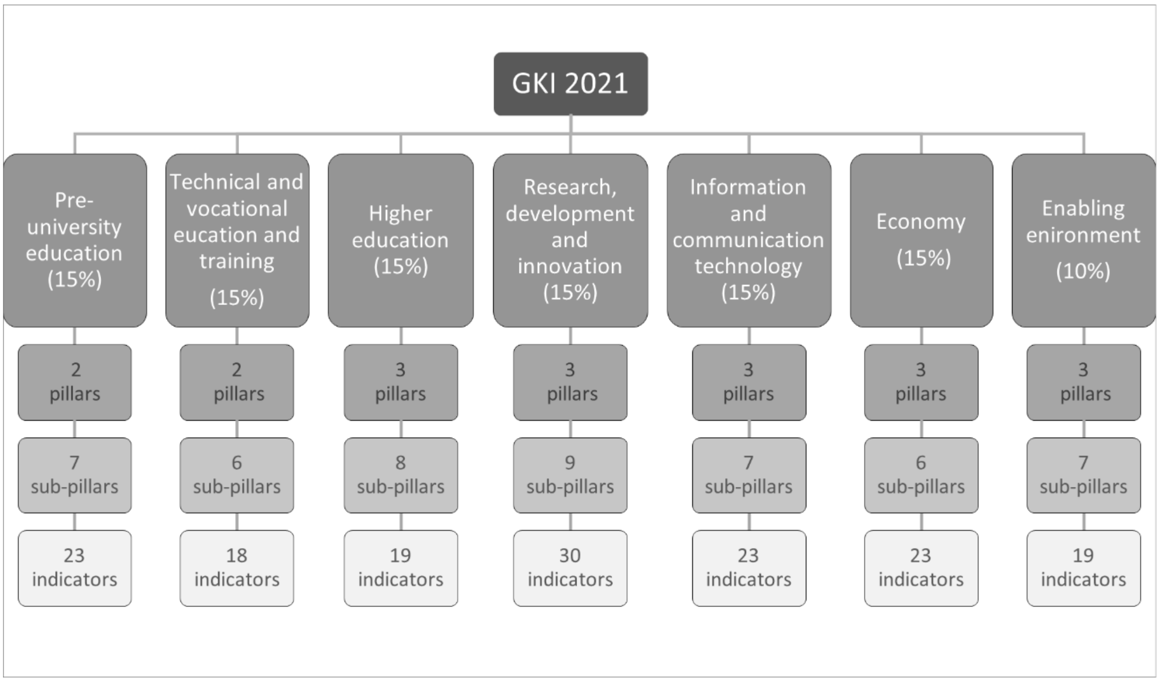

Figure 3: The Structure of GKI

5.3 European Innovation Scoreboard (EIS) - Summary Innovation Index (SII)

Included countries: 38 (EU countries + United Kingdom, Switzerland, Norway, Iceland, Israel, Serbia, Turkey, Montenegro, North Macedonia, Bosnia and Herzegovina, Ukraine)

Since 2001, the European Commission has been developing the European Innovation Scoreboard (EIS) as a comparative analysis of research and innovation performance in the EU, other European countries and regional neighbours (EU + United Kingdom, Switzerland, Norway, Iceland, Israel, Serbia, Turkey, Montenegro, North Macedonia, Bosnia and Herzegovina, Ukraine), which was introduced as part of the Lisbon strategy. Since 2003, the Summary Innovation Index (SII) has been calculated to evaluate the innovation performance of EU member states, drawing on statistics from a variety of sources (Hollanders, 2009).

In 2021, the EIS-SII consisted of four pillars (including 12 *subpillars)*. See Table 4

Table 4: EIS-SSI Pillars and Subpillars (Hollanders & Es-Sadki, 2021)

Framework conditions:	*Human resources*
	Attractive research systems
	Digitisation
Investments:	*Finance and support*
	firm investments
	Use of IT
Innovation Activities:	*Innovators*
	Linkages
	Intellectual assets
Impacts	*Employment impact*
	Sales impact
	Environmental sustainability

Some major changes in the construction of EIS-SII occurred in 2008 (Hollanders, 2009), in 2017 (Hollanders and Es-Sadki, 2018), and most recently in 2019, when the author of the report points out that results from EIS-SII 2018 and EIS-SII 2019 cannot and should not be compared between different EIS-SII reports because for several indicators data has been revised in the external sources from which data have been extracted; the time period covered in both reports is different, with the older used in EIS-SII 2018 no longer being used in EIS-SII 2019; data transformations have been applied to a slightly different set of indicators (Hollanders, 2020).

