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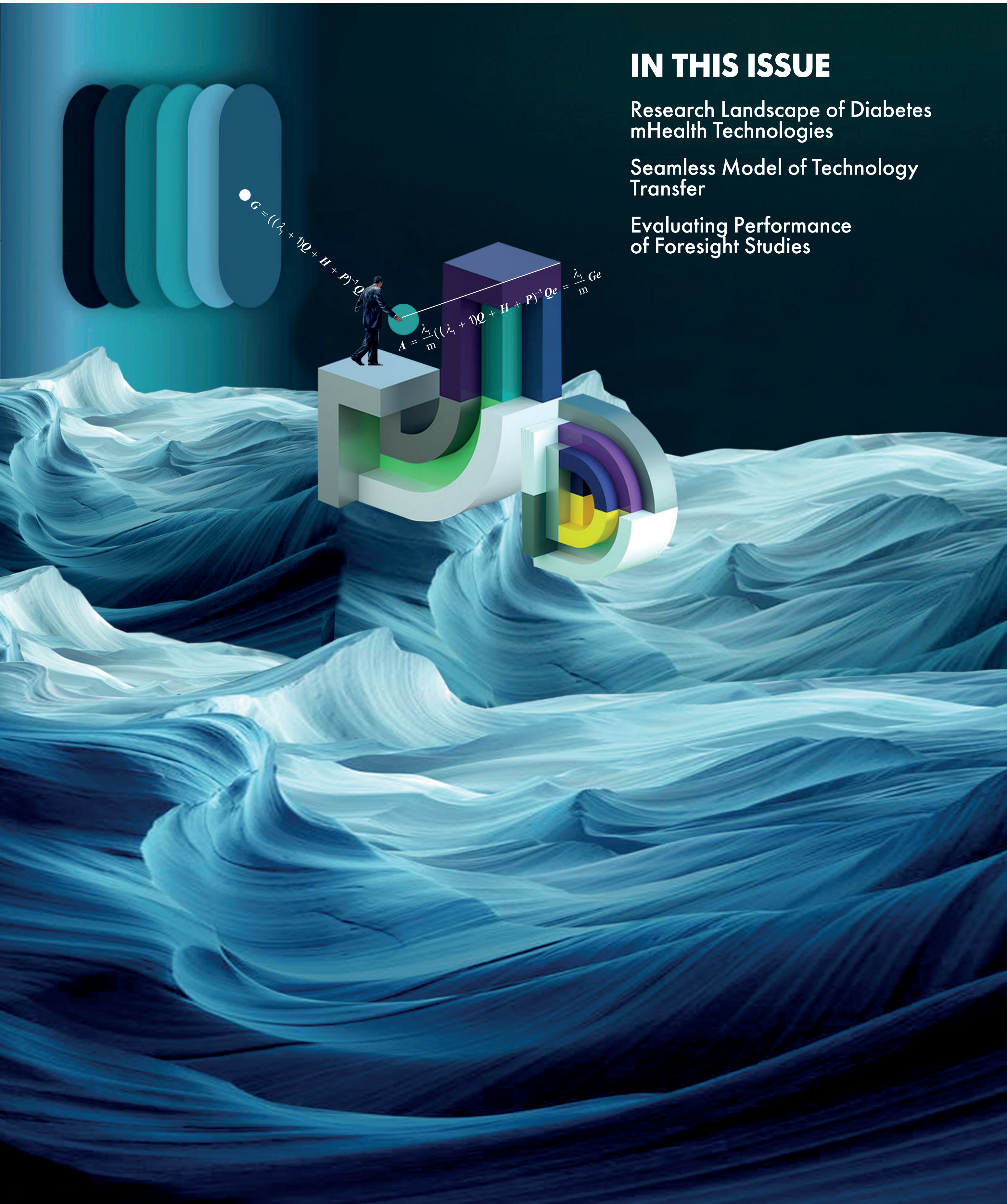

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Foresight and STI Governance is an international interdisciplinary peer-reviewed open-access journal. It publishes original research articles, offering new theoretical insights and practice-oriented knowledge in important areas of strategic planning and the creation of science, technology, and innovation (STI) policy, and it examines possible and alternative futures in all human endeavors in order to make such insights available to the right person at the right time to ensure the right decision.

The journal acts as a scientific forum, contributing to the interaction between researchers, policy makers, and other actors involved in innovation processes. It encompasses all facets of STI policy and the creation of technological, managerial, product, and social innovations. *Foresight and STI Governance* welcomes works from scholars based in all parts of the world.

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- Technological trends, breakthroughs, and grand challenges;
- Technological change and its implications for economy, policy-making, and society;
- Corporate innovation management;
- Human capital in STI;

and many others.

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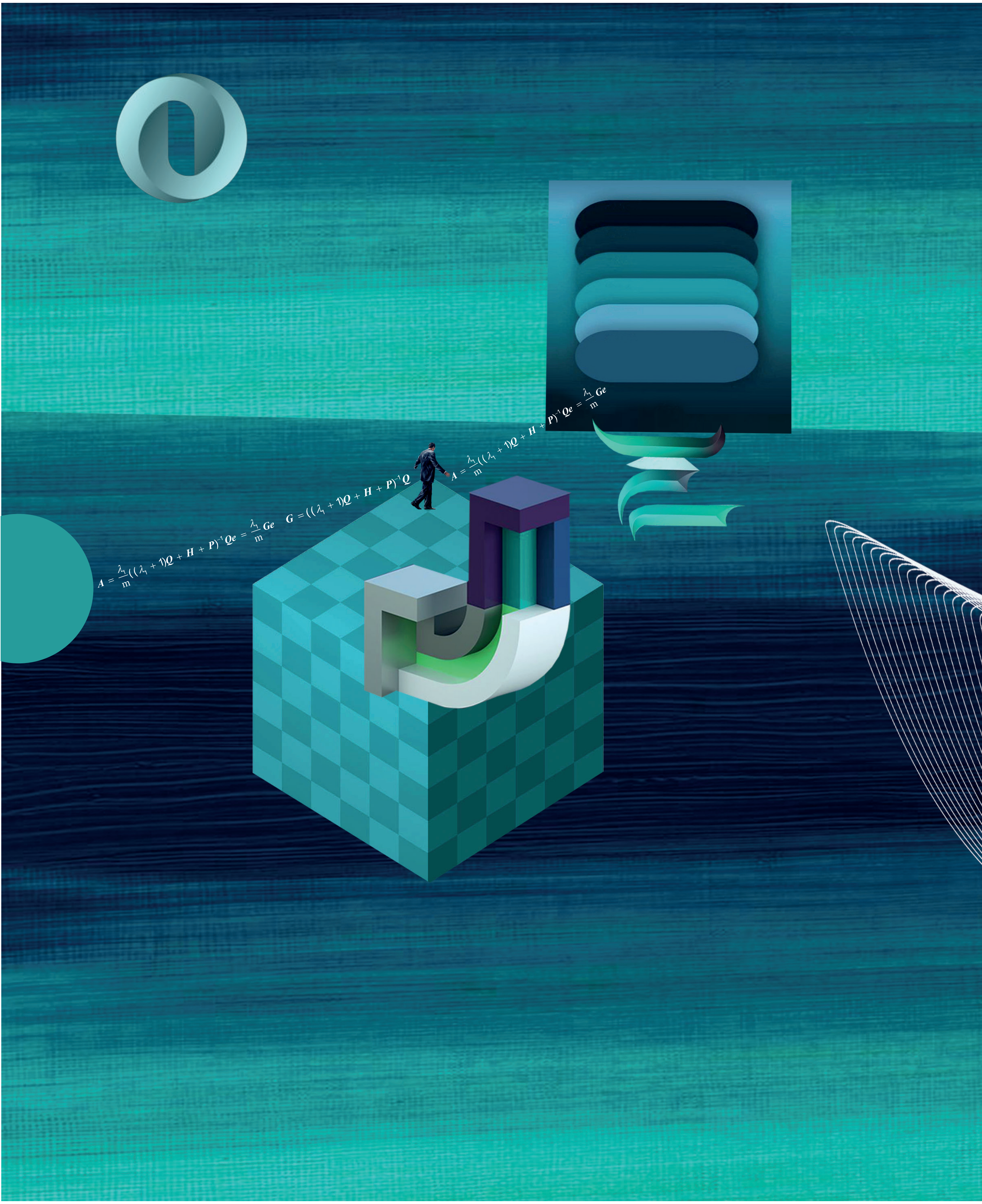
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From Discrete Skills to Holistic Creative Human Potential: An Emerging Approach in Theory and Practice

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Abstract

The study aims to empirically demonstrate and conceptually interpret the manifestations of an emerging approach to the issues of human capital, its measurement and development on the international academic, expert, and corporate agenda. We document a gradual shift from a focus on individual skills, their measurement and development, to an approach that considers the complexity of human capital and emphasizes holistic individual activity and the proactive role of the individual in his/her human development and in transforming the corporate environment.

The authors show that the formation of this novel approach can be associated with new trends in socio-economic development, including the growing share of non-routine jobs, the transformation of work formats and broader processes of de-structuration, which require a proactive role of the individual in the maintenance and development of social structures, including business organizations. The study has shown that the formation of this new approach occurs gradually and simultaneously at the global level on the academic, expert, and corporate agendas, but with varying degrees of intensity and with different focuses. At the same time, it is the corporate agenda that can be regarded as a frontier. This study is based on a content analysis of academic publications, expert reports of international organizations and think tanks, as well as public reports and documents of the world's leading innovative companies. The research employs the Big Data intelligence system iFORA.

Keywords: skills; human capital; agency; human potential; education; labor market

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Introduction

Skills have long been a topical subject of academic and expert discussions in fields of economics, management, psychology, and education. An interest in this key element of human capital (or "human potential" as a broader concept gradually being introduced into discourse that adds to the prior commonly used term[1]) is in many ways determined by changes occurring on the labor market and in professions. The existing literature has at length described how the technological progress transforms the nature of labor by creating demand for new skills related to the application of specific technologies, especially digital (ILO, 2021a). These changes are evident in the language used to describe professions, job functions, and educational results, with a focus on skills as universal and discrete units of human capital/potential, according to the Gary Backer and Theodore Schultz concept (Becker, 1964; Schultz, 1961). Its circulation prompted a widespread compilation of "key skills" and "universal competences" lists (OECD, 2014).

At the same time, there are other shifts that are happening on the labor market, like a higher share of non-routine jobs requiring creativity and a proactive approach (Lewandowski et al., 2020; Liu et al., 2021), the introduction of artificial intelligence capable of substituting algorithmized work operations (Autor, 2022), the growth of informal and self-employment, and the rapid development of small businesses amidst a decreasing share of a larger corporate sector (ILO, 2021b). Creative labor is classified as a poorly algorithmized activity because it cannot be reduced to a sum of separated skills. In a situation where not only the general structure of professions, but also their internal features, are changing rapidly, as well as due to greater opportunities for the labor force to move between companies and industries, the skills themselves and their outcomes are becoming harder to describe empirically.

Therefore, on the one hand, we are witnessing a continuous decomposition of human potential and an increasing relevance of general skills for achieving success in the modern economy (Chan et al., 2017), and on the other hand, there is an idea that real labor activity should leverage a set of skills that is gaining more popularity (Acemoglu, Autor, 2011; Autor, Handel, 2013). All this makes searching for new ways to define and assess human potential relevant.

Skills research is developing in several subject areas, including labor economics, management, organisational psychology, psychometrics, sociology, and education. A paradigm shift has been observed in each area — from the focus on individual skills, their measurement, and development to uncovering a holistic nature of human potential. This latter approach is based on a proactive role that individuals play in the development of both their own potential and the environment, first of all, the corporate environment. Education science documents links between various skills and their endogeneity (Hampf et al., 2017) together with a targeted search for radically new approaches to assessing education results and their manifestations in the real world (Andrade, 2019). The management and organizational phycology literature demonstrates a prominent trend to view individuals holistically as bearers of not only skills, but also talent (Rotolo et al., 2018; HBR, 2016), in addition to discussing corporate practices of measuring the progress of each employee and unlocking their potential (Ryan, Derous, 2019).

The aim of this study is to conceptually describe and theoretically interpret an emerging approach to human potential management as focused on its holistic and dynamic nature, rather than discrete and structurally determined. For this purpose, issues of the content and assessment of human skills that are important for individual and aggregate success have been reviewed in international academic, expert, and practical (corporate) discourse. The research conjecture is that this gradually forming, emerging approach is global and unravels simultaneously in the three aforementioned dimensions with various degrees of intensity and points of emphasis. In order to test this conjecture, we conducted a content analysis of three discourse segments surrounding the discussion and measurement of skills — academic, expert and corporate. The research is founded on advanced international discussions about skills provided primarily in academic publications for 2013–2020 in areas of economics and management, as well as in expert reports of international organizations and think tanks, in public reports and documents of leading innovative companies of the world.

The report is divided into three sections. In the first we provide a review of existing studies in the areas of human capital/potential maintenance and skill measurement. The methodology of the empirical portion is described in the second section and stipulates, in particular, the use of the iFORA Big Data Intelligence System. The third section systematizes the key results of the empirical part — a content analysis of the international discourse about skills and their assessment. In conclusion, there is a discussion of achieved results.

[1] https://ncmu.hse.ru/, accessed 16.12.2023.

Theoretical Background of the Study

Human capital/potential: discreteness vs cohesiveness

Human capital features as a key category in discussions about socioeconomic development factors, non-tangible corporate assets, and talent management; in recent years, the term "human potential" has come to be used more frequently to refer to this. According to the basic human capital theory (Becker, 1964; Schultz, 1961), it represents an outcome of investing into individual education and training aimed at the acquisition of competences (skills) and higher productivity. It is suggested to break down human capital within this theory into general and specific skills (Becker, 1964; Schultz, 1961).

Specific (professional) skills are not to be associated with a specific workplace because they are easily transferrable when switching from one company to another within the corresponding industry (Mayer et al., 2012). On the contrary, the general human capital easily transforms into *de facto specific*, when employers are investing into training of general competences that reach outside of employees' immediate ongoing obligations and functions (Acemoglu, Pischke, 1999). It has been suggested in literature to operationalize specific human capital as a combination of skills performed at the workplace — general, universally applied, and professionally specific (Lazear, 2009).

Skill measurement is considered a challenging task, whose difficulty is highlighted not only in specific psychometric studies, but also in management literature dedicated to intellectual capital and non-tangible corporate assets (Bontis, 2001; Marr, Chatzkel, 2004). Due to skills' endogeneity, it is problematic to find a causal connection between owning several of them and individual productivity (Hampf et al., 2017). The successful acquisition and application of skills are affected by other skills and factors which do not allow one to postulate with confidence if and to what extent specific competences increase the individual's productivity. At the same time, skills do not exist in silos, they build up on the labor market and create a cumulative effect. In labor economics literature, there is a particular notion that has taken root of so called "*bundles of skills*" or work tasks, i.e., sets of competences within specific professions that workers must possess simultaneously (Acemoglu, Autor, 2011; Autor, Handel, 2013). Considering the added complexity of labor in nearly all spheres and the growth of the non-routine component (Lewandowski et al., 2020), it becomes less and less productive from a practical standpoint to study skills separately. Non-routine jobs give priority to the end product, rather than owning certain skills. In the context of emerging configurations the individual activity requires continuous rebuilding and mobilization of all potential to solve various tasks. Such an approach acknowledges that a complex set of competences, settings, experiences, capabilities, and other characteristics that in foreign managerial discussions is frequently called *talent,* does not lend itself to compartmentalization.

Therefore, the question of whether human potential could be reduced to a collection of skills, including personal traits (with a possibility of their enhancement), or it represents a dynamic continuity which is developing under the influence of environment (including organizational), individual choice, and goalsetting, remains unsettled. The answer to that question is crucial for an adequate understanding of not only the content of human capital/potential but also the role individuals play in the contemporary socioeconomic development.

Human potential assessment: skills vs activity

Discussions about evaluating human performance in labor productivity from the standpoint of skills highlight two well-established economic approaches. The first one focuses on accumulating the human capital, *owning* specific skills (*skill proficiency*), the second one — on their actual *application* (*skill use*) at the workplace.

The proficiency assessment of a particular skill is described in the human capital theory and supported by many economic studies dedicated to exploring linkages between the level of such capital and labor productivity on the national, corporate, and individual scale (Angrist et al., 2021; Bontis, 2001). Psychometrics specialists are developing high precision tools for assessing the proficiency level of specific skills (Nusche, 2008).

The real *skill use* approach is based on labor market theories that demonstrate that labor productivity and corporate efficiency depend both on the level of human capital and on the quality of workplaces (Sattinger, 1993). Here, it is important to understand the intricacies of skill application — how much they are engaged when performing work tasks. In literature adjacent to economics, an alternative, third approach is actively developing, centered around *professional enhancement*, or *skill development*, which implicitly means both the mastery and the productive use of particular skills. The key role in these discussions is assigned to the idea of the continuous education of humans and lifelong development of their capabilities, whereas the assessment of skill proficiency and their use at the workplace is seen only as a part of the process of discovering individuals' potential. The *skill development* subject area has become mainstream in education as part of the lifelong learning concept that implies a never ceasing acquisition of new and enhancement of existing competences whilst changing specializations and workplaces (Kim, Park, 2020).

The described transformations reform corporate performance management systems: leading companies are opting out of one-time employee performance measurement methods and introduce feedback mechanisms and continuous development of personnel (HBR, 2016). Monitoring systems integrated into such mechanisms allow for following both the individual progress of an employee and his/her performance for the company. It extends the skill development discourse to the *talent development* concept, which supports highlighting individuals' potential with a focus on their activity results.

Human performance in labor productivity, along with the corporate context surrounding it, is generally becoming too complex to view the employee only through the lens of his/her separate skills or even their application. Today, such approach looks anachronistic. The cross-disciplinary discussion is gradually moving toward evaluating the actual *result* of individual activity as a consequence and the product of the holistic potential development that includes skills in a particular environment — professional or corporate.

Passive and active role of an individual in the development of his/her potential and the organizational environment

The traditional opinion on the human capital accumulation factors is focused on the crucial role of family and the state (as a source of institutional opportunities) at the earliest stages of individual development, all the way up to the level of higher education and corporate (employer) — at the next stage. The spontaneous initiative, agentic role of the individual himself/herself is perceived as peripheral, firstly, because of a child's limited capacity or inability to earn his/her own money or the lack of education; and further on — due to the employer's understanding that labor productivity associated with technological modernization requires personnel training, i.e., the development of their human capital. However, the situation is constantly changing. Employer surveys around the world document a higher demand for personnel initiative in issues of both developing one's own human capital and contributing into the efficiency of the company (WEF, 2018). Such claim for agency is typical not only for largest firms in leading countries: the empirical data for Russia[2] uncovered a deficit of acumen among managers, heads of departments, and organizations. Meanwhile, the corporate sector does not have a by-default provision of human capital development for employees; it relies solely on their own discretion.