Between 2001 and 2021, the number of indicators increased from 17 to 32. The levels increased from two to the current three (as of 2017). The total number of countries analysed naturally increased to 38 as more countries became EU members (change from 17 to 27).

EIS-SII is calculated as the unweighted average of the rescaled scores for all indicators that have been assigned the same weight (1/32, where data is available for all 32 indicators) (Hollanders & Es-Sadki, 2021). The structure and weights of the EIS-SII pillars are shown in Figure 4.

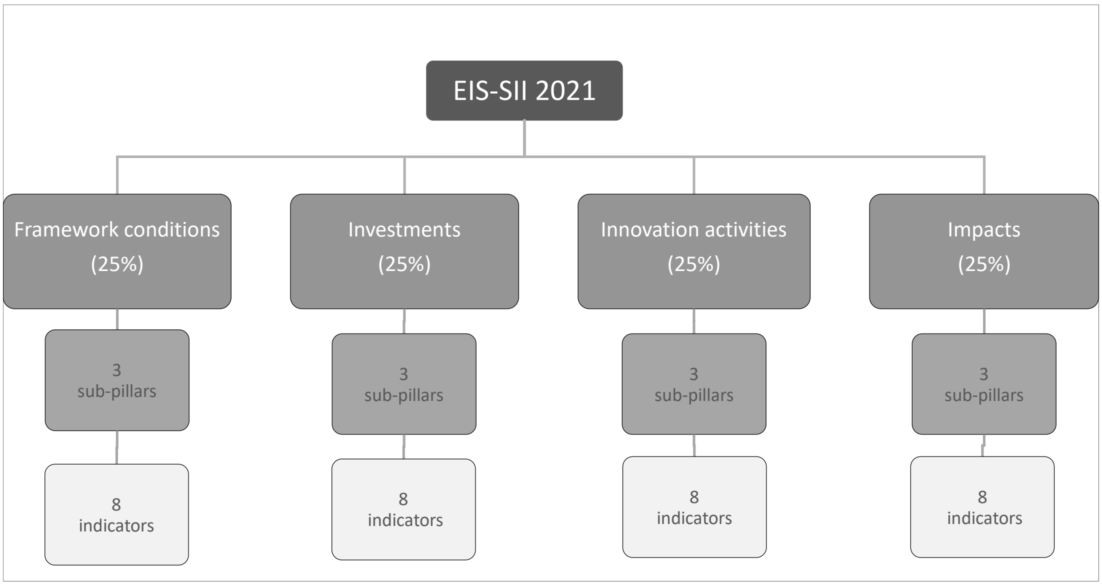

Figure 4: The Structure of EIS-SII

5.4 The Digital Economy and Society Index (DESI)

Included countries: 28/27 EU countries.

Since 2014, the European Commission has been monitoring member states' digital progress through the Digital Economy and Society Index (DESI) reports. DESI was developed according to the guidelines and recommendations in the OECD's *Handbook on Constructing Composite Indicators: methodology and user guide*. Each year, DESI includes country profiles that support member states in identifying areas requiring priority action as well as thematic chapters offering a European-level analysis across key digital areas, essential for underpinning policy decisions (European Commission, 2021). In 2021, the Commission adjusted DESI to reflect the two main policy initiatives that will have an impact on digital transformation in the EU over the coming years: the Recovery and Resilience Facility and the Digital Decade Compass (European Commission, 2022).

In 2021, DESI consisted of four pillars (including 10 *subpillars*). See Table 5.

Table 5: DESI pillars and subpillars (European Commission, 2022)

Human Capital:	*Internet user skills*
	Advanced skills and development
Connectivity:	*Fixed broadband take-up*
	Fixed broadband coverage
	Mobile broadband
	Broadband prices
Integration of digital technology:	*Digital intensity*
	Digital technologies for businesses
	e-Commerce
Digital public services:	*e-Government*

Changes in the DESI index: The names of the pillars have remained almost unchanged. Their number decreased from five that the index had in 2015-2020, except for 2019 when Research and Development ICT was added and the index had as many as six, to four that it has had since 2021 (the Use of Internet pillar was removed).

To align DESI with the four cardinal points and the targets under the Digital Compass, to improve the methodology and take account of the latest technological and policy developments, the Commission made several changes to the 2021 edition of the DESI. Those indicators that had no significant changes in quantity and varied around the current number of 33 are now structured in the four main areas in the Digital Compass, replacing the previous five-dimensional structure (European Commission, 2021). The number of hierarchical *levels* increased from two to the current three.

In DESI, the aggregation of indicators into subdimensions, of subdimensions into dimensions, and of dimensions into the overall index, was conducted from the bottom up using simple weighted arithmetic averages following the structure of the index. The DESI structure and pillar weights are shown in Figure 5.