In sociologic discussions the mentioned initiatives are integrated into a wider socioeconomic context related to de-structurization — a shift in the development of social institutes accompanied by a higher dependence of the structural change on individual proactive action (Sorokin, 2023). Another concept that explains the companies' demand for personnel agency is the hypermanagement theory that describes how macro-cultural aspects of the liberal models' expansion in the corporate sector of developed countries not only promote the reproduction of traditional practices on various management levels, but also facilitate missionary work, innovation, and authentic approachs that have a higher cultural legitimacy despite possessing often dubious utility (Bromley, Meyer, 2021).

A considerable and growing part of the labor force is included in the informal and other types of nonstandard employment (platform, self-employment, freelance, etc.) which by definition do not imply the employer's (commissioner's) responsibility for the development of the contractor's human capital. A share of adult population that was involved in platform employment in Europe and North America in 2015–2019 varied, according to various estimates, between 1% and 22% (ILO, 2021b). According to some estimates, by mid 2020s up to a half of the labor force in developed countries will engage in such forms of labor participation (Kuzminov, etc., 2019). During the creation of human capital theory in 1950s–1960s, amid the rapid growth of the corporate sector, the self-employed and short-term contractors were seen as a disappearing element of the social structure and the platform economy did not exist at all (Marginson, 2019).

To summarize, the growth of socioeconomic volatility and fluidity renders useless the approach that appeared during the time when the human capital theory was formed, where separate skills were viewed as key factors of professional success of an individual. In the context of de-structurization, human capital is becoming less prone to decomposition into separate skills and their utility is becoming harder to evaluate empirically when they are detached from other skills. Moreover, on the back of structural changes, the value of narrow skills themselves becomes limited since they are meant to be used in stable conditions. A special meaning is now attached to individual characteristics that allow for the proactive development of one's own self and environment (Sorokin, 2023).

Methodology

This study is using the subject field survey method to analyze the economic and managerial discussion around skills and their assessment. It is aimed at determining the empirical features of the aforementioned transfer from skill assessment in the *skill pro-*

[2] https://hh.ru/article/25225, accessed 16.12.2023.

ficiency logic to the holistic monitoring of individual development and labor productivity, including the role of personal initiative and agency — *talent development*. For this purpose, we have conducted a content analysis of the advanced international discourse and singled out three discourse fields and three source types: academic publications, expert publications, and industrial corporate reports. We selected English publications in the years of 2013–2020. The year of 2013 was chosen as a starting point because of a surge of attention on measuring the specific skills after the first PIAAC[3] round for OECD countries was released. The sample is cut off at 2020 for a valid reflection of publications' citations.

Two data resources were used as sources of scientific publications. To map the academic field and identify frontier discourses, we used the iFORA Big Data Intelligence System[4] (further — iFORA) with over 600 million documents that include scientific articles and pre-prints of leading global publishing holdings. The iFORA-based search found 13,525 text matches of specified keywords[5] (see more below). The following detailed analysis of mainstream academic discourse was done using Scopus — the largest database of publications, greater by a third than the Web of Science.[6] The Scopus-based search was aimed at finding most cited academic articles. With its help, two subsamples of the 50 most cited works were composed for content analysis. Such a stereoscopic approach enabled a comprehensive, holistic coverage of the academic discussion — starting with the broad picture provided by iFORA and finishing with pinpoint Scopus miscooptics; apart from that having two independent samples per search helped in cross-validating the results.

Under expert discourse we understand reports of leading international organizations and think tanks that specialize in researching skills, education, and the labor market. Among them are: The World Economic Forum, OECD, International Labour Organization, The World Bank, UNESCO, Cedefop, McKinsey, Boston Consulting Group, Deloitte, LinkedIn, ManpowerGroup, and PricewaterhouseCoopers. Searching for relevant reports was done using the official websites of organizations. The final sample included 36 reports dedicated to issues of human capital development, skills, and their assessment. The academic value of the international expert discourse analysis for the specified range of questions is explored in detail in the work (Moschetti et al., 2020).

The sampling of relevant corporate reports was done in the following way. From the 2020 ranking of most innovative companies of the world according to Boston Consulting Group[7], 20 companies were randomly selected. The advantage of this report is in the assessment of firm's innovativeness, which includes a personnel potential development module (*talent & culture domain)*. Reports containing information about personnel management practices and corporate management programs were gathered for the analysis, as well as publications in corresponding sections of official websites. The final sample included 47 publications, including 15 corporate reports and 32 publications on official websites.

The search of relevant publications within reviewed discourses — academic, expert, and corporate — was done by keywords and their derivatives. In the first case, the Scopus search was conducted using the SciVal tool (by article titles, keywords, and abstracts) with a subsequent "manual" relevance check. The iFORA semantic analysis was conducted using interactive web-based user interfaces. All expert publications and corporate reports were analysed entirely manually through the selection of relevant reports by keywords — the same work that was done in SciVal. When studying each of the three discourses, full texts of manually pre-coded publications were analyzed (apart from downloading text matches from iFORA) according to two types of codes:

1) *Type of skill*. With attachment of the following tags: (a) only general skills, (b) only professional skills, (c) general and professional skills, specifying the type (specifying skills of both types), (d) general and professional skills, without specifying the type (specifying skills of both types but without fitting them into general/professional categories). The last type is operationaliz as a holistic approach to human potential.

2) *Type of approach (discourse) about skills and human potential*: (a) *skill proficiency*, (b) *skill use*, (c) *skill development*, and (d) *talent development*. The coding was based on keywords (tags). To code *skill proficiency* the following tags were used: "skill level", "skill proficiency", "skill supply", "stock of skills", "skill deficit", "skill shortage". To code *skill use*: "skill utilization" and "skill use". To code *skill development* — "skill development"; *talent development* — "talent development" and "employee development". In case of manual coding (for all sample elements described above, apart from iFORA da-

[3] The Programme for the International Assessment for Adult Competencies is an international study of competences of the adult population that is conducted under the auspices of the Organisation of Economic Co-operation and Development (OECD).

[4] The iFORA Big Data Intelligence System has been developed and applied within analytical and research work of the Institute of Statistical Studies and Economics of Knowledge of the USE University.

[5] Syntax search query in iFORA web interface: "skill level" OR "skill utilization" OR "talent development" OR "skill development".

[6] https://www.elsevier.com/?a=69451, accessed 16.12.2023.

[7] https://www.bcg.com/publications/most-innovative-companies-historical-rankings, accessed 16.12.2023.

tasets) an additional differentiation between skill development and talent development was done due to their contextual proximity. Talent development included publications that simultaneously met two conditions: discussion of, firstly, the development and/or assessment of a skill set, not separate skills, and secondly, a possibility of monitoring individual progress and performance/labor productivity.

The data from the iFORA collection of scientific publications were downloaded by tags that were used to code approaches — "skill level", "skill utilization", "talent development", and "skill development". In doing so, we avoided additional coding of the corresponding data, however, we grouped text matches for all four approaches depending on the semantic proximity to keywords.

Results

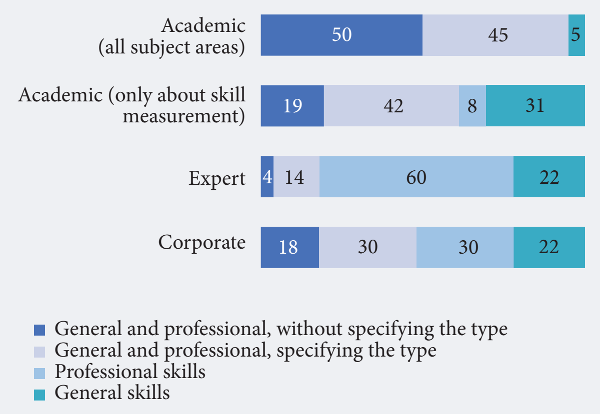
First signs of the holistic approach to human potential: blurring the lines between skills

In all three reviewed discourses, the holistic approach to human potential does not have a strict differentiation between general and professional competences and is actively represented only in the discourse of leading companies (Figure 1). In academic and expert literature this approach appears much rarer — in less than 20% (vs 50% in the corporate discourse).

General and professional (specific) competences are viewed in the academic literature mostly in silos. Over a half of most cited publications are about either exclusively general or exclusively specific competencies. The share of the latter (60%) means that this area has achieved the greatest amount progress in competence evaluation, however leading the discussion about this topic is left only to the discretion of psychometrics and narrow specialists, first of all, medical staff. So, we see there is a particular divide in academia: the academic discourse supports breaking down human potential into general and professional competences, but it contradicts the global economic mainstream that blurs the line between the general and specific human capital (Gathmann, Schönberg, 2010; Lazear, 2009).

The prevailing expert discourse is gravitating toward discussing either only general competences (31% of publications), or universal and professional skills together, thus continuing their alienation from each other and classifying the latter as specific. Most recognized expert publications are often based on leading academic works, in many ways borrowing their approaches and conclusions. The conspicuous interest in general skills is partially related to a mainstream concept of *lifelong learning* that expert organizations promote (OECD, 2021; UNESCO, 2023). The key role on this agenda is played namely

Figure 1. **Types of skills prevailing in international academic (Scopus), expert, and corporate discourses about skills (% of all references in 2013–2020 publications) (N=183)**



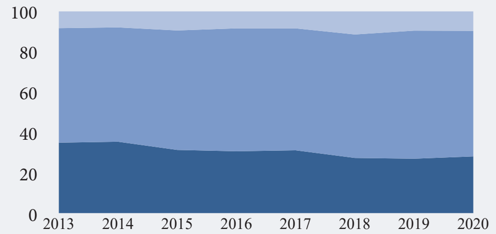
Source: authors.

by universal competences, and skills rooted at the workplace are pushed to the background.

On the contrary, there is practically no difference between general and professional competences in the public discourse of leading global companies. Businesses need all skills, capabilities, and talents because general skills are easily specified at the workplace in the process of their application, and many professional skills are universal by nature and workers retain them even if their position at the company changes. This is something economists confirm as well: the "specificity" of human capital is recognized when competencies are applied in the corporate context, used in the execution of job tasks, and not by their affiliation with a particular professional field (Van Der Velden, Bijlsma, 2019).

In the end, the corporate discourse about skills turns out to be paradoxically closer to advanced academic developments in the field of human capital, than the academic and expert mainstream that gravitates toward particular skills and breaking down human potential into separate types of competences. It is namely during the discourse of leading companies that one notices attempts to escape the competence-based concept and the compartmentalization of human potential and work toward a holistic perception of an individual and his/her capabilities. On the other hand, such results, especially in academic discourse, may be associated with our approach to skill-focused sampling. It shifts the sampling of academic articles to traditional skill discussions in education, whereas the holistic logic of *talent development*, as was shown above, is commonly found in

Figure 2. **Type of discourse about skills that prevails in academic literature (frequency of occurrence in iFORA database, %) (N=13525)**



8.3	7.9	9.5	8.4	8.5	11.4	9.6	9.6
56.8	56.7	59.2	60.9	60.4	61.3	63.4	62.2
34.9	35.4	31.3	30.7	31.1	27.3	27.0	28.1

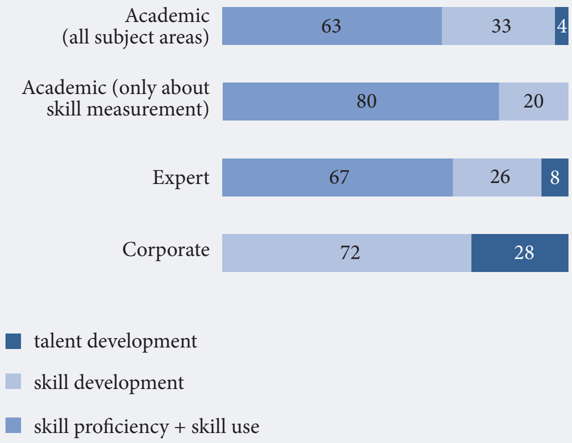
talent development
skill development
skill proficiency

* The total of 100 refers to a sum of occurrences for all three types in each year.

** Publications classified under the "skill use" approach made up less than 1% of the sample and are not represented in the legend.

Source: authors.

Figure 3. **Prevailing types of international academic (Scopus), expert, and corporate discourse about skills (% of all references in 2013–2020 publications) (N=183)**



Source: authors.

the managerial discourse. Consequently, the holistic sense is neglected in scientific discussions — the holistic discourse of talent development lies sometimes on another conceptual level which is radically different from the category of skills.

Proficiency in separate skills vs the holistic development of human potential

The review of 2013–2020 iFORA-sampled scientific publications for the skills research area (Figure 2) demonstrates the prevalence of the *skill development* discourse — the frequency of occurrence is over 60%. This may be related to the international dissemination of the lifelong learning concept[8] and the growth in the number of studies demonstrating positive individual and country-specific effects from *developing* particular competences. A third of relevant scientific works have a *skill proficiency* narrative, the popularity of which has substantially decreased (from 35% to 28%) during the review period, while *skill development* (from 57% to 62%) and talent development (from 8% to 10%) discourses have expanded.

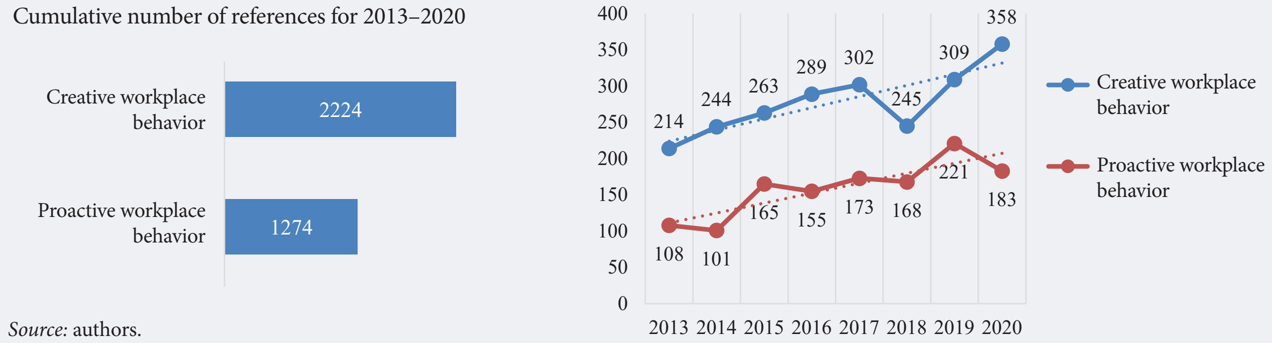
The Scopus-based analysis of most cited publications in the skills research area (Figure 3) showed that their focus differs from a wider sample (Figure 2), where the skill use approach is prevailing. This might be related to the fact that most cited publications often cover empirical studies aimed at the evaluation of a particular skill proficiency (not the comprehensive assessment of talent development that is still problematic to achieve through the academic lens). As expected, it is namely the skill proficiency approach for particular skills that prevails in the subsample of scientific articles and continues to remain a part of the scientific mainstream. It is obvious that both discourses — leading academic and expert — are mostly based on the idea of skill proficiency and the latter is in many ways only a projection of impactful empirical studies and is developing in the direction outlined for it.

The discourse of leading companies represented in corporate reports demonstrates an outspoken holistic orientation in the human potential development and individual talent. Within this discourse the issues of skill proficiency and measurement are pushed back due to their integration into more common staff progress and performance monitoring mechanisms (save for special recruitment situations and the development of screening tools).

Unlike academic and expert publications, corporate reports to a larger extent reflect real practice and to a smaller extent stem from previous studies, even with the consideration of a possible corporate dis-

[8] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021G1214(01), accessed 16.12.2023.

Figure 4. **Contextual side of scientific publications' agenda by proactive or creative behaviour at the workplace (number of references in 2013–2020 in iFORA database) (N=3498)**



Source: authors.

course shift toward socially accepted behavior. That is probably why, due to organizational and technological limitations related to the introduction of the holistic approach to human potential "in action", even leading global companies have not participated in the holistic discourse of talent development and monitoring mainstream. Less than 30% of corporate documents referred to this category.

Corporate role in advancing the agenda of holistic development and the monitoring of human potential

The corporate sector places more resolute demands on human development regarding its employees as key assets and sources of new value (Oppong et al., 2019). The corporate demand for technological innovation and business process transformation propels the corporate entrepreneurship policy forward based on the support of employees' innovative and proactive behaviour through the creation of favorable environment (Urbano et al., 2022). The is why namely companies become the main proponents of a new human potential development and evaluation paradigm (Cappelli, Tavis, 2016) based on a proactive role of individuals and their enhancement. We documented an expansion of a rhetoric concerning the proactive and creative behavior at the workplace on the 2013–2020 scientific agenda (Figure 4). Both elements remain holistic structures that are impossible to reduce to a set of separate unrelated skills (Corazza et al., 2022), and their main metric is actual activity and labor productivity. However, the specific skill proficiency narrative retains its importance for companies as a conceptual foundation of human potential development and assessment, especially at the recruitment stage. The HRtech market offers hundreds of solutions in this area[9] (KPMG, 2022).

To develop and assess employee potential, companies turn to new forms of talent management that are booming due to the progress of digital technologies. In management and organizational psychology literature, there is an active discussion of a growing segment of advanced digital tools for personnel performance monitoring (Rotolo et al., 2018; Rotolo, Church, 2015), in particular the digital trace and tracking of individual labor productivity (Chamorro-Premuzic et al., 2016; Jeske, 2022). According to the data of Capterra consulting company, there are over 500 digital products with similar functions that exist in English only. The accumulation of similar data at current and previous workplaces help build predictive models of employee performance which may be later used when making recruitment decisions (Woods et al., 2020; Ryan, Derous, 2019; Sajjadiani et al., 2019; Chamorro-Premuzic et al., 2017; Wenzel, van Quaquebeke, 2018).

So, we see that it is namely the companies that are standing at the forefront of holistic human potential monitoring and assessment, as they are the main beneficiaries of hired labor.

Discussion and Conclusions: Prospects for and Limitations of a New Approach

In the context of a growing share of complex, nonroutine jobs and the transformation of organizational forms across the globe, the demand for human potential is changing. Successful labor market presence as an entrepreneur, a self-employed person, or a contractor most often requires comprehensive characteristics — creativity, proactive behavior, and setting own one's development trajectory. Our mapping of a field of international discussions about human potential and skills helped to document the

[9] https://www.hrtechmarket.com/all-hr-tech-solutions/skills-testing-and-assessment, accessed 16.12.2023.

formation of a *new approach to human potential*. It is too early to say that it will displace a traditional competence-based approach with a focus on particular skill proficiencies, with sets of skills predefined by the requirements of a particular workplace. However, one can already single out its *distinctive traits* that are gradually being rooted in the literature, albeit being scattered among weakly related discussions in economics, management, organizational psychology, sociology, and several other disciplines.

Firstly, it is a holistic take on an individual and his/her potential. Individuals are regarded as comprehensive factors that contribute to labor productivity not with a limited number of separate pre-defined skills or a formal education, but through a wider variety of interconnected features they develop. Not all of them could be easily measured using traditional tools, especially considering skills' endogeneity and the blurring line between general and professional skills as indicated by economists.

Secondly, the human potential assessment is conducted through activity and a seamless integration of the corresponding mechanism into the employee development ecosystem. The employee potential is evaluated amid the real performance of current tasks, i.e., applying competences and other individual traits while considering job context, co-workers, work intensity, and other parameters. This context in all its complexity is impossible to model in the research environment in its entirety, even in an advanced competence measurement system. In this way, the assessment of separate skills does not lose its meaning, but rather its importance as an independent institutional practice, thus becoming more and more integrated into building competences.

Thirdly, the expansion of workers' role in choosing a direction in which to build up potential must be considered. The role of employees in forming and perfecting skills, as well as in building a general trajectory of moving within a company, has increased. Pre-defined top-down trajectories of development with specific sets of required skills are replaced by a more flexible approach based on an employee's initiative and willpower to behave proactively and control one's own professional movement, which changes the organizational structure that gradually reorients itself toward flexible job formats.

The interpretation of the individual's role and capabilities in these processes is based on more general ontological foundations, which in sociology are called "problems of structure and action" and describe the subject's independence from the social environment. The current academic and public discourse is dominated by structural determinism that denies a person a meaningful and independent creative role in the development of social structures (Kurenoy, 2023). In this paper, we rely on the solution of the ontological "problem of structure and action" proposed in the work (Archer, 2003). An important aspect of human potential, understood holistically, in this perspective is the recognition of its independent *ontological* nature in the face of external structures and the ability to transform through individual action, i.e., agency. At the same time, in the context of de-structuration, the specific direction of such transformation is set not by the environment, but by the individual himself/herself (Sorokin, 2023).

The spread of "talent in action" ideas and proactive human potential development is facilitated by rapid technological progress in the field of documenting and monitoring such potential (Buitrago-Ropero et al., 2023). However, digital technologies do not answer all the questions. In particular, a possible breakthrough in the documentation of human potential in complex, context-specific and activity-related manifestations is limited by a number of *challenges*.

Firstly, new technological solutions are built around obsolete constructs. Despite significant progress in measurement, there has been no comparable development in the conceptualization of new constructs and, more broadly, the content of human potential (capital) together with their documentation and monitoring system (Ryan, Derous, 2019). Moreover, new digital tools used by corporate HR services are often nothing more than advanced versions of traditional mechanisms that are neither breakthrough, nor substantially new (Chamorro-Premuzic et al., 2016).

Secondly, the introduction of digital tools for tracking personnel activities and the performance of work tasks within the framework of the new approach may have the opposite effect and reduce the quality of recruitment. Some researchers see a threat in innovative predictive productivity models based on big data concerning human activity and bearing the risk of distortions, which are fraught with errors in forecasts and HR decisions (Church, Silzer, 2016). Skepticism toward new digital tools is widespread in academia due to the lack of reliable empirical evidence of the validity of the analytics provided by them (Chamorro-Premuzic et al., 2016).

Thirdly, the "talent in action" concept goes beyond the simple collection and analysis of big data about an individual's activities. At its center is the active role of the employee himself/herself in the development of his or her personal human potential and the company. However, this aspect remains on the periphery of scientific discussion; most often, the topic of proactivity is limited to discussing its role in performing immediate work tasks (Li et al., 2020; Kim et al., 2009) or participating in abstractly understood entrepreneurial activities (Hu et al., 2018).

Fourthly, the development of a new approach and its implementation in the form of digital solutions are uneven. Its greatest dissemination can be expected in countries and companies that are at the forefront of scientific and technological progress with a high proportion of highly qualified employees and the cultural support for the ideas of the development and expansion of individual opportunities.

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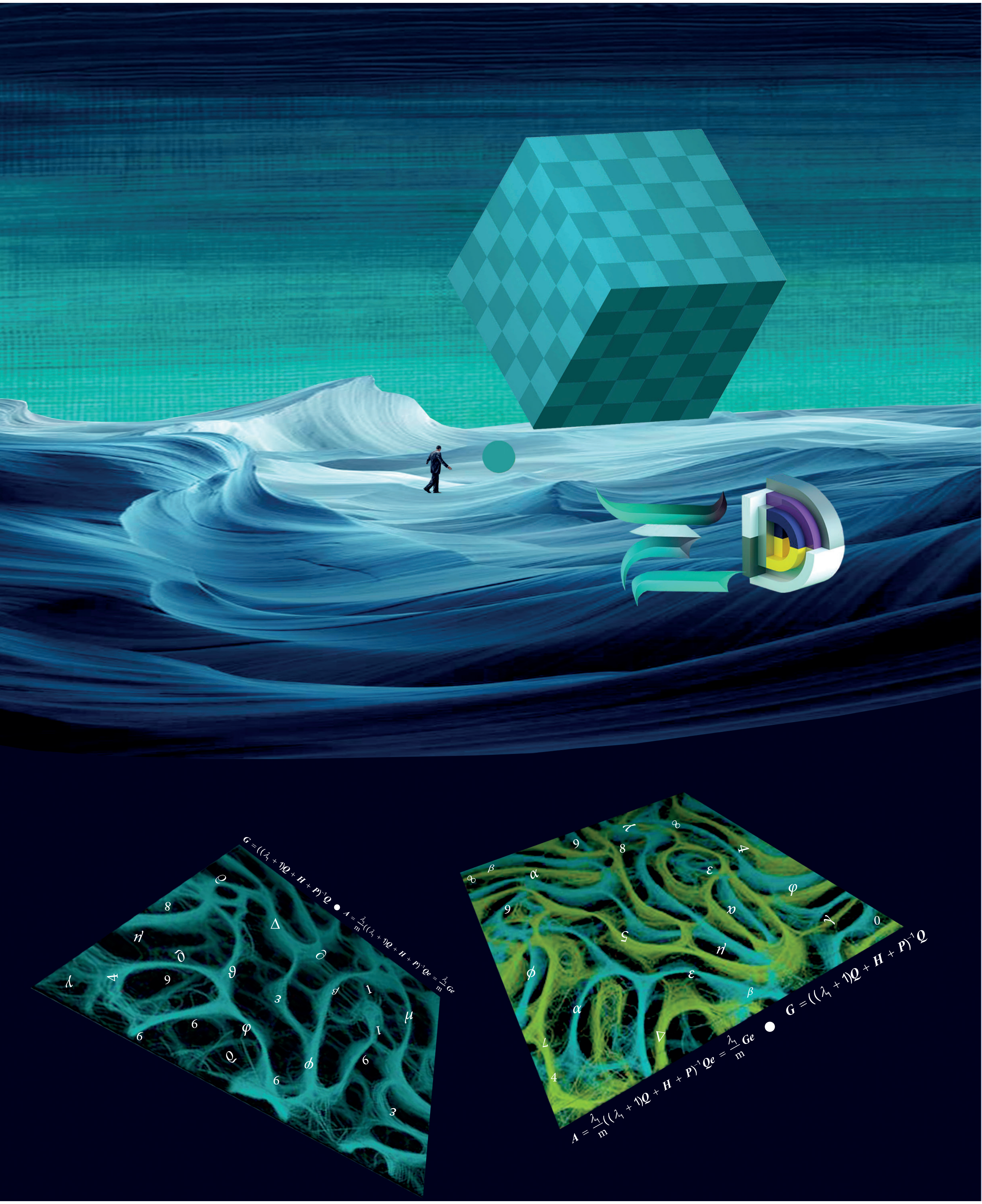
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Research Landscape of Diabetes mHealth Technologies

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Abstract

In recent years, more and more generic technologies have appeared, allowing one to find answers simultaneously along different dimensions, "fan" solutions for urgent and complex problems are synthesized and cumulative effects emerge. This article analyzes the potential of such technologies using the example of mobile health (mHealth), which provides rapid access to medical services even in the most remote regions, mitigating the inequalities between different segments of the population in this regard. The implementation of mobile health becomes especially important in the context of the rapid spread of chronic and autoimmune diseases, which strongly impact the quality and duration of life. Smart applications based on AI and virtual reality provide the opportunity to manage one's health by combining patient self-monitoring with rapid consultations with medical staff. By doing so, risks are reduced and physiological and mental well-being is enhanced. This article conducts a large-scale literature review of diabetes management techniques through mobile technology to systematize and identify the most advanced solutions. For such innovations to maximize their impact, public health policies must be aligned with a digitalization strategy.

Keywords: generic technologies; mHealth; health innovation; chronic disease management; diabetes; health services; health self-management; health policy; digitalization strategy

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Introduction

The constant development of digital technologies has created many opportunities in the field of digitalization by enabling the integration of physical and digital activities. Many sectors, especially healthcare, are putting in great effort to accelerate digitalization (Leung et al., 2017). Digital healthcare integrates digital information, health services, and patient care to facilitate activities such as care delivery, patient documentation, prescriptions, interventions, and health monitoring (Sharma et al., 2018). Preventive medicine options are expanding, treatment is becoming more personalized and reaching all segments of the population, including in remote areas (Ronquillo et al., 2022). Emerging technologies can help patients improve their health conditions (Williams et al., 2019) and provide personalized care plans. This empowers patients by enabling them to learn and manage their diseases (Ding et al., 2019).

mHealth is a term commonly used in the health sector concerning the use of mobile technology to improve health conditions, providing benefits such as reducing costs, facilitating monitoring activities, and encouraging self-management activities and healthy lifestyles (Kumar et al., 2013). mHealth can facilitate the healthcare delivery by removing barriers related to geographic location (Nahum-Shani et al., 2016) and time, as consultations, interventions, and medical care can be provided remotely at any moment (Stoyanov et al., 2015). Mobile technologies such as wearable devices, smartphones, sensors, and mobile apps offer new opportunities to improve health. mHealth furthermore has a significant impact on chronic disease management. For example, thanks to the strong connection of people to their smartphones (Hamine et al., 2015) and the apps available, it is possible to help control obesity, heart disease, and diabetes, among others (Silva et al., 2015).

Research in this area is particularly relevant given the projected increase in the dynamics of diabetes. According to data for 2021, its global prevalence among adults aged 20-79 years was 9.3% (about 463 million people). By 2045, 783.2 million people in this age group (12.2%) are projected to have diabetes. Thus, the number of patients will increase by 25% from current levels by 2030 and by 51% by 2045. As for global health expenditures for this type of disease, in 2021 they were estimated at $966 billion and by 2045 the amount will be $1.054 trillion (IDF, 2021).

Diabetes mHealth research is evolving rapidly. Diverse studies have embraced the application and development of mobile technology to improve disease control, monitoring, treatment plans, interventions, and lifestyle changes to assist in the daily management of this disease. However, no research has explored the dynamics of the scientific progress of Diabetes mHealth to identify research topics in the field, which is crucial to make better decisions regarding Research and Development (R&D) and Innovation. The aim of our study is to fill this gap. The results of this review can inform the planning of public health policy. We have identified relevant research topics, the support of which will increase the effectiveness of innovation in this area.

Methodology

Word distribution analysis involves a set of scientific literature documents and a word partition of their article titles, author keywords, and keywords plus[1] to reveal the main research topics (Wang, Ho, 2016). Identifying research topics within this field can help researchers, academics, industry, decision-makers, and policymakers to prioritize their R&D efforts, and provide a panorama for future research directions. For this purpose, the SCI-Expanded database was used, which is a prestigious scientific collection that includes over 9,500 journals, 182 subject categories, and covers up to 61 million records from Clarivate Analytics.[2] The dataset was obtained after the publication of the Journal Impact Factor 2021, which was reported in the Journal Citation Report (JCR)[3] and the period from 1998 to 2021 was considered.

A search strategy was created accordingly focused on article-type documents. Relevant diabetes-related terms were incorporated into the search strategy and those related to mobile technologies. In addition, exclusion terms were included to avoid documents that contained key terms but were related to other topics, such as genetics, proteins, mobile health as a physical unit, wearables with no mobile or wireless capabilities, and others. The keywords used are displayed in a Venn diagram as shown in Figure 1. These keywords were incorporated into a search query using quotation marks and Boolean operators that are displayed in the same figure. This search query was executed on SCI-Expanded using the Topic option, which includes searching by title, abstract, author keywords, and Keywords Plus.

From 1998 to 2021, a total of 1,848 articles were obtained. To strengthen the certainty of the results, Ho's group developed a "front page" filter that was applied in this study to reduce irrelevant articles (Wang, Ho, 2011). This resulted in 1,668 articles that represented 90% of the original 1,848 articles. Further manual analysis was conducted obtaining 1,574 articles on Diabetes mHealth research.

In general, the article title, author keywords, and Keywords Plus in SCI-Expanded convey the most important information about the research. Words from these article sections provide readers with the relevant details of a topic and the main author's focus (Mao et al., 2010; Fu et al., 2013). Manual codification was performed to identify words from the title, author keywords, and Keyword Plus of the 1,574 retrieved documents. Stop words such as prepositions, conjunctions, pronouns, articles, and so on were removed as they were irrelevant to the analysis.

In the case of the title, the phrases were divided into single words to perform statistical analysis. The title contains significant information with details that an author uses to denote the relevance of the topic discussed, becoming the first view for the reader. This information contributes to identifying the focus and emphasis of studies. A total of 3,467 words were found in the article titles after removing stop words. Table A1 (see Appendix) shows the top 50 most frequent single substantive words considering the number of articles in which the word appears in the title, its ranking according to the number of articles containing the word in the 1,574 retrieved documents.

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[1] Keywords Plus from Web of Science offers additional search terms formulated using words and phrases extracted from the cited paper titles by the authors (Mao et al., 2010).

[2] https://clarivate.com/products/scientific-and-academic-research/research-discovery-and-workflow-solutions/web-of-science/web-of-science-core-collection/science-citation-index-expanded/, accessed 05.04.2023.

[3] https://clarivate.com/blog/the-2021-journal-citation-reports-a-continuing-evolution-in-journal-intelligence/, accessed 05.07.2022.

In the authors' keywords, the phrases were kept intact, in contrast to the title where the phrases were split into single words. Author keywords provide information that can reveal scientific directions and research trends, which is useful for the continuous monitoring of science and technology (Mao et al., 2010). After excluding stop words, a total of 3,274 author keywords were identified. However, only 419 of them appeared in three or more articles. This means that 2,523 keywords appeared in only one article and 332 keywords appeared in two articles, probably indicating different research foci and a discontinuity in topics. Table A1 shows the top 50 most frequently used author keywords according to their rank considering the number of articles in which the term appears and its percentage relative to the total number of articles.

Similarly, for Keyword Plus, phrases were retained intact as they were provided. In addition, the development of a Keyword Plus statistical analysis allows for more detail and insight into advances in Diabetes mHealth by comparing similar and dissimilar trends in author keywords. A total of 2,287 Keywords Plus were identified. Table A1 shows the top 50 most frequently used Keywords Plus considering their rank, the number of articles containing them, and their corresponding percentage in relation to the total number of articles.

After the statistical word analysis of article titles, author keywords, and Keywords Plus, the word distribution analysis was performed to detect similar phrases or common single words and generate supporting words, which contain the resulting integrated terms. The word distribution analysis provides relevant clues, subjective focus, and the emphasis of research based on supporting words to determine a research topic, in this case on Diabetes mHealth. The use of supporting words can overcome the possible weaknesses exhibited by a separate analysis of statistical word distribution in article titles, author keywords, and Keywords Plus (Mao et al., 2010; Fu et al., 2013; Wang, Ho, 2016).

To determine supporting words, only terms that appeared in three or more articles in either titles, author keywords, or Keywords Plus were considered. A total of 1,876 terms met this criterion (939 from titles, 419 from author keywords, and 516 from Keywords Plus). These terms were grouped as supporting words by manual inspection to finally identify the most relevant research topics. Certain terms were discarded by their broad meaning, while others, although broad, were matched into the research topic that made them most meaningful. Finally, each research topic and its supporting words were validated by incorporating feedback from experts. The results are presented in the next section.

Results and Discussion

The word distribution analysis allowed for determining research topics and their respective ranking as a result of the supporting words. A total of 141 research topics were identified which were grouped into the following six categories: 1) Health problems, 2) Technologies, 3) Applications, 4) Global perspectives, 5) Population groups, and 6) Healthcare professionals. Table 1 contains a general description of the content of these topics while the Table 2 lists the keywords that define research topics in these categories. The top three categories with the most research topics were "Health problems", "Technologies", and "Applications" with 31, 29, and 27 research topics, respectively. A detailed overview of the research topics included in each of these top three categories along with their supporting words is provided below.

Each article in the set of scientific documents can contribute to more than one research topic. For example, the article entitled "Impact of Daily Physical Activity as Measured by Commonly Available Wearables on Mealtime Glucose Control in Type 1 Diabetes" contributes to Category 1 "Health problems" in the topic of Type 1 diabetes mellitus, as well as to Category 2 "Technologies" in the topic Wearable, and in Category 3 "Applications", in the research topics of glucose handling, physical activity, and food intake.

Category 1. Health Problems

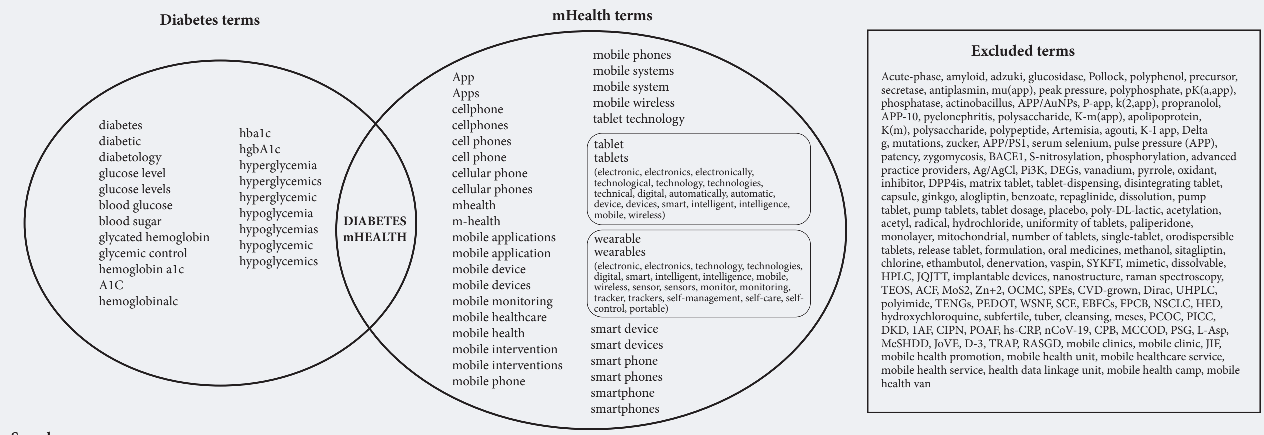
This category contains research topics where mHealth has been contributing to solving diabetes health problems, including by identifying diseases, complications, risk factors, and medical conditions, which can be considered sub-categories of "health problems". **Table A2** lists the research topics identified in this category by rank and subcategory.

These sub-categories diseases, diabetic complications, risk factors, and complications, consider 13, seven, eight, and three research topics respectively, a total of 31 research topics in this category. Type 2 Diabetes mellitus, gestational diabetes mellitus, cardiovascular diseases, type 1 diabetes mellitus, and chronic diseases are the top five research topics in the "diseases" sub-category. Diabetic retinopathy and diabetic foot are the top two topics in the "diabetic complications" sub-category, while obesity is the top topic in the "risk factor" sub-category. Figure 2 displays a graph of the topics mentioned previously with the number of articles that contain their supporting words in the title, author keywords and Keywords Plus, distributed by year of publication. This graph shows the main research focus and the development trends in the branch of health problems.

Diabetes mellitus occurs when the body does not produce the insulin it needs, preventing adequate control of blood glucose levels. It has several classifications, each with a different pattern and treatment, the most common being Type 1, Type 2, and gestational diabetes. The research topic of "Type 2 diabetes mellitus" refers to a type of diabetes mellitus in which the body does not produce enough insulin or is resistant to insulin, so it is not possible to properly regulate the level of glucose in the blood. This can cause risks in the body, especially in the eyes, heart, feet, nerves, and kidneys. To cope with it, it is important to make lifestyle changes such as improving diet and exercise habits, taking medications properly, and undergoing regular medical examinations. In our analysis 324 articles were related to this topic. Recent advances in digital platforms and their evaluation, as well as text messaging strategies through social media apps and Short Message Service (SMS), have seen remarkable development. Li et al. (2021) uncovered that mHealth management for patients with Type 2 diabetes has better cost-effectiveness characteristics than conventional care. An instant messaging social networking app can be beneficial to increasing the knowledge on self-care activities and improving intervention programs in patients with Type 2 diabetes (Alanzi et al., 2018; Middleton et al., 2021).

The research topic of "Type 1 diabetes mellitus" covers a type of diabetes mellitus in which the pancreas produces very little or no insulin due to the loss of insulin-producing beta cells in the pancreas as a result of a genetic condition that manifests itself at an early age. Therefore, lifelong insulin administration, continuous glucose monitoring, carbohydrate intake control, and exercise are required to reduce the risk of developing other complications. A total of 185 articles are on this topic.

Figure 1. **Venn Diagram of Diabetes mHealth Terms and the Resulting Query**



Search query

((TS=((«diabetes» or «diabetic» or «diabetology» or «glucose level» or «glucose levels» or «blood glucose» or «blood sugar» or «glycated hemoglobin» or «glycemic control» or «hemoglobin a1c» or «A1C» or «hemoglobinalc» or «hba1c» or «HgbA1c» or «hyperglycemia» or «hyperglycemics» or «hyperglycemic» or «hypoglycemia» or «hypoglycemias» or «hypoglycemic» or «hypogtycemlcs» and («app» or «apps» or «cellphone» or «cell phones» or «cell phone» or «cellular phone» or «cellular phones» or «cellphones» or «mhealth'» or «m-health» or «mobile applications» or «mobile application» or «mobile device» or «mobile devices» or «mobile monitoring» or «mobile health» or «mobile healthcare» or «mobile intervention» or «mobile interventions» or «mobile phone» or «mobile phones» or «mobile systems» or «mobile system» or «mobile wireless» or «smart device» or «smart devices» or «smart phone» or «smart phones» or «smartphone» or «smartphones» or ((«wearable» or «wearables») and («electronic» or «electronics» or «technology» or «technologies» or «digital» or «smart» or «intelligent» or «intelligence» or «mobile» or «Wireless» or «sensor» or «sensors» or «monitor» or «monitoring» or «tracker» or «trackers» or «self-management» or «self-care» or «self-control» or «portable»)) or «tablet technology» or ((«tablet» or «tablets; and («electronic» or «electronics» or «electronically» or «technological» or «technology» or «technologies» or «technical» or «digital» or «automatically» or «automatic» or «device» or «devices» or «smart» or «intelligent» or «intelligence» or «mobile» or «wireless»))))) NOT (TS=(«acute-phase» or «amyloid» or «adzuki» or «glycosidase» or «pollock» or «polyphenol» or «precursor» or «secretase» or «antiplasmin» or «mu(app)» or «peak pressure» or «polyphosphate» or «pK(a,app)» or «phosphatase» or «actinobacillus» or «APP/AuNPs» or «P-app» or «k(2,app)» or «k(app)» or «propranolol» or «APP-10» or «pyelonephritis» or «polysaccharide» or «K-m(app)» or «apolipoprotein» or «K(m)» or «polysaccharide» or «polypeptide» or «artemisia» or «agouti» or «K-I app» or «Delta g» or «mutations» or «zucker» or «APP/PS1 « or «serum selenium» or «pulse pressure (APP)» or «patency» or «zygomycosis» or «BACE1» or «S-nitrosylation» or «phosphorylation» or «advanced practice providers» or «Ag/AgCl» or «Pi3K» or «DEGs» or «vanadium» or «pyrrole» or «oxidant» or «inhibitor» or «DPP4is» or «matrix tablet» or «tablet-dispensing» or «disintegrating tablet» or «capsule» or «ginkgo» or «alogliptin» or «benzoate» or «repaglinide» or «dissolution» or «pump tablet» or «pump tablets» or «tablet dosage» or «placebo» or «poly-DL-lactic» or «acetylation» or «acetyl» or «radical» or «hydrochloride» or «uniformity of tablets» or «paliperidone» or «monolayer» or «mitochondrial» or «number of tablets» or «single-tablet» or «orodispersible tablets» or «release tablet» or «formulation» or «oral medicines» or «metanol» or «sitagliptin» or «chlorine» or «ethambutol» or «denervation» or «vaspin» or «SYKFT» or «mimetic» or «dissolvable» or «HPLC» or «JQJTT» or «implantable devices» or «nanostructure» or «raman spectroscopy» or «TEOS» or «ACF» or «MoS2» or «Zn+2' or «OCMC» or «SPEs» or «CVD-grown» or «Dirac» or «UHPLC» or «polyimide» or «TENGs» or «PEDOT» or «WSNF» or «SCE» or «EBFCs» or «FPCB» or «NSCLC» or «HED» or «hydroxychloroquine» or «subfertile» or «tuber» or «cleansing» or «meses» or «PCOS» or «PICC» or «OKO» or «1AF» or «CIPN» or «POAP» or «hs-CRP» or «nCoV-19» or «CPB» or «MCCOD» or «PSG» or «L-Asp» or «MeSHDD» or « JoVE» or «D-3» or «TRAP» or «RASGD» or «mobile clinics» or «mobile clinic» or «JIF» or «mobile health promotion» or «mobile health unit» or «mobile healthcare service» or «mobile health service» or «health data linkage unit» or «mobile health camp» or «mobile health van»))) and PY=1998-2021 and DT=article

Source: authors.

Progress in food tracking algorithms, wearables, and artificial pancreases have enabled advances in the control and management of Type 1 diabetes, improving patients' quality of life. Alfonsi et al. (2020) demonstrate the feasibility of a mobile app for carbohydrate counting based on food image recognition through machine learning to support young people with Type 1 diabetes mellitus. Al Hayek and Al Dawish (2020) demonstrate the effectiveness of flash glucose monitoring to improve diabetes distress, glycemic levels, and sleep quality in young adults with Type 1 diabetes mellitus. Ahmed et al. (2020) highlighted perspectives on the use of technologies related to do-it-yourself (DIY) artificial pancreas systems for young patients with Type 1 diabetes mellitus, which involves the use of open-source digital models to determine the delivery of insulin.

The research topic of "cardiovascular diseases" refers to health conditions that negatively affect the heart, blood vessels, and arteries, causing damage to a variety of organs, including the brain, kidneys, eyes, and others. High blood sugar levels, sedentary lifestyle, and being overweight are risk factors that can damage blood vessels. The number of articles related to this topic is 129. There have been important advances in the use of digital tools to improve education, behavioral changes, and the control of cardiovascular disease. Ernsting et al. (2019) identified the need for digital literacy and behavioral change techniques to improve the effective use of health apps in patients with cardiovascular disease, diabetes, or both. Nepper et al. (2019) revealed the effective use of a mobile phone text messaging program to improve cardiovascular disease education and promote risk awareness, healthy eating, and self-management activities. Cirilli et al. (2019) proved the feasibility of using a wearable to track physical activity to reduce cardiovascular risk factors that persist in diabetes and identified novel microRNA biomarkers for future research.

The research topic of "chronic diseases" covers health conditions lasting one year or more that demand constant attention, changes in daily activities, and behavioral limitations. Diseases such as diabetes, cancer, asthma, and heart failure are considered chronic diseases. The number of articles related to this topic is 123. Some studies are beneficial not only for diabetes but also for other chronic diseases. Progress in the usefulness of mobile applications and digital environments for chronic diseases is highlighted. Abbasi et al. (2020) assessed the attitudes of patients with chronic diseases toward the use of mobile technologies and found that the attitudes of diabetic and multiple sclerosis patients were more positive compared to those of asthmatic patients. Omboni et al. (2021) determined the usefulness of a telehealth platform at scale for chronic disease management to identify deteriorations in one's health status.

The research topic of "diabetic retinopathy" concerns complications related to the eyes in patients with diabetes. A total of 103 articles are linked to this topic. The potential impact of digital technology on the screening, control, and management of diabetic retinopathy has received much attention. Nunes et al. (2021) developed a mobile tele-ophthalmology system for primary care diabetic retinopathy screening that is easy to use by non-ophthalmology clinicians, reducing costs and helping to increase screening coverage. Malerbi et al. (2020) determined the feasibility of a smartphone-based portable retinal camera for diabetic retinopathy screening, useful for improving detection. Jebaseeli et al. (2020) proposed an Internet of Things (IoT) framework for diabetic retinopathy diagnosis based on sensors, information sharing, and mobile applications that has reached 99.58% accuracy.

The research topic of "obesity" focuses on a medical condition caused by excess body fat, which increases the risk of devel-

Table 1. **The General Description of the Thematic Categories**

Category	Contents
Health problems	Diabetic complications and risk factors that mHealth technologies have made significant progress in addressing
Technologies	High-tech solutions that improve patient follow-up, patient self-management, communication between parties and therapeutic program development
Applications	Innovative mHealth software applications to address a variety of diabetic issues, changing the traditional ways of managing the course of the disease
Global perspectives	Prevalence of diabetic diseases, country-specific risk factors (dietary culture, lifestyle, etc.), preventive measures
Population groups	Demographic factors - age, gender, geography, etc.
Healthcare professionals	Development of professional competencies that contribute to the advancement of diabetes treatment methods

Source: authors.

oping various health problems such as Type 2 diabetes, heart disease, high blood pressure, high cholesterol, and others. Excess body fat can cause cells to become less sensitive to insulin, forcing the pancreas to produce more insulin to keep sugar levels under control, which can lead to insulin resistance and the development of Type 2 diabetes. A total of 101 articles are related to this topic. There have been recent advances in the promotion of weight loss and intervention programs using apps, text messaging, and artificial intelligence. Several studies proved the effectiveness of mobile lifestyle interventions to reduce body weight, glucose levels, and lipid metabolism in overweight or obese adults (Zhang et al., 2021; Stephens et al., 2019).

The research topic of "gestational diabetes mellitus" (GDM) refers to a type of diabetes mellitus in which there is a degree of glucose intolerance that is first identified during pregnancy, mainly due to hormonal changes. It requires control of food intake, pharmacological intervention, and constant monitoring during pregnancy. A total of 81 articles are associated with this topic. Valuable advances are highlighted in mobile applications that incorporate intelligent algorithms to improve the detection and control of gestational diabetes. Some researchers validated the utility of a mobile application focused on restoring optimal weight in women with recent gestational diabetes mellitus to improve health habits and caloric intake through postpartum lifestyle interventions to reduce the risk of developing Type 2 diabetes mellitus (Lim et al., 2021; Velardo et al., 2021)

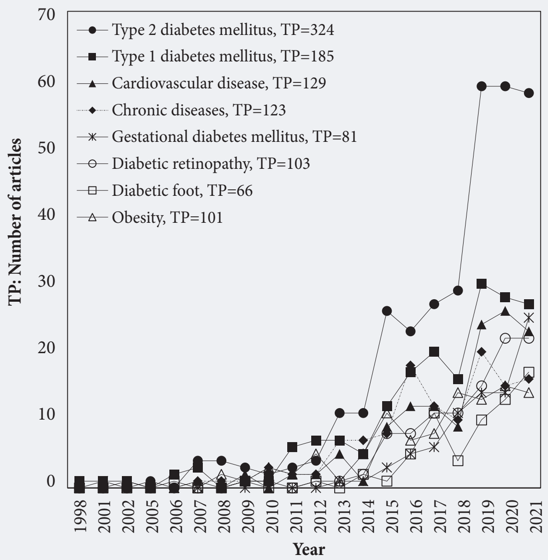
Finally, the research topic of "diabetic foot" describes a variety of complications related to the region of the foot in patients with diabetes. In addition to damaging blood vessels, high blood glucose levels can damage nerves in the feet, resulting in loss of sensation, wound infections, ulcers, and possible amputation. Adequate blood sugar control, regular foot examinations, and appropriate footwear use can reduce diabetic foot complications. A total of 66 articles are related to this topic. Advances in smartphone cameras, machine learning models, and innovative smart devices such as insoles have been emphasized to implement monitoring and control programs for diabetic foot conditions. Wang et al. (2021) demonstrated the accuracy of a wireless footwear system including an insole for daily monitoring of plantar pressure in diabetic foot patients, providing real-time information via mobile phone for the early detection of anomalies.

Table 2. **Distribution of Research Topics by Categories**

Category	Keywords to describe research topics
Health problems	Type 2 Diabetes mellitus; Gestational diabetes mellitus; Cardiovascular disease; Type 1 diabetes mellitus; Chronic diseases; Coronary-heart-disease; Cancer; Non-communicable disease; Comorbid; Covid-19; Asthma; Chronic obstructive pulmonary disease; Multiple sclerosis; Diabetic retinopathy; Diabetic foot; Wound healing; Hypoglycemia; Diabetic peripheral neuropathy; Diabetic nephropathy; Ketoacidosis; Atrial fibrillation; Myocardial-infarction; Stroke; Obesity; Hypertension; Metabolic syndrome; Insulin resistance; Prediabetes; Hyperglycemia; Sedentary behavior; Smoking
Technologies	Smartphones; Mobile Apps; Sensors; Wearables; Text messaging; Machine learning; Internet; Artificial intelligence; Artificial pancreas; Medical devices; Big data; Internet of things (IoT); Biosensor; Smart contact lens; Web-based; Video games; Cloud computing; Fundus camera; Virtual reality; Calls; Tablet; Voice assistant; Blockchain; Electrocardiogram; Photoplethysmography; Glucometer; Infrared; thermography; Spectroscopy; 3D-Printing
Applications	Glucose handling; Interventions; Patient monitoring; Diabetes self-care; Physical activity; Healthcare delivery; Medication adherence; Diabetes education; Usability evaluation; Behavior change; Treatment; Patient examination; Healthy lifestyle; Decision-support-systems; Food-intake; Diabetes prevention; Personalized medicine; Insulin delivery-system; Mental health; Weight control; Patient empowerment; Electronic health record; Social support; Health promotion; Blood-pressure control; Diabetes management; Health policy
Global perspectives	Healthcare practice; Patients' perspectives; Risk factors; Population; Prevalence; Primary care; Facilities; Mortality; Barriers; Public health; Pervasive healthcare; Survivors; Costs; Communities; Rural; Low-resource; Underserved; Urban; Socioeconomic; Developing countries; Digital divide; Ethnic-differences; Middle-income countries; Segmentation; Disability
Population groups	Adults; Adolescents; Children; Older adults; Youth; Women; Men; China; India; Africa; United States; Bangladesh; Latin America; Arabia Saudi; Norway; Asia; Pakistan; United Kingdom; Europa; Australia; Brazil; Canada; Peru; Taiwan
Healthcare professionals	Physician; Nurse; Pediatrician; Student; Specialist

Source: authors.

Figure 2. **The Main Research Topics and their Development Trends in the Health Problems Category**



Note: Here and in subsequent figures, the number of articles containing auxiliary words in the title, author's author keywords, and Keywords Plus, distributed by year of publication, is shown.

Source: authors.

Category 2. Technologies

This category includes those topics that focus on the technologies needed to assist patients with diabetes. Technology provides solutions to diabetes mellitus and the health problems associated with this disease by providing new tools and resources to improve the efficiency of diabetes management and control, including patient education and monitoring, intervention programs, and blood glucose control. Table A3 displays the research topics identified in this category by rank.

Smartphones, mobile apps, sensors, wearables, text messaging, and machine learning are the top six research topics. Figure 3 presents a graph with the number of articles containing the supporting words of these top six topics in their title, author keywords, and Keywords Plus, distributed by year of publication. This graph displays the main emphasis of technology research and its progression trends.

The research topic of "smartphones" (the total number of articles on this subject is 494) highlights advances in the use of the smartphone camera as a mechanism for collecting data to be processed with machine learning algorithms and the use of the flashlight as a mechanism for inducing actions. Jain et al. (2021) demonstrated the reliability of a smartphone-based fundus camera to capture ocular images to be processed by an offline artificial intelligence algorithm to detect diabetic retinopathy. Song et al. (2021) demonstrated the viability of a smartphone-based fluorescence microscope with a customizable optofluidic lens and sensors to determine glucose levels, which are beneficial for facilitating the timely detection of diabetes.

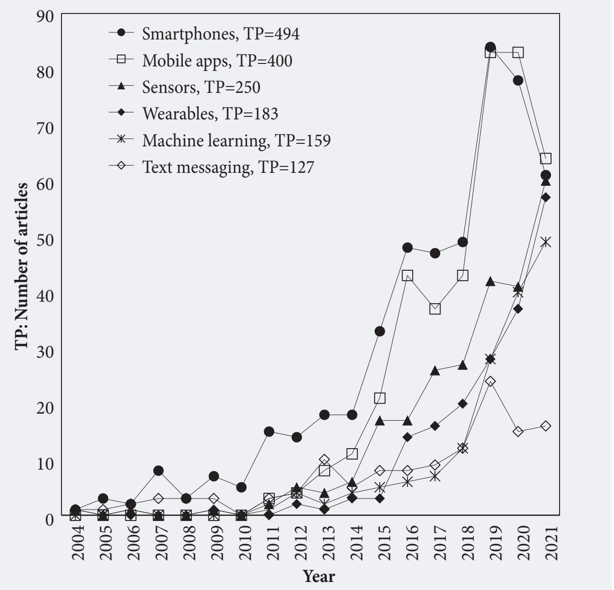
The research topic of "mobile apps" refers to software designed to run on mobile devices, such as smartphones, electronic tablets, and wearable devices, which provide a wide range of functions and services useful for healthcare services. There are 400 articles related to this topic. Notable advances include the integration of smart devices, artificial intelligence, and digital interfaces powered by mobile applications to facilitate diabetes care. Some studies validated the effectiveness of a telemedicine strategy integrated with a mobile application and web portal to monitor a basal-bolus insulin therapy in diabetic patients (Franc et al., 2020; Hernandez-Ordonez et al., 2020).

The research topic of "sensors" involves the use of sensor technology to detect and measure changes in the environment in response to physical or chemical stimuli such as temperature, pressure, light, proximity, sound, and motion. In healthcare, sensors are useful for monitoring vital signs, tracking physical activity and medication adherence, and detecting irregular behaviors. The number of articles associated with this topic is 250. Recent advances emphasize the integration of multiple sensors to obtain parameters in a non-invasive manner, providing timely warnings of adverse conditions and promoting actions to improve diabetes control and treatment. Sawaryn et al. (2021) presented the advantages of sensors to identify movements and postures, useful for estimating energy expenditure and ensuring correct hormone administration in a Bi-Hormonal Artificial Pancreas system. Baig et al. (2021) validated the effectiveness of using sensors in a wearable body vest, Internet of Things (IoT) monitoring, and artificial intelligence algorithms to detect prediabetes and Type 2 diabetes.

The research topic of "wearables" refers to a technology device that is placed on the body in the form of an accessory or clothing to perform a specific function. Typically, wearables incorporate sensors and wireless communication to share useful information for health monitoring and fitness tracking. There are 183 articles on this topic. Recent advances in wearables have emphasized their accessory form and mechanisms to measure glucose using non-invasive resources such as sweat, tears, and urine. Advances are also being made to deliver medication and indicate risk conditions for developing diabetic complications. Smart devices such as socks, clothing, diapers, mouthguards, and contact lenses are underlined. There are proposals to use a smart sock with infrared thermography to control the temperature of different regions of the foot to prevent diabetes-related problems such as ulceration and infection (Torreblanca-González et al., 2021; Beach et al., 2021). Arakawa et al. (2020) validated a wearable mouthguard biosensor to obtain glucose concentrations in human saliva that correlate with blood sugar levels, enabling non-invasive glucose monitoring for diabetic patients.

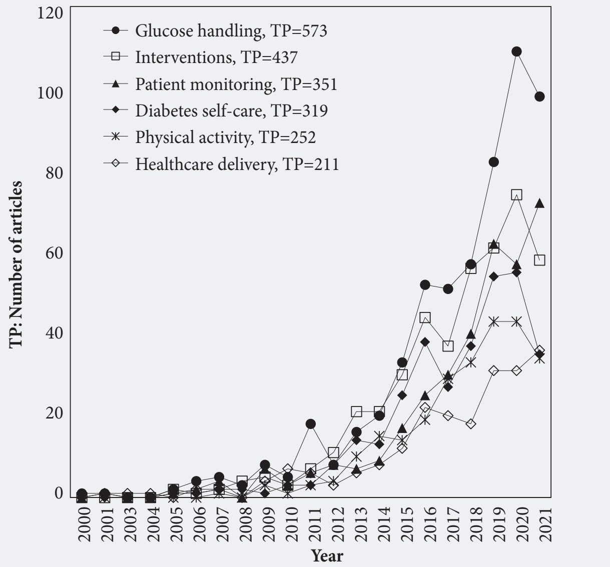
The research topic of "machine learning" covers computer algorithms that are trained to recognize and analyze patterns in large datasets for learning and decision-making activities to improve the performance of a task. Machine learning algorithms can be useful for analyzing data to determine diagnoses and health conditions, to develop personalized treatment plans, to predict patient outcomes and to provide tailored recommendations. The total number of articles on this topic is 159. There has been remarkable progress in machine learning algorithms to predict possible diabetes health conditions, using data from videos and images in addition to text. Besides, the incorporation of machine learning into digital platforms and smart devices is also highlighted. Nasser et al. (2021) verified the accuracy of a cloud-based deep learning algorithm combined with the Internet of Things (IoT) technologies for diabetes monitoring, providing patients with a prediction of future glucose levels. Stolfi and Castiglione (2021) confirmed

Figure 3. **The Main research Topics and Their Development Trends in the Technologies Category**



Source: authors.

Figure 4. **The Main Research Topics and Their Development Trends in the Applications Category**



Source: authors.

the effectiveness of an emulator based on complex simulations using machine learning methods that incorporate metabolic, nutritional, and lifestyle data to predict the development of Type 2 diabetes, enabling its application on mobile devices to perform self-management activities. Islam et al. (2021) proposed a machine-learning algorithm to detect non-invasive glucose levels based on videos of an individual's fingertip via smartphone cameras, which are processed into a photoplethysmography (PPG) signal.

Finally, the research topic of "text messaging" describes the exchange of text messages through cellular or digital networks, using mobile devices or computers. The number of articles linked to this topic is 127. Automatic generation of personalized messages reminds patients of timely glucose control and encourages physical activity (Aguilera et al., 2020; Kundury et al., 2020).

Category 3. Applications

This category includes topics where mHealth has been applied to provide solutions to various diabetes issues. Through continuous advances in this technology, novel and innovative applications in diabetes care are likely to emerge that will change the way this disease is controlled and managed. **Table A4** shows the research topics in this category according to their rank. As mentioned before, the number of articles that each supporting word appears in either article titles, author keywords, and Keywords Plus were summed to determine the corresponding rank.

Glucose handling, interventions, patient monitoring, diabetes self-care, physical activity, and healthcare delivery are the top six research topics. Figure 4 presents a graph with the number of articles containing in their title, author keywords, and Keywords Plus, the supporting words corresponding to each of the top six topics, distributed by year of publication. This graph allows for the identification of the focus in the applications category and its evolutionary trends.

The research topic "glucose handling" considers the context of the glucose control process, involving glucose detection, regular blood glucose testing, and the maintenance of blood sugar close to healthy levels. The number of articles associated with this topic is 573. Recent advances in this field are considering non-invasive alternatives to measure glucose levels, such as sweat and tears. Vaquer et al. (2021) demonstrated the efficacy of a mobile colorimetric wearable biosensor for detecting glucose concentration in sweat, comprising filter paper, a sweat volume sensor, and a color chart for signal normalization. This can be used with a smartphone camera to read the signal. Wang et al. (2018) developed a multilayer modified test paper to detect glucose concentration supported by a smartphone as a reading signal. This provides non-invasive detection of glucose levels based on tear samples. Pustozerov et al. (2020) developed a model to predict postprandial glucose patterns using a decision tree gradient boosting algorithm, based on information from a mobile app where individuals registered their food habits and context.

The research topic of "interventions" includes the context of actions undertaken to prevent, treat, and improve diabetes outcomes. Patients are encouraged to learn about their glucose instability and a lifestyle that produces favorable conditions to improve their health, such as exercise, stress reduction, and a healthy diet. There are 437 articles associated with this theme. Notable developments in using mobile technologies such as smartphones, apps, IoT, and smart wearables have been made to conduct intervention activities. Kato et al. (2020) revealed the effectiveness of an Internet of Things (IoT)-based lifestyle intervention, including remote health guidance and wearable devices to improve diabetes control.

The research topic of "patient monitoring" considers the processes that enable the continuous monitoring of a patient's health. It includes remote monitoring of health behaviors, alerts in case of health changes that may have a negative impact, and the continuous measurement of vital parameters such as temperature, blood pressure, pulse, blood oxygen saturation, and so on. The number of articles related to this topic is 351. Progress has been made around the architecture to connect multiple technologies such as the Internet of Things (IoT), smartphones, and smart wearables for monitoring diabetic patients. Rghioui et al. (2020) effectively developed a smart architecture based on machine learning algorithms to connect smart devices and sensors for patient monitoring.

The research topic of "diabetes self-care" refers to the set of activities and habits that diabetic patients have to do on their own to achieve better control of their disease and prevent complications. Patient education is necessary to facilitate knowledge acquisition and collaborative participation with health professionals to develop self-management skills such as self-monitoring of glucose, consumption of healthy foods, regular exercise, adequate intake of medications, and constant monitoring of feet and eyes to avoid complications. There are 319 articles on this topic. Significant progress in this field comes from digital platforms such as mobile apps and their integration with wearable devices. Luo and White-Means (2021) confirmed the feasibility of using mobile apps as a low-cost resource for conducting diabetes self-management activities in underserved diabetic patients with limited access to primary care providers.

The research topic of "physical activity" includes body movements that involve energy expenditure, such as exercise, walking, aerobic, and fitness activities. The total number of articles on this topic is 252. Advances in wearables with innovative designs and mobile apps to track physical activity have been identified. Li et al. (2021b) validated the efficiency of exercising supported by a chest band wearable and mobile application compared with traditional exercise. Ehrlich et al. (2021) confirmed the effectiveness of a wrist wearable to track physical activity in women with gestational diabetes. Martinato et al. (2021) demonstrated the accuracy of a smartwatch to monitor physical activity in older adults.

Finally, the research topic of "healthcare delivery" examines the provision of medical care to patients through interactions with healthcare professionals, such as consultations, medical services, recommendations, examinations, diagnoses, treatments, and procedures. The overall number of articles on this topic is 211. There have been advances in resolving communication challenges and providing remote alternatives for clinical consultations and care delivery using digital technologies. Shaw et al. (2020) identified effective communication strategies to improve the quality of interactions through video consultations.

Conclusion

Mobile health is in a phase of rapid development. There is a dynamic flow of emerging opportunities to improve prevention and timely interventions to improve health. This is especially evident in diabetic diseases and related complications. Research in this area is particularly relevant given the projections of accelerating diabetes dynamics that predict a 25% increase in the number of patients in 10-15-year increments (IDF, 2021). Smart applications based on AI and virtual reality are expected to create advanced solutions that provide a new quality of life, reduce risks, and enhance physiological well-being.

A word distribution analysis allowed for the identification of research topics on Diabetes mHealth for understanding their progress, which is useful for decision-making regarding R&D and Innovation. A total of 141 research topics were identified and grouped into six categories: health problems, technologies, applications, global perspectives, population groups, and healthcare professionals. An overview of the top three categories with the most research topics was developed. Diabetes mHealth represents an innovative alternative for improving the control of this disease by using mobile technology to improve blood glucose levels. The main specific health problems addressed by mHealth were Type 2 diabetes mellitus, gestational diabetes mellitus, cardiovascular disease, Type 1 diabetes mellitus, and chronic diseases, as well as related complications such as diabetic retinopathy and diabetic foot, furthmore, obesity as a risk factor. Machine learning algorithms, mobile applications, and smart devices are making remarkable advances in diabetes detection, control, and management, enabling care anytime, anywhere.

The main technologies employed in Diabetes mHealth research were smartphones, also known as mobile phones, followed by mobile applications, which are software developed for mobile devices, commonly known as mobile apps, mobile applications, app, and apps. Then comes sensors, which are mainly used in wearables and IoT to detect physical impulses and convert them into electrical and digital signals for further analysis. Next are wearables that are useful for health monitoring and physical activity tracking. Then there is text messaging, which is useful for establishing communication between healthcare professionals and patients. Finally, machine learning, which helps identify patterns and make predictions based on large amounts of information. The Internet of Things (IoT) is evolving in Diabetes mHealth research, which integrates wireless devices and wearables to create systems that facilitate healthcare delivery and monitoring. These technologies promote the empowerment of patients to participate in self-management and educational activities necessary to control their health conditions and make more effective joint decisions with their physicians. The main applications of diabetes mHealth comprises activities such as glucose handling, interventions, patient monitoring, diabetes self-care, physical activity, and healthcare delivery.

Medical practices supported by mobile technologies present several challenges. Remote connections miss the opportunity of practicing detailed physical exams, reduce interactions- with nonverbal signs that are important for effective communication, in addition bias regarding the context of patients' living conditions that influence their health may be present. Moreover, since patients have different levels of access to technology and education, this can result in poor individual health engagement. However, mHealth advances intend to enhance healthcare professional services and reach the highest number of people; it provides solutions for remote locations where the number of healthcare professionals is low. The uniqueness of mHealth lies in the opportunity of linking patients to health services in a more extensive way. Public health management strategies aligned with digital health efforts can reduce health disparities improving healthcare access for vulnerable populations. In addition, public health will be influenced by AI and IoT concerning how to cope with large volumes of information regarding the social complexity of this illness, providing more efficient solutions to determine regions of high prevalence, demographic groups, access to health services, and even factors that may be triggering diabetes complications. The final aim is to allocate resources more efficiently, anticipate health issues, enhance education programs to prevent and improve control of the disease, promoting equitable access to health.

Considering current knowledge on the research topics in Diabetes mHealth, future studies should identify technological advances in patents, policies, regulations, and ethical issues related to the field. The research topics identified in this study provide insights for researchers, decision-makers, and policymakers to prioritize their R&D efforts, effectively consolidate their areas of interest, and explore new topics with innovative and practical solutions. This supports the growth of the field by providing a panorama for future research directions to address the challenges of diabetes and its impact on society through mobile technology and digital developments.

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APPENDICES

Table A1. **Top 50 Most Frequently Used Terms in Titles, Author Keywords and Keywords Plus**

Words in title	TP	R (%)	Author keywords	TP	R (%)	Keywords Plus	TP	R (%)
diabetes	725	1 (46)	diabetes	238	1 (19)	care	205	1 (15)
mobile	347	2 (22)	mHealth	193	2 (15)	management	194	2 (14)
type	336	3 (21)	diabetes mellitus	132	3 (10)	glycemic control	171	3 (12)
patients	256	4 (16)	mobile health	127	4 (10)	adults	134	4 (10)
trial	244	5 (16)	telemedicine	122	5 (10)	health	124	5 (8.8)
health	237	6 (15)	self-management	98	6 (7.7)	risk	122	6 (8.7)
controlled	191	7 (12)	type 2 diabetes	91	7 (7.1)	intervention	120	7 (8.5)
glucose	173	8 (11)	smartphone	85	8 (6.7)	system	112	8 (7.9)
randomized	171	9 (11)	mobile phone	66	9 (5.2)	self-management	107	9 (7.6)
system	170	10 (11)	type 1 diabetes	61	10 (4.8)	physical-activity	93	10 (6.6)
intervention	142	11 (9)	ehealth	58	11 (4.5)	mellitus	92	11 (6.5)
care	137	12 (8.7)	physical activity	52	12 (4.1)	prevalence	90	12 (6.4)
monitoring	137	12 (8.7)	mobile applications	41	13 (3.2)	interventions	82	13 (5.8)
diabetic	129	14 (8.2)	machine learning	37	14 (2.9)	technology	82	13 (5.8)
management	128	15 (8.1)	type 2 diabetes mellitus	36	15 (2.8)	outcomes	78	15 (5.5)
app	117	16 (7.4)	digital health	35	16 (2.7)	metaanalysis	73	16 (5.2)
self-management	114	17 (7.2)	hypertension	33	17 (2.6)	support	72	17 (5.1)
mellitus	104	18 (6.6)	self-care	33	17 (2.6)	adherence	66	18 (4.7)
smartphone	104	18 (6.6)	telehealth	33	17 (2.6)	disease	66	18 (4.7)
support	100	20 (6.4)	obesity	32	20 (2.5)	impact	65	20 (4.6)
wearable	98	21 (6.2)	mobile apps	31	21 (2.4)	prevention	65	20 (4.6)
control	95	22 (6)	technology	31	21 (2.4)	people	64	22 (4.5)
adults	89	23 (5.7)	chronic disease	29	23 (2.3)	association	56	23 (4)
activity	78	24 (5)	e-health	27	24 (2.1)	validation	54	24 (3.8)
analysis	78	24 (5)	continuous glucose monitoring	26	25 (2)	children	53	25 (3.8)
phone	76	26 (4.8)	exercise	25	26 (2)	blood-glucose	51	26 (3.6)
protocol	76	26 (4.8)	glucose	25	26 (2)	glucose	51	26 (3.6)
technology	74	28 (4.7)	text messaging	25	26 (2)	adolescents	50	28 (3.5)
risk	72	29 (4.6)	artificial intelligence	24	29 (1.9)	education	48	29 (3.4)
mHealth	70	30 (4.4)	diabetic retinopathy	23	30 (1.8)	exercise	48	29 (3.4)
blood	68	31 (4.3)	internet	23	30 (1.8)	obesity	48	29 (3.4)
evaluation	67	32 (4.3)	primary care	23	30 (1.8)	internet	45	32 (3.2)
physical	63	33 (4)	gestational diabetes	22	33 (1.7)	program	43	33 (3)
development	62	34 (3.9)	internet of things	22	33 (1.7)	health-care	42	34 (3)
clinical	61	35 (3.9)	m-health	22	33 (1.7)	design	41	35 (2.9)
feasibility	58	36 (3.7)	randomized controlled trial	22	33 (1.7)	randomized controlled-trial	40	36 (2.8)
insulin	58	36 (3.7)	blood glucose	21	37 (1.6)	telemedicine	40	36 (2.8)
digital	57	38 (3.6)	qualitative research	21	37 (1.6)	efficacy	38	38 (2.7)
patient	57	38 (3.6)	gestational diabetes mellitus	20	39 (1.6)	hypoglycemia	37	39 (2.6)
people	57	38 (3.6)	mobile application	20	39 (1.6)	model	37	39 (2.6)
disease	55	41 (3.5)	sensors	20	39 (1.6)	mortality	37	39 (2.6)
randomised	55	41 (3.5)	type 2	20	39 (1.6)	therapy	37	39 (2.6)
apps	54	43 (3.4)	prevention	19	43 (1.5)	complications	35	43 (2.5)
improve	54	43 (3.4)	app	18	44 (1.4)	life-style intervention	35	43 (2.5)
assessment	53	45 (3.4)	hba1c	18	44 (1.4)	behavior	32	45 (2.3)
gestational	53	45 (3.4)	prediabetes	18	44 (1.4)	cardiovascular-disease	32	45 (2.3)
pilot	53	45 (3.4)	wearable sensors	18	44 (1.4)	quality-of-life	32	45 (2.3)
program	51	48 (3.2)	adherence	17	48 (1.3)	trial	32	45 (2.3)
detection	50	49 (3.2)	cellular phone	17	48 (1.3)	weight-loss	32	45 (2.3)
design	49	50 (3.1)	diabetes management	17	48 (1.3)	quality	31	50 (2.2)

Note: TP: Number of articles; R (%): Ranking and percentage of the number of articles compared to the total number of articles.
Source: authors.

Table A2. **Research Topics on Health Problems with Their Supporting Words**

Rank	Research topic	Supporting words from title, author keywords, and keywords plus	TS
		Sub-category "Diseases"	
1	Type 2 Diabetes mellitus	diabetes mellitus type 2, "diabetes mellitus, type 2", diabetes type 2, t2dm, type 2, type 2 diabetes, type 2 diabetes mellitus, type-2, type-2 diabetes mellitus, type-2 diabetes-mellitus	212
2	Gestational diabetes mellitus	gestational, gestational diabetes, gestational diabetes mellitus, gestational diabetes-mellitus, gdm, antenatal care, neonatal, maternal, maternal health, pregnancy, pregnant, pregnant-women, postpartum, gestational weight-gain, maternal obesity	196
3	Cardiovascular diseases	cardiovascular, cardiovascular disease, cardiovascular diseases, cardiovascular outcomes, cardiovascular risk factors, cardiovascular risk-factors, cardiovascular-disease, vasculature, heart-disease, heart-failure, heart-rate, heart-rate-variability, cardiac, cardiac rehabilitation, cardiometabolic	142
4	Type 1 diabetes mellitus	diabetes mellitus type 1, "diabetes mellitus, type 1", iddm, type 1, type 1 diabetes, type 1 diabetes mellitus, type-1	120
5	Chronic diseases	chronic, chronic conditions, long-term, chronic disease, chronic diseases, chronic disease management, chronic illness	120
6	Coronary-heart-disease	coronary, coronary-heart-disease, artery	20
7	Cancer	cancer	18
8	Non-communicable diseases	non-communicable, non-communicable disease, non-communicable diseases, noncommunicable diseases	18
9	Comorbid	comorbid, comorbid depression, comorbidity	13
10	Covid-19	covid-19, pandemic	13
11	Asthma	asthma	5
12	Chronic obstructive pulmonary disease	copd	4
13	Multiple sclerosis	multiple sclerosis	3
		Sub-category "Diabetic complications"	
1	Diabetic retinopathy	diabetic retinopathy, diabetic-retinopathy, retinal, retina, retinal images, retinal imaging, retinopathy, microvascular complications, ophthalmology, ophthalmoscopy, eye diseases, macular, macular edema, ocular, optical, optical coherence tomography, slit-lamp biomicroscopy, tele-ophthalmology, tele-ophthalmology, visual acuity, acuity, blindness, hyperacuity, edema	180
2	Diabetic foot	Diabetic foot, diabetic foot ulcer, diabetic foot ulcers, amputations, gait, foot, foot ulcers, ulcer, ulceration, ulcers, plantar, plantar pressures, thermal, thermography	134
3	Wound healing	wound, wound healing, healing, wounds, infection, epidermal, skin, transdermal, chronic wounds, impairment, dressing	66
4	Hypoglycemia	hypoglycemia, hypoglycaemia, severe hypoglycemia	65
5	Diabetic peripheral neuropathy	diabetic peripheral neuropathy, neuropathy, nerve, joint, peripheral, pain	34
6	Diabetic nephropathy	diabetic nephropathy, kidney, chronic kidney-disease	13
7	Ketoacidosis	ketoacidosis, acid	12
		Sub-category "Risk factors"	
1	Obesity	obese, obese adults, obesity, overweight	144
2	Hypertension	hypertension, hypertensive	95
3	Metabolic syndrome	metabolic, metabolic health, metabolic syndrome, syndrome, metabolic-control, metabolism, metabolite	60
4	Insulin resistance	insulin resistance, resistance, insulin sensitivity, insulin-resistance, cells, dna, beta-cell function	41
5	Prediabetes	pre-diabetes, prediabetes	40
6	Hyperglycemia	hyperglycemia	30
7	Sedentary behavior	sedentary, sedentary behavior, sitting	18
8	Smoking	smoking, smoking-cessation	9
		Sub-category "Complications"	
1	Atrial fibrillation	atrial, atrial fibrillation, atrial-fibrillation, fibrillation	26
2	Myocardial-infarction	acute, acute myocardial-infarction, myocardial-infarction, infarction, ischemia	17
3	Stroke	stroke	16

Note: TS: The total sum is the addition of the number of articles that each supporting word appears in either article titles, author keywords, and Keywords Plus.
Source: authors.

Table A3. **Research Topics on Diabetes mHealth Technologies with Their Supporting Words**

Rank	Research topic	Supporting words from title, author keywords, and keywords plus	TS
1	Smartphones	cell, cell phone, cell phones, cell-phone, cellphone, cellular, cellular phone, cellular phone, smartphone, smartphone-based, smartphone-powered, smartphone-enabled, smartphones, phone, phone-based, phones, telephone, mobile phone, mobile phone technology, mobile phones, radiation, photography	594
2	Mobile Apps	app, app-based, apps, health apps, mobile app, mobile application, mobile applications, mobile apps, mobile health applications, mobile phone applications, phone applications, smartphone app, smartphone application, smartphone application (app), smartphone applications, smartphone apps, application, applications, apple, android, diabetes apps	440
3	Sensors	sensing, sensing technology, sensitive, sensitivity, sensor, sensor-based, sensors, wearable sensor, wearable sensors, electrochemical, electromagnetic, energy harvesting, magnetic, calibration, self-powered, remote sensing technology, glucose sensor, optical sensors, wireless sensor networks, temperature sensors, accelerometer, accelerometers, accelerometry	269
4	Wearables	wearable, wearable computing, wearable device, wearable devices, wearable electronic devices, wearable electronics, wearable system, wearable technology, wearables, portable, wristband	188
5	Text messaging	message, message-based, messages, messaging, messaging system, short message service, short-message service, sms, text message, text messages, text messaging, text-med, text-messaging, chat	171
6	Machine learning	machine learning, deep learning, pattern recognition, patterns, algorithm, algorithms, mpc, artificial neural networks, neural networks, convolutional, convolutional neural network, classification, classifier	165
7	Internet	internet, internet use, internet-based, net, network, networks, wireless, wireless communication, architecture	162
8	Artificial intelligence	artificial intelligence, ai, reinforcement learning, offline, ontology, taxonomy, online, computer vision, computational modeling, computer, computer-based, computerized, simulation, image processing, image-based, images, imaging	153
9	Artificial pancreas	artificial pancreas, bionic pancreas, artificial, pancreas, implantable	103
10	Medical devices	device, devices, medical devices	101
11	Big data	big data, big, data mining, data models, data-driven, information, information-seeking, search	91
12	Internet of things (IoT)	internet of things, internet of things (iot), iot, iot-based, things	75
13	Biosensor	biosensing, biosensor, biosensors, mouthguard biosensor, optical biosensor	65
14	Smart contact lens	lens, lenses, contact, smart, tear glucose	65
15	Web-based	web, web-based, patient portal, portal, content	57
16	Video games	video games, video, videos, game, games	27
17	Cloud computing	cloud, cloud computing, cloud-based	24
18	Fundus camera	fundus, fundus photography, retinal camera	20
19	Virtual reality	virtual, augmented	16
20	Calls	call, calls, automated calls	13
21	Tablet	tablet, tablet-based, screen	11
22	Voice assistant	voice, assistant, assisted	11
23	Blockchain	Blockchain	10
24	Electrocardiogram	electrocardiogram, ecg	10
25	Photoplethysmography	Photoplethysmography	9
26	Glucometer	Glucometer	7
27	Infrared thermography	infrared thermography	6
28	Spectroscopy	spectroscopy, near-infrared	6
29	3D-Printing	3d-printed	4

Note: TS: The total sum is the addition of the number of articles that each supporting word appears in either article titles, author keywords, and Keywords Plus.

Source: authors.

Table A4. **Research Topics of Diabetes mHealth Applications with Their Supporting Words**

Research topic	Research topics of Diabetes mHealth applications with their supporting words	TS
Glucose handling	glucose, glucose control, glucose detection, glucose oxidase, glucose-tolerance, impaired glucose-tolerance, loop glucose control, overnight glucose control, sugar, glycaemia, glycaemic, glycaemic control, glycemic, glycemic control, glycemic index, blood glucose, ambulatory glucose profile, blood glucose monitoring, blood glucose self-monitoring, blood-glucose, blood-glucose control, self-monitoring of blood glucose, plasma-glucose, hba, hba(1c), hba1c, 1c, a1c, fasting, hemoglobin, glycosylated haemoglobin, glycated hemoglobin a1c, biomarker, biomarkers, strip, basal, postprandial, ppg	755
Interventions	intervention, interventions, complex intervention, complex interventions, life-style intervention, life-style interventions, lifestyle intervention, multifactorial intervention, motivational interviewing, emid	443
Patient monitoring	health monitoring, monitor, monitored, monitoring, monitoring-system, monitors, follow-up, patient monitoring, remote monitoring, home health monitoring, home-based, home-use, telemonitoring, tracker, trackers, tracking, biomedical monitoring, self-monitoring, self-tracking, continuous glucose monitoring, continuous glucose monitoring (cgm), cgm, glucose monitoring, glucose monitoring-system, patch, non-invasive, noninvasive, invasive	434
Diabetes self-care	diabetes self-management, self-management, self-management support, self care, self-care	401
Physical activity	exercise, aerobic exercise, activation, activity recognition, activity tracker, fitness, motor activity, physical, physical activity, physical-activity, cardiorespiratory fitness, free-living, free-living conditions, walking, energy expenditure, energy-expenditure	388
Healthcare delivery	telemedical, telemedicine, telemedicine system, remote consultation, medical services, interactions, interactive, interactive diary, providers, delivery of health care	252
Medication adherence	adherence, improve adherence, medication adherence, medication, patient compliance, compliance, nonadherence, reminder, reminder system, reminders, medicine	251
Diabetes education	diabetes education, education, educational, health education, health literacy, literacy, management education, patient education, self-management education, training, coaching, retention, awareness, health coaching, learned, lessons	246
Usability evaluation	usability, usability evaluation, usage, usefulness, utility, utilization, utilizing, efficient, user, users, user acceptance, user centered design, user-centered, user-centered design, profile, profiles, performance, heuristic, heuristic evaluation, evaluation studies, experience, experienced, experiences	245
Behavior change	behavior, behavior change, behavior modification, behavior-change, behavior-change techniques, behavioral, behavioral medicine, behaviors, behaviour, behaviour change, behavioural, health behavior, intention, self-efficacy, change, changes, readiness	245
Treatment	therapy, therapeutic, counseling, counselling, acceptability, acceptance, acceptance and commitment therapy, intensive, treat, treated, treatment, guidance, guidelines, recommendation, recommendations, recommender system, position statement, adoption, rehabilitation, clinical-practice guidelines	242
Patient examination	diagnosed, diagnosis, diagnostic, diagnostics, disease diagnosis, detect, detection, simultaneous, examining, newly, exploratory, exploring, screening, recognition, determinants, determination, determine, evaluate, evaluating, indicators	234
Healthy lifestyle	life, life-style, lifestyle, lifestyle modification, lifestyles, health-related quality of life, healthy, healthy lifestyle, quality, quality of life, quality-of-life	225
Decision-support-systems	decision, decision support, decision-support, decision support systems, decision-support-systems, decision-making, support, supporting, clinical decision support, clinical decision support system	222
Food-intake	diet, diet monitoring, dietary, bolus, bolus calculator, calculation, calculator, counting, carbohydrate, carbohydrate counting, disorder, disorders, eating, energy-efficient, energy-intake, food, food-intake, food recognition, intake, meal, mealtime, ersonalized, nutrition, nutrition assessment, nutritional, protein	219
Diabetes prevention	diabetes prevention, prevent, prevention, prevention program, preventive, preventive medicine, primary prevention, perceived, perception, perceptions, secondary, secondary prevention	213
Personalized medicine	personal, personalized, personalization, personalized, personalized medicine, tailored, precision, precision medicine, predict, predicting, prediction, predictive, predictive models, predictive-validity, predictors, model-predictive control, prognosis, prospective	168
Insulin delivery-system	insulin delivery, insulin delivery-system, automated insulin delivery, insulin injections, multiple daily injections, insulin pump, insulin pump therapy, loop insulin delivery, insulin-treated, intensive insulin therapy, insulin therapy, insulin, titration, pump, pump therapy	166
Mental health	distress, anxiety, psychological, psychological distress, psychosocial, depression, depressive, phq-9, mindfulness, rationale, balance, mental, mental health, mental-health, cognitive, cognitive-behavior therapy, stress, sleep, night, nocturnal	159
Weight control	weight, weight loss, weight management, weight-gain, weight-loss, weight-loss interventions, body, body composition, body weight, body-mass index, waist circumference, gain	146
Patient empowerment	patient engagement, patient empowerment, patient participation, patient satisfaction, patient-centered, patient-centered care, satisfaction, self-efficacy, treatment satisfaction, motivation, encourage, nudge, empowerment, empowerment scale, do-it-yourself, self-reported, engage, engagement	132
Electronic health record	electronic health record, electronic health records, electronic medical record, health records, health information, record, records, patient-generated, patient-generated data, patient-generated health data, sharing, documentation, personal health record, personal health records, phr, history, interoperability, electronic	115
Social support	social support, social, social media, media, culturally, context, focus, focus groups, family, group, groups, help, peer, peer support, peer support	110
Health promotion	health communication, health promotion, promote, promoting, promotion, communication, dissemination	78
Blood-pressure control	blood pressure, blood-pressure, blood-pressure control, pressure	64
Diabetes management	diabetes management, care management, disease management, health management, management-system, managing, control 1st	61
Health policy	health policy, standard, financial incentives, incentives, privacy, willingness, willingness-to-pay	29

Note: The total sum is the addition of the number of articles that each supporting word appears in either article titles, author keywords, and Keywords Plus.
Source: authors.

Public Procurement Policies to Foster Innovation Development

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Abstract

Government and public sector demand from the perspective of demand-push policies as a tool of technology and innovation policy have been discussed in detail in the literature. Policymakers have always considered advantages such as promoting local production goals, reducing imports and dependence upon foreign countries, and meeting domestic needs with technology development and innovation. In Iran such policies have been designed and implemented and can be classified into two categories: horizontal and vertical policies. Horizontal policies refer to policy programs that regulate the general government market and the public sector. In vertical policies, however, government demand in a particular product area is regulated. In order to analyze the different types of application of these policies in Iran, several cases of horizontal and vertical policies have been studied and compared in this article. From the horizontal policies, the law of maximum use of domestic power and Foreign Finance Credit have been selected. Among the vertical policies, the policy of 10 basic oil products and the experience of the Iran-Lab-Expo have been examined. Attempts have been made to analyze and compare the above policies based on the general pattern of government programs to stimulate government demand for technology and innovation. Finally, the lessons learned from Iran's policy experiences in the field of public sector demand orientation as a tool of technology and innovation policy are described.

Keywords: innovation policy; public procurement; demand push; regulatory framework; multiple case studies

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Introduction

Policymakers and researchers are very interested in explaining the ability of the public sector to foster innovation at companies through public procurement (Tammi et al., 2020). In fact, with a share of 12% of GDP and 29% of the total expenditures of governments in the Organization for Economic Cooperation and Development (OECD), public procurement can be considered a policy tool, a driver for realizing strategic goals (Dai et al., 2021).

There has been a lot of evidence in the field of innovation policy in recent decades that has confirmed and emphasized the use of public procurement as a policy tool to stimulate demand (Crespi, Guarascio, 2019; Uyarra et al., 2020). As an example, Adler et al. (2015) examined the impact of public procurement on innovation through a survey of companies and suppliers and reached several important conclusions that prove the effectiveness of these policies:

1. The majority of the innovative companies (around 67%) have considered being a supplier of the public sector to be effective in their innovative activity.
2. More than 75% of these innovative companies have reported that they were able to receive other government contracts in addition to the previous ones. Also, 50% of these companies reported sales contracts with private companies and 30% of them reported sales abroad in areas related to public procurement contracts.

The implementation of this policy in countries often takes the form of a "Buy Local" policy. This policy has been introduced in the United States in the form of the "Buy American Act" and is similar to the domestic purchase preference in Canada, Australia, New Zealand, Turkey, India, and many other countries (Naegelen, Mougeot, 1998).

Today, many developed and developing countries have put supports into place for innovation-oriented public procurement as an independent tool or part of a systematic strategy and effort, such as a "policy mix" or "mission-oriented policies" (Mazzucato, 2018) in their program. These countries, in formats such as upgrading existing frameworks in contracts, improving organization and capabilities, identifying, specializing, and marking needs, as well as setting incentives for innovative solutions to solve problems, have put it on their agenda (Georghiou et al., 2014).

Empirical studies at the sector level have confirmed the realization of goals such as protectionism, improvement of the institutional environment, and the level of domestic production capacity as week as environmental and social aspects in the industrial development policy of countries. Nevertheless, the negative effects of these policies should be considered in their design, especially those violating the competitive environment and creating obstacles to facilitating market liberalization, increasing the risk of inefficiency, reducing productivity, and also reducing the connection of domestic companies to the global value chain (Narimani et al., 2019a).

Some researchers believe that the existence of a common model and similar practical approaches to the various dimensions of these policies and their adjustment depends on the characteristics of the countries involved and the desired goals of the policymakers (Wint, 1998; Khor, 2003). Therefore, it is necessary to study the specific experiences and conditions of each country in order to develop a suitable public procurement policy model (Narimani et al., 2019a).

In Iran, different types of policies have been designed and implemented, horizontally oriented policies that include the government programs in general and vertically oriented ones that are implemented in specific sectors and specific technology fields (Narimani et al., 2019b).

This research attempts to investigate the most important dimensions and characteristics of these policies using the method of a multiple case study. Based on this, in horizontal policies, the authors examine the dimensions of the law on the maximum use of Iran's production and service capacity and the protection of Iranian goods, the law on holding tenders, and the requirements for using export credit facilities (finance), and in vertical policies, the exhibition of laboratory equipment and materials made in Iran and the program related to the ten basic petroleum products are selected and reviewed.

For this purpose, in the second part of the manuscript, by reviewing the innovation-based theoretical frameworks of public procurement development, a framework has been developed to explain the aforementioned areas. In the third section, the research method of the manuscript is explained, and in the fourth part, the research findings are elaborated. Finally, the analysis of the research findings and a policy framework for improving this policy tool have been described.

Literature Review

The importance of demand for innovation and technological change has been studied in the literature since the 1960s (Schmookler, 1962). Godin and Lane (2013) have stated that despite the demand-pull policies and their impact on innovation, the demand elasticity model has become a multifaceted and successful model for driving innovation. One of the most important tools of demand-pull policies is public procurement, which is known as an effective tool for creating innovations and encouraging industrial restructuring (Crespi, Guarascio, 2019). The ways in which PP can affect the market have been discussed in the innovation literature mainly from two perspectives (Bleda, Chicot, 2020).

In the first view, it is based on solving "market failures" in the field of information deficiencies and asymmetries. In this view, markets are considered pre-existing or "given". The second view emphasizes the importance of knowledge and interactive learning on markets. This view posits that markets are rarely predetermined and that they must be created and changed and developed over time. Therefore, the analyses within this view are a more realistic and dynamic view of what innovation markets are and how they work. Regardless of the different views, in a wide range of company-level surveys, the effectiveness of public procurement has been confirmed as the most important incentive for the company to invest in innovation and the driving force of technology diffusion. The most important reasons for using this tool can be summarized as follows:

1. Market public procurement creates or increases the demand for specific goods or services, while reducing product development costs and the risks associated with research and development activities. In other words, public procurement ensures a minimum market size and improves the predictability of demand and thus may drive innovation. Therefore, public procurement can eliminate market failure for R&D activities (Bleda, Chicot, 2020).
2. Government organizations can act as the main user and finance the learning costs or innovative product improvement. As the main buyer, in various industries, these organizations can provide information about the needs and unmet needs of the market, which in turn will lead to innovation at companies (Dai et al., 2021).
3. Public procurement can facilitate standard setting and technology diffusion. In addition, public procurement can address system failures by improving interactions between users and producers (Uyarra et al., 2014).

In the literature, there are two different understandings (narrow and broad) of the concept of public procurement supporting innovation (PPI). In a limited sense, public procurement as an innovation policy tool is usually referred to as "indigenous technology provision", which means the provision of products that have not yet been produced but can be developed in a reasonable amount of time. These products usually require research and development. Also, these policies are more focused on radical innovations and ignore other types of innovations (Uyarra, Flanagan, 2010).

Generally, PPI is defined as the procurement activities of public agencies that encourage all types of innovation (including radical and incremental or product and process innovations) (Rolfstam, 2012). In fact, incremental innovations resulting from public purchases, which are based on the adaptation or improvement of existing solutions and products or even non-technological innovations, can have a greater impact on the market and innovative activities (Lember et al., 2011).

Furthermore, the broad definition of PPI implies that innovation can be a by-product of public procurement, regardless of whether public procurement is explicitly dedicated to innovation (Uyarra, Flanagan, 2010). Some researchers also believe that conditions can be considered in foreign contracts, such as technology attachment and internal manufacturing requirements (commitment to purchase a certain part of the project's components and equipment internally, even if the work is referred to outside), the innovation development is considered indirectly (Ssennoga, 2006).

For optimal use of these tools, some researchers have described various dimensions. As an example, Uyarra et al. (2014), in addition to the government's policy efforts, things such as supply capabilities, risk management, interactions between suppliers and buyers, transparency of government demand, detailed specifications in tenders, incentives to provide innovative solutions, management of intellectual property rights, and access to bids as well as other restrictions on the bidding process are key features of effective public procurement programs.

They conclude that the characteristics of the suppliers and the nature of the market are the most important influencing dimensions in public procurement that supports innovation. From the perspective of small and medium enterprises, the main obstacles to using this capacity in the development of innovation can be found in the lack of information exchanges and interactions between enterprises and government agencies that are responsible for contracts. In addition, the lack of proper specialization of the topics related to the holding of tenders for the development of innovation and weakness in the acceptance and risk management structures of the contracting authorities are also other obstacles (Uyarra et al., 2014).

Uyarra et al. (2020), based on the study of Wanzenbock et al. (2019), have also considered four different scenarios to explain the problem/solution-based public procurement framework. They have proposed a hybrid strategy (government as the R&D buyer), a solution-based strategy (government as the catalyst), a problem-based strategy (the government as the main user), and the government as an intermediary. These scenarios are followed to mobilize public purchases as one of the main components of innovation policy.

By examining these concepts as a part of research related to innovation-supporting public procurement, the dimensions of a suitable policy for this area can be found in the "formulation of innovation demand" (Uyarra et al., 2014), "the capabilities of supplying products and innovations by suppliers" (Edquist et al., 2015; Lember et al., 2014), "the role of intermediary institutions to reduce the risk of transactions" (Edler et al., 2015; Landoni, 2017; Georghiou et al., 2014), and "governance and regulatory structure" (Rolsfam, 2012; Vecchiato, Roveda, 2014; Li et al., 2015).

Research Method

Empirical evidence on the effects of public procurement on firm innovation outcomes is lacking (Dai et al., 2021). Based on this, it seems that a case study is a suitable method for use in research related to public procurement. This research using a multiple-case study (Appendix 1) is based on qualitative content analysis and examines public procurement in Iran presenting the strategic principles of formulating an effective innovation policy.

For analysis, based on Wolcott (2008), three stages of description, analysis, and interpretation of the textual data resulting from the interviews were used. Undoubtedly, the interview is the most common technique for conducting systematic social research. Therefore, for collecting data, the researchers use a semi-structured in-depth interview that allows the interviewee to describe, without any limitations, as much as possible about their experiences, understanding, actions, and behaviors. Despite the limitations due to the COVID-19 pandemic, most interviews were conducted in person by researchers to obtain more satisfactory results while observing health protocols. This approach allowed the researchers to use information from previous interviews in subsequent ones. The purpose of the interviews was to understand and explain the complexity and processes involved in the implementation of public procurement policies in four case studies. The majority of the interview time was devoted to identifying initiatives employed and lessons learned by individuals who played an active role or had significant experience in the process.

In the content analysis stage (primary and secondary coding), the success and failure factors in the historical process of implementing the studied policies were first coded and categorized based on the results obtained from the interviews. Then, in the second stage, the obtained codes were classified and collected into relevant themes based on their internal coherence and consistency. Finally, after examining and identifying the themes as the main factors influencing policymaking and implementation, the researchers were able to discover a set of key factors. A network of themes was then discussed for each case study.

In this study, alongside data triangulation (using all source of data, e.g., policymakers, buyers, suppliers, etc.), interviews continued until the theoretical saturation of the topics was achieved. In other words, researchers found that there was no longer possible new data. Based on the results obtained, the components of each theme have coherence and consistency in terms of meaning and concept within each theme, while clear differences also exist between them. The grouping of themes was carried out according to the obtained content and, in cases where similarities existed, based on the literature and theoretical foundations of public procurement literature.

Horizontal Policy Case Studies

The Law of Maximum Use of Internal Capability

The maximum law was proposed in the form of a proposal by the parliament members in 1996 and was approved. However, the government's five-year delay in implementing the law was a sign of the lack of coordination between the government and the parliament and the government's reception of the implementation. Although the obligation to comply with the law is stipulated in the general approved projects, the law did not have a proper enforcement guarantee.

Within the normal and non-project purchases of the government, as well as the projects of non-governmental public institutions, the implementation of the law has not been very successful. An analysis of the implementation of the law on the maximum use of internal power was conducted, this was required to be observed in many subject laws, including foreign finance and foreign exchange reserves, tenders, construction projects, and so on. In 2018, this law has been reviewed and amended again. The table in the Appendix 2 compares the categories extracted from the conducted interviews as well as the initial categories extracted from the new version of this law.

According to most of the experts and interviewees, this law has not been implemented properly and has not been effective enough in improving internal power. Only in limited cases in Iran's steel production chain has this law been effective in increasing Iran's technological capability (Attarpour et al., 2023).

The main institutional obstacles to the implementation of this law, many of which have been addressed in the new law, will be explained below.

One of the issues that has affected the effectiveness of the implementation of this law is the weak support of the country's financial system for domestic producers.

In fact, government employers prefer to meet their needs with foreign finance due to the budget deficit and liquidity challenges. It is natural that foreign financiers in the form of export credit institutions consider their mission to be the development of their resident country's exports and benefit from cheap export credits. Of course, in the new law, an attempt has been made to fix this shortcoming to some extent by regulating the internal financing system.

Another weakness of this law, according to one of the interviewees, was stated that:

> *As long as they don't want to implement the law, state institutions and companies are investors, this law will not be implemented and this is the main problem of the law, not the financing system.*

The experience of successful countries in promoting domestic manufacturing, such as Nigeria and Brazil, shows that specialized institution building in the body of organizations in charge of economic sectors is more successful than dividing those institutions in charge of particular economic sectors from those in charge of technological development.

The use of risk management capacity, especially in the production of new and advanced goods (which is also neglected in the new law) and the lack of an evaluation system and database of internal technical capabilities as well as the requirements of government departments are other institutional problems impeding the implementation of the law.

Export Credit Facility (Finance)

The credit line that is the subject of this research includes 72 export credit (finance) facilities, which in turn include 13 items. Mutual purchase agreements make seven of those items while construction, operation, assignment contracts account for four.

Five ministries in Iran account for the most approved sectoral projects. Based on this, the largest priority projects of each of the five ministries have been selected for case study. Appendix 3 presents a summary of the topics mentioned in the interviews.

Based on an analysis of the conducted interviews, the most important issues that should be paid attention to in increasing the effectiveness of this public procurement policy for improving domestic technical capacity can be summarized as follows:

1. The presence of domestic contractors as intermediaries in export credit facility projects (finance) is necessary.
2. The use of various financial instruments in a specialized and combined manner (avoiding the entire project's reliance on tied foreign loans and the combined use of domestic financing institutions to provide cash flow along with various loans for different parts of the project)
3. Public-private partnerships for formulating and implementing technological priorities, especially the presence of knowledge institutions such as internal engineering offices or private knowledge-based companies as an entity for absorbing and transferring technology.
4. Statistics of internal technical, engineering, and technological capabilities and the preparation of a national capabilities bank (a database of companies with internal competences)
5. Developing a foreign exchange policy compatible with industrial and technological policy (determining the exchange rate of the project from the perspective of external sustainability)
6. The need to internationalize the legal structure and corporate governance of domestic contractors.

Vertical Policy Case Studies

Exhibition of Laboratory Materials and Equipment Made in Iran

The history of the "Made in Iran" exhibition goes back to the experience of the special staff members for the development of nano technologies in pre-purchasing related equipment and donating them to users, which has been on the agenda since 2006.

At that time, although the program of selling products to potential customers was also followed, this policy was not very successful in practice. Equipment customers were mainly looking for products with special features and the manufactured equipment was not necessarily suitable for them. Furthermore, the manufacturers demonstrated non-competitive performance in terms of production features, delivery time, and so on, regardless of the market conditions. Based on this, since 2013, it was decided that the contracts should be concluded with the buyers first, and then according to their conditions, the construction order contracts should be concluded with capable manufacturers. Appendix 4 presents a summary of the interviews about the "Made in Iran" exhibition. In the following years, the experience of the nanotechnology headquarters in designing the development model of the nanotechnology equipment market was noticed by the Vice President of Science and Technology of Iran, and from 2013 until now, in five periods, the initial model was expanded and generalized from the nanotech field to laboratory equipment and materials in all fields.

The implementation of this policy continues with the participation of public and government sectors as well as knowledge-based manufacturing companies. The increase in the quantitative statistics of the exhibition and the continuation of its implementation show that paying attention to the challenges of implementing this policy and its achievements can inspire the design of more effective policy models to take advantage of the demand of the government and the public sector for technology and innovation.

Based on an analysis of the conducted interviews, the important points for the effective use of this political tool can be summarized as follows:

1. The majority of buyers are governmental and their unfamiliarity with the innovations and complexities of the industry as well as the inefficient financial structure and cost accounting of universities and research institutions can be challenges;
2. Scattered purchases by universities and research institutions;
3. Ignorance and lack of trust of government buyers with regard to the technological and innovative capabilities of domestic enterprises.
4. Management of exchange costs and intermediary institutions
5. The presence of a specialized custodian organization next to government buyers

Ten Groups of Strategic Products for the Oil Industry

The localization plan of 10 groups of goods and equipment needed by the oil industry was put on the agenda in 2013 by the order of the Minister of Oil and with the cooperation of Sharif University with the aim of strengthening domestic capabilities and making the oil industry rely more on the products of Iranian manufacturers.

The main mechanism in this plan was that in addition to the three characteristics of quality, price and time, technological capability was also considered one of the determining features of the tender winner based on a designed model. To determine the level of technology in such tenders, the "Evaluation of Qualitative Competence and Technological and Production Capability" model is used. This model was a combination of three models, that describe levels of technological, manufacturing and commercial readiness, accordingly (TRL, MRL and CRL). Therefore, companies that have technological and production capabilities and can formulate and implement a technology development roadmap were selected in this process. This shows that the current production capacity of these companies, which demonstrates the existence of more absorption capacity and basic capabilities, is more important. Appendix 5 shows the execution coordinates for this program.

Based on an analysis of the conducted interviews, this program has not been able to have the necessary effectiveness in improving the technological and construction capabilities for various reasons, the most important of these are as follows:

- Absence of purchase guarantee mechanism by oil industry companies
- Incomplete evaluation system in determining the ability to build as the most important factor in determining the quality score of bidders
- Absence of a specific plan for capacity development in the government system
- Impossibility of cooperation with foreign companies for technology transfer
- Absence of coordinating institutions to implement this program.

Summarized Insights from Case Studies

Based on the findings of our research on the challenges of the effective implementation of public procurement policies of the government, the historical course of the implementation of four policy programs can be seen in Figure 1. As it is known, these policies first started with horizontal policies in Iran, and then, due to the low effectiveness of these policies, special and vertical policy programs were designed. In general, the strengths and weaknesses of the government's horizontal and vertical procurement policies in stimulating innovation can be summarized in Table 1. The investigated demand stimulation policies can be classified based on Figure 2 and Table 2.

Discussion and Conclusion

Demand stimulation policies have always been considered a tool of innovation policy in different countries. However, their effectiveness in developing domestic manufacturing and innovation capabilities has always faced many problems.

In this study, the experience of these policies in Iran has been discussed. It should be acknowledged that although these policies, especially vertical programs, have been successful in creating a market for domestic companies and their existing products, they have not had much impact on the development of innovation in the country.

By examining the issues raised in this study, it is clear that the effectiveness of vertical programs for public procurement policies to meet the current needs of the sector and create a market for manufactured and standard products is higher than the horizontal policies. Based on this, it is necessary to convert horizontal policies such as the law of maximum use of internal power into specific policy programs in each sector so that their capacity can be used properly.

The most important factor in the implementation of such policy programs is the transformation of upstream documents into sectoral executive programs and the willingness and commitment of the country's executive bodies to develop internal capabilities. However, the experience of more advanced countries shows that different economic sectors have prepared and implemented a specific strategy for the development of capabilities based on their upstream documents. Examples of this type of planning can be seen in South Korea (Lee, 2004), China (Mu, Lee, 2005), and India (Kale, Little, 2007).

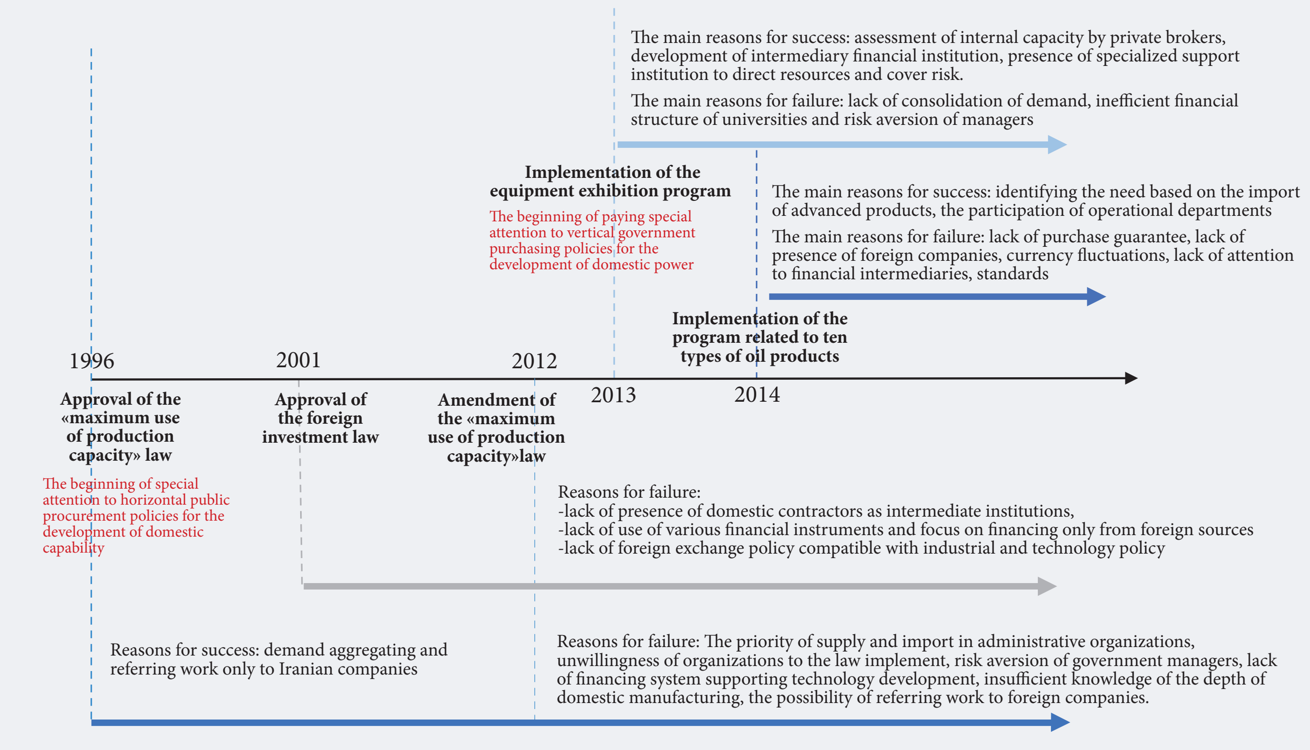
In some cases, they have specified exactly which parts of the value chain of the sector or project should be produced inside the country and with the use of human resources and the participation of local companies. In Iran, despite the absorption capacity and appropriate technical and engineering capability, this type of planning has not yet found its proper place, and the regulatory system does not have enough dynamics and knowledge to promote the technological capabilities of the country.

Based on the analysis of the findings, the characteristics of a public procurement program that supports innovation can be summarized in the following cases.

Case 1. Formulation of Demand Based on Priorities in Different Sectors

One of the most important dimensions related to the formulation of demand is identifying the needs and priorities of the sectoral organizations and focusing on meeting them by using government rationality. As seen in the experience of the domestic manufacturing equipment exhibition, one of the weaknesses of this program was the lack of purchasing priority at universities, which has led to scattered purchases (a lack of consolidation of demand) and will impede the effectiveness of the government's resource allocation. Another benefit of identifying priorities is identifying areas with high added value in large projects, which will increase the bargaining power of internal parties and their political intelligence. In addition to this, the detection of technological needs based on the amount of imports has also been considered in the project for 10 types of petroleum products, which, while devel-

Figure 1. **Historical evolution of the implementation of horizontal and vertical public procurement policies supporting innovation**



Source: authors.

oping technological capability and domestic production, has reduced the dependence of the country in areas with high added value and can even create export markets.

Case 2. Identifying, Evaluating, and Improving Internal Capability, a Basis for Upgrading Internal Capability

One of the most important challenges after supply has been the clarification of internal capacity in the field of equipment production. If this issue is addressed in all industrial fields of the country, it will face many complications. This is the reason why the self-expression mechanism was used in the maximum law, but such an approach was not efficient.

This challenge becomes more important where less control and supervision is applied. Meanwhile, in some advanced industries and high-tech areas, simply putting together parts and assembling work is considered a serious technical and engineering ability. However, identifying the depth of internal construction by separating the levels of technology complexity is both costly and a specialized field required for the implementation of the maximum law that should be developed in the country.

In addition to transparency and predictability, the aggregation of demand on the market of the public sector is a very important policy tool in promoting domestic technological and innovative capabilities. Many international experiences, especially in the field of innovation, even in European countries, have shown the special importance of this policy in promoting domestic capabilities. In general, the statistics of internal technical, engineering, and technological capabilities and the creation of an atlas of national capabilities (a database of companies with internal competences) by the economic sectors of the country, including the following items, can be helpful:

- Government and public sector participation with private technology and knowledge-based companies should be on the agenda;
- Assessing the technological, engineering, and knowledge capabilities of domestic companies and preparing a complete list of domestic capabilities;
- Supporting the creation and development of a network of specialized companies for evaluating the capabilities of private technology;
- Preparation of a list of competent domestic companies by sector and related sub-sectors.

Case 3. Intermediary Institutions (Management of Exchange Rate Costs) Are the Main Players in Coordinating Supply and Demand

Actions such as the following should be included 0n the agenda:

Table 1. Strengths and weaknesses of horizontal and vertical policies to promote government public procurement with the aim of developing the market for innovative products

a) Demand transparency

	Horizontal Type of Policy
Strengths	• Attention to the demand side with the requirement of identifying the policy target markets
Weaknesses	• Lack of awareness of the components of the value chain • Low attractiveness of projects for assimilating foreign resources and low exchange rates of projects • Contradiction between regulatory regulations, especially in the field of supporting domestic manufacturing and attracting foreign direct investment
	Vertical Type of Policy
Strengths	• Using the mechanism and market model against technology (obligation to transfer technology from abroad by the winning companies in the tender) • Direction of government subsidies toward domestic purchases • Development of a leasing mechanism for buyers from the non-governmental sector • Better possibility of analyzing the value chain of production development, determining strategic items and required equipment
Weaknesses	• Lack of proper prioritization and lack of clear purchasing priorities at government agencies • Willingness to buy foreign products • Lack of financial resources and lack of diversity in innovative financial instruments • Lack of special support for non-government buyers • Precedence of foreign exchange and meeting the need for innovation and technology development • Not paying attention to the duration of support for domestic companies and distorting the competition factor

b) Recognizing, Evaluating, and Developing Internal Capabilities

	Horizontal Type of Policy
Strengths	• Creating databases of internal capabilities • Compilation of regulations and instructions to identify qualified companies
Weaknesses	• Lack of sufficient recognition of internal capabilities in the field of general contractors and qualified suppliers • Failure to pay attention to second category referrals • Referral of work with low added value to domestic companies • Low power of engineering and project control management departments at domestic companies • Lack of attention to knowledge management in large projects of the country
	Vertical Type of Policy
Strengths	• Development of quantitative and qualitative evaluation system of domestic companies • High variety of domestically made equipment in specialized fields • Obligation to provide after-sales service and proper warranty for products • Preparation of a quality assessment model and technical capability
Weaknesses	• Weakness in marketing and dependence on seasonal exhibitions • Lack of formation of innovative cooperation networks between active companies in the same field • Uncertainty of order amount • Lack of company rating and accreditation • Failure to identify the depth of technology in order to distinguish capable domestic producers from importers and assemblers

c) Intermediate Institutions

	Horizontal Type of Policy
Strengths	• Considering insurance and investment guarantee of public and private contractors • Paying attention to social security insurance contracts • Paying attention to the improvement of the standard system and the development of product conformity certificates • Providing incentives and effective tax exemptions
Weaknesses	• Absence of internal binding financing system and letter of credit (LC) system in Rial (Iranian currency) and foreign currency • Not fully understanding the requirements related to cross-selling financing and finance • Lack of support from the domestic financing system for issuing technical and engineering services and winning domestic contractors and builders in international tenders. • Lack of appropriate tariff system to support domestic products and technologies • Lack of attention to the empowerment of domestic companies
	Vertical Type of Policy
Strengths	• Organizing brokers to evaluate and coordinate supply and demand • The presence of innovative financial institutions for things such as producer financial guarantee, management of government budget fluctuations, and contract regulation • Requirement to compile a road map for the development of technology and innovation as a commitment of tender winners
Weaknesses	• Low interaction between buyer and seller in order to performance improvement and equipment quality • Financial and information gap between companies and government buyers • Absence of advance payment mechanism and need-based purchase guarantee

Table 1 continued

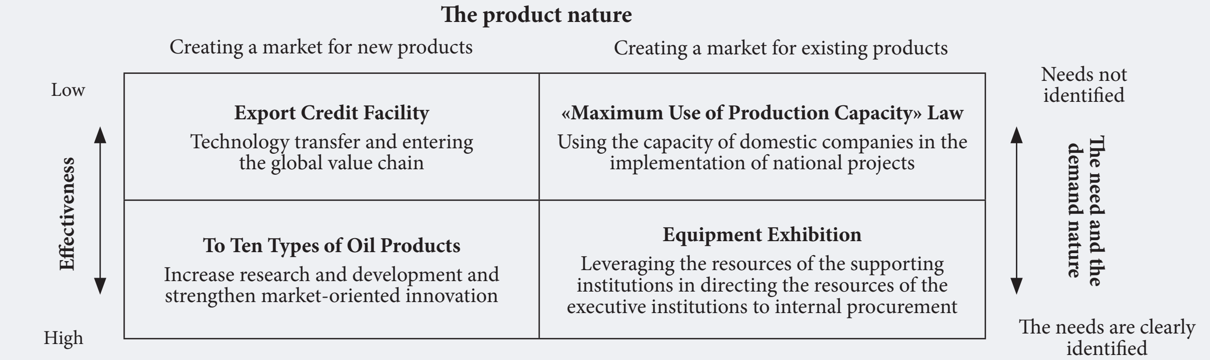
d) Governance Structure

Horizontal Type of Policy	
Strengths	• Explaining the mechanism of monitoring the good implementation of programs
Weaknesses	• The focus of the executive bodies on the provision and absence of a regulatory system for the development of domestic production capacity • Low risk tolerance of the highest executive authority of devices to support domestic production • Weakness of government employers in project design and lack of specialized ability to supervise and manage projects • Lack of actual calculation of foreign finance costs by executive bodies
Vertical Type of Policy	
Strengths	• Improving internalization and technological level of products by creating a leveling mechanism for domestically manufactured technological products • The role of the intermediary specialized policy agency in providing subsidized resources, implementing and reducing the risk of vertical programs • Horizontal and vertical coordination between different departments of the queue and headquarters of the buyer organization
Weaknesses	• Low attention to guaranteed purchase against gratuitous aid (market creation) • Lack of attention to the production of export-oriented products • Low management of collusion and dealing with corruption

Table 2. **Effectiveness Requirements for the Analyzed Government Programs**

Category	Description
Export Credit Facility	
Demand	Prioritizing domestic supply and specific work division between domestic and foreign companies
Supply	Identifying capable domestic companies and requiring them to be used in international projects
Intermediary institutions	Promotion of internal tied financing and development of internal contractor as an intermediary entity
Governance	Reducing the cost of using unsecured commercial loans
«Maximum Use of Production Capacity» Law	
Demand	Transparency and consolidation of demand and referral of work to Iranian contractor companies
Supply	Identification of Iranian general contractors, determining the value of work for the internal party in each project in points with high added value
Intermediary institutions	Development of domestic tied financing
Governance	Improvement of sector regulatory system
To Ten Types of Oil Products	
Demand	Recognition of sensitive points with high valuation based on value chain analysis
Supply	Identification of the indigenous chain and the requirement to formulate a technology development plan with a focus on technology transfer from abroad
Intermediary institutions	Specialization of the tender process using technological capability criteria
Governance	The presence of support institutions and main purchasing companies
Equipment Exhibition	
Demand	Specifying the purchase priority and aggregating universities' budgets for purchase
Supply	Evaluation and ranking of companies and allocation of subsidies according to the depth of domestic manufacturing capability
Intermediary institutions	Creation of specialized intermediary financial institution, organizing sales brokers and management of exchange costs
Governance	Promoting the role of development and support institutions
Source: authors.	

Figure 2. **Classification framework of public procurement policies of the government and their purposes**



Source: authors.

- Development of specialized financial institutions, especially to reduce the risk of contracts between buyers and sellers
- Development of standard and guarantee tools
- Developing a binding financing system for large domestic projects with the aim of requiring general contractors to buy from domestic companies
- Specializing the process of holding tenders, especially in the area of quality evaluation of bidders and abandoning tender procedures for the first production of required products.
- Development of complementary programs such as guaranteed purchase or pre-purchase programs for products that are manufactured for the first time in the country.

Case 4. Improving the Governance System to Develop Sectoral Innovations

One of the important requirements for the implementation of the innovation government demand policy is to change the organizational strategies, especially those governing the interaction between the relevant sectoral agencies and the ministries in charge of innovation, which requires the existence of an implementation roadmap with clear and transparent goals. There are working groups made up of sectoral agencies and ministries in charge of innovation and governance (Edler, Georghiou, 2007). In the experience of the "Made in Iran" exhibition, two ministries related to higher education and health played an effective role, both as ministries in charge of technological development in the country and as sector agencies in the form of buyers of laboratory equipment and materials.

The cooperation and coordination of the aforementioned institutions, which in recent years have had mission differences due to some parallel work, have been critical for the continuity and stability of the implementation of this policy. The synchronization of government agencies and the effective division of labor between sector and innovation institutions is an important requirement for the stability and expansion of policies to stimulate government demand for technology and innovation.

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Appendix 1. **Horizontal and Vertical Policies for Using Public Procurement in the Development of Production Capacity and Innovation**

Policy	Selection Reasons	Data Collection Method
Horizontal Policy Type		
The law of maximum use of internal capability (1996)	The implementation of the law in 1996 and the existence of a trustee organization	A semi-structured in-depth interview with nine experts involved in the implementation of this law in three areas: 1- governance and policymaking, 2- executives and general contractors, and 3- associations. (Overall 445 minutes)
Foreign finance rules (2001)	Implementation of the law on encouraging and supporting foreign investment and contracts approved by the Economic Council	A semi-structured in-depth interview with 22 related experts in the executive branch (Overall 836 minutes)
Vertical Policy Type		
10 types of oil products (2015)	High focus on meeting the needs of a specific sector in the field of high-tech products	A semi-structured in-depth interview with nine participating experts from the scientific and technological fields including a vice president, research and technology funds and private companies (Overall 562 minutes)
Exhibition of laboratory equipment and materials (2012)	Directing government resources into financing models to create markets for technology-based companies in a specific area	Examining executive processes as well as semi-structured in-depth interviews with five experts from key stakeholders at the Ministry of Petroleum (Overall 236 minutes)

Appendix 2. Classification of Categories Extracted from the Interviews and the Text of the Law Approved in 2018

Forming Demand

- Policy targeting markets and policy inclusion
- Demand transparency
- Future demand forecasting
- Referral of work on a conditional basis and against the requirement to improve technical capacity and export
- Estimating market size and planning to identify and meet requirements (demand)
- Value of work done internally

Evaluation, Recognition, and Promotion of Internal Capabilities (Supply)

- Identifying qualified contractors and obtaining loans for them from the National Development Fund if they win domestic and international tenders.
- Identification of 10 to 15 important and qualified contractors for second category referral
- Strengthening engineering departments and project control management at domestic companies
- Create and develop GCs and MCs to take over projects
- Regulation of competence recognition and job referral
- The value of the work of the internal party in areas with higher added value

Intermediate Institutions

- Financing (letter of credit (LC) in Rial (Iranian currency) and foreign currency
- Fully understanding the requirements related to cross-selling financing
- Allocation of loans in case of providing technical and engineering services and winning domestic contractors and builders in international tenders
- Insurance and investment guarantee of public and private contractors
- Tax relief and exemption, avoiding tax risks
- Development of product conformity certificates
- Social security insurance in contracts
- Strengthen innovation and research and development
- Preventing the import of products that exist inside the country
- Empowering domestic companies

Governancce

- Sector regulation system for the development of internal capbilities
- Knowing the value chain of the project and specifying the important points that should include foreign-Iranian partnerships
- Unwillingness of the authorities to implement the law
- Risk aversion of the highest executive authority of law enforcement agencies
- Absence of a mechanism to monitor the good implementation of law
- Non-punishment of those who disobey the law

Appendix 3. Summary of the Opinions Expressed in the Interviews about Export Credit Facilities

Forming Demand

- Inability of most of the projects to cover their costs and earn foreign currency for the country
- There is a gap between the amount announced by the Economic Development and Cooperation Organization as the creditor country's share (85% of the project credit) and the amount specified by the country's laws (51% of the minimum share of the Iranian side).
- Not forming a transparent division of labor between domestic and foreign companies in international division of labor (Experience of entrusting minor tasks to local activists in large contracts)

Evaluation, Recognition, and Promotion of Internal Capabilities (Supply)

- The need to increase the quality and quantity of general contractors and developer companies
- Lack of involvement of Iranian contractor companies in relation to the country's expertise and technical ability and referring work in the later stages of the project to outside companies
- Lack of attention to knowledge management in large projects of the country
- The need for support from qualified contractors to obtain facilities (providing guarantees, etc.)
- Failure of the policy requiring the transfer of technical knowledge in contracts and large foreign investments in the country
- Emphasis on the the percentage of construction within the project instead of the quality of work referral to achieve the goals of improving internal capacity at the project and department level.
- Non-recognition of domestic capacity building in national projects

Intermediate Institutions

- Necessity of financing engineering and using new methods in project financing
- The need to expand the financing of domestic production (letter of credit (LC) system in Rial (Iranian currency) and foreign currency)
- Recognizing requirements related to cross-selling financing and finance
- The impossibility of using export credit facilities for domestic purchases
- The need to develop a specialized financing system to support the promotion of technological capability with international standards
- The need for domestic contractors as intermediary institutions in export credit facility projects

Governance

- Weakness of government employers in project design and a lack of specialized ability to supervise and manage projects
- Non-compliance of the legal structure and governance of contractors with international financial laws
- Lack of real calculation of foreign finance cost by public administrators (insurance cost, currency fluctuations, etc.) and a lack of a short-term vision of executives to overcome current challenges
- International non-binding commercial loans are more expensive
- The unwillingness of the government to accept the risk of the domestic private sector
- Lack of concern for the technology development from the managers of government agencies
- Knowing the value chain of the project and specifying the important points that should be considered for external-internal participation
- Conclusion of formal contracts with Iranian companies by foreign parties in order to not comply with the 51% limit

Appendix 4. **Summary of the Interviews in about the Made in Iran Exhibition**

Forming Demand

- Uncertainty of purchasing priorities of universities
- Willingness to buy foreign products
- Diversity in purchasing officials
- Financial challenges faced by universities in equipment purchasing
- The difference in support between different levels of technology
- Non-allocation of subsidies based on the universities' needs
- Lack of special support for non-government buyers
- The length of the decision process and the degree of realization of pre-factors
- Spreading the budget out at universities and buying non-priority items

Evaluation, Recognition and Promotion of internal capabilities (supply)

- High variety of provided equipment
- Weak marketing and dependence on exhibitions
- Ratio of quality to the price of products
- Creating the opportunity to cooperate with other companies in order to promote the value chain
- Failure to provide after-sales service and proper warranty for products
- Uncertainty in the amount of sales
- Ranking of companies and accreditation
- Expanding the market and gathering demand and creating economies of scale
- Depositing the guarantee and deducting the collateral

Intermediate Institutions

- Innovation in regulating brokerage contracts
- Creation and structuring of sales agents
- Clarify the evaluation process
- Regulation of the contract to reduce the financial costs of companies
- Amendment of contracts during the initial process
- Dispute resolution and jurisdiction of financial, legal, technical, and executive disputes
- Buyer and seller interactions to improve the performance and quality of equipment
- Producer's financial guarantee and management of government budget fluctuations
- Financial and information gap between companies and universities

Governance

- Guaranteed purchase against free aid (market creation)
- Improving internalization and technological level of products by creating a classification mechanism
- Moving toward the development of product exports
- The need to support the leasing plan for the purchase of non-government sectors
- Subsidy distribution based on cooperative purchases
- Management of collusion and dealing with corruption
- Coordination of the Ministry of Science, Research and Technology as the agency in charge of buyers
- The role of the scientific and technological vice president in providing subsidized resources and implementation
- Executive-expert capability of the Nano Technology Development Council

Appendix 5. **Summary of the Interviews about the "Made in Iran" exhibition (Narimani et al., 2018)**

Forming Demand

- Estimated market size is about 80 trillion Rial (Iranian currency) (about 200 million dollars).
- Import analysis and identification of priorities with the aim of localizing more than 80% of strategic goods and equipment needed in the oil industry
- Analysis of the value chain of production development, determining the main items and sub-items of the required equipment (526 main items and 73,850 sub-items)
- Using the market model against technology (obligation to transfer technology from abroad by winning companies)
- Focus on the parts industry as a basic industry

Evaluation, Recognition, and Promotion of Internal Capabilities (Supply)

- Preparation of long and short list of oil industry suppliers
- Evaluation and identification of the manufacturers present on the short list
- Consolidation and integration of a vendor list
- Paying attention to the technology dimension in the quality evaluation indicators of bidders
- Preparation of evaluation model for qualitative qualification and technological capability
- The greater importance of manufacturing capability in evaluating the technical score of companies (focusing on the development of technological capability at companies that have created at least basic capabilities)
- Specializing in determining the technical score of companies based on the technology level of selected items
- Identification of a capable and indigenous chain and a commitment to increase the level of manufacturing readiness, technological readiness, and general company readiness

Intermediate Institutions

- Specialization of tender processes with the aim of developing technology (technological tendering)
- Facilitating the terms of contracts (text, amount, method of payment, conditions, preferences and guarantees)
- Using the capacity of supporting institutions to provide knowledge-based economy (Innovation and Prosperity Fund)
- Qualitative evaluation of bidders
- Requirement to create a road map for technology development (improvement of internal manufacturing)

Governance

- Forming a joint working group between the stakeholders of the Ministry of Oil and the main purchasing companies
- The presence of representatives of operating companies affiliated with the Ministry of Oil
- Creating specialized working groups for each group of goods and participation in selecting companies and evaluating activities
- Making the payment contingent upon the achievement of the road map goals

Conceptualizing a Seamless Model of Technology Transfer: Evidence from Public Research Institutes and Universities in Indonesia

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Abstract

Technology transfer (TT) is essential in transforming and mobilizing technological knowledge from public research institutes (PRIs) and universities into innovations. The concept of TT has become the center of scholarly attention since implementing the Bayh-Dole Act in 1980. In its progression, TT models and practices varied across organizations. The standard adopted model at Indonesian PRIs and universities is the dissemination model. This classic model is problematic yet suitable for technological knowledge production within these organizations. Consequently, TT performance could be better; only a few technologies were successfully commercialized and became innovations. Meanwhile, most research results ended as publications and new intellectual properties. Therefore, a new model needs to enhance the TT processes. This study uses a multiple-case study approach to conceptualize a "seamless" technology transfer model. This model provides a holistic view of processes and components of technology transfer in the dimensions of knowledge creation, diffusion, and absorption, which are intertwined. The model differs from the existing concept that segregates components in each dimension; it allows actors and determinants to be involved (or utilized) in multiple dimensions to cater to a better TT process.

Keywords: research and development; technology transfer; public research institutes; technology transfer; universities; seamless model of technology transfer

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Introduction

Technology transfer (TT) is a peculiar phenomenon among countries, organizations, and individuals. It has drawn scholarly attention since the realization of the Bayh-Dole Act in 1980. At that time, the US government was concerned about the low utilization rate of their patents; among 28,000 patents, less than 5% were licensed to industries (USGAO, 1998). This act became the foundation of funded technology commercialization by universities, not-for-profits, and small businesses. The TT concept evolved into broad discourses in its progression, and scholars agreed that it could substantially benefit nations and organizations (Mansfield, 1975; Mayer, Blaas, 2002; Ramanathan, 2011). Through TT, research institutions can increase economic innovation and productivity, create jobs, and help overcome social problems (Zuniga, Correa, 2013). TT processes push R&D results into industrial innovation and create more value in society (Cohen et al., 2002).

Furthermore, various TT models have been produced over time, yet need more consensus on ideal implementation. The notable models are the Bar-Zakay model (Bar-Zakay, 1970; Ramanathan, 2011; Wahab et al., 2009) model, (