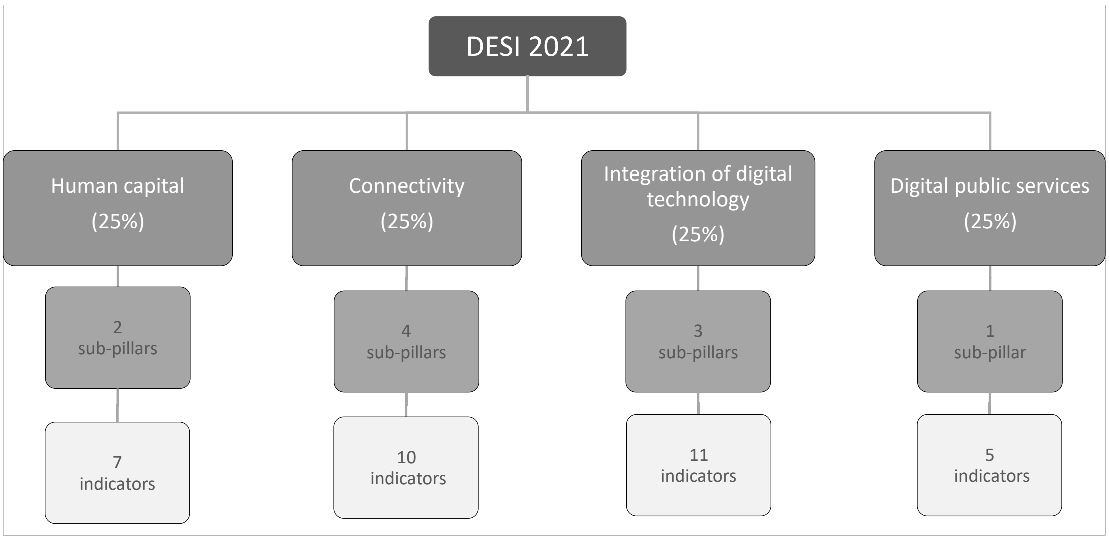

Figure 5: The Structure of DESI

6. Conclusions

The methods of measuring KE at the macroeconomic level have evolved over time, from measurements based on national income accounting to the creation of indices based on the identification and combination of relevant indicators. The paper points out a few issues associated with the measurement of KE, for example, an issue concerning a definition of KE that would be sufficiently specific and generally accepted to allow unambiguous approach to measurement of KE. We believe that, based on the existing definitions, it is not possible to carry out a clear measurement of KE. The problem with the definition of KE stems, among other things, from the semantic ambiguity of the concept of knowledge and the definition of its scope, which is usually limited to explicit scientific facts, unlike knowledge management in the socioeconomic literature, resulting in a large part of the knowledge system being eliminated from KE calculations. The creators of the four KE indices subject to analysis utilise a certain amount of KE indicators or pillars, which can be viewed as a shared core matching the pillars defined by the World Bank. These include, for example, the level of ICT use, used by Machlup in his calculations (information machines), as well as OECD, WB, and the EIS-SII, DESI, GII and GKI indices. Similarly, the level of *R&D* that is included in the calculations according to Machlup, OECD, WB, EIS-SII, GII and GKI is measured. The area of *human resources* can be found in OECD, WB or EIS-SII, DESI, GII and GKI calculations. *Innovation* is part of the OECD and WB measurements as well as the EIS-SII, GII and GKI indices. In the context of KE, *patents* are observed in OECD, WB or in the EIS-SII, GII and GKI indices. Similarly, the field of *education* was integrated into the measurements according to Machlup, WB or the EIS-SII, GII and GKI indices. Despite these shared areas, there are apparent differences among the individual KE indices. In addition to the set of such intersecting indicators and pillars, we can also identify a relatively large set of unique and distinct indicators and pillars used to build individual KE indices. We also identified a small number of indicators that capture more subjective types of knowledge, for example, in the GKI index: creative services exports as % of total trade in services; Entertainment & Media market/th pop. 15-69; Mobile app creation/bn PPP$ GDP (GKI). Naturally, we encounter the fact that the creators of different indices assigned various weights to the same or intersecting indicators. Moreover, we identified inconsistency even within the individual KE indices as their authors quite often changed their methods to create indices, as well as the KE pillars and indicators themselves and their weights, which also points to varying perception of KE principles by the index creators themselves. To broadly assess the meaningfulness of such inconsistent KE measurements in each situation, it will be necessary to carry out at least a correlation analysis of measurement results and a semantic analysis of indicators of individual indices, which will be the goal of our further work.

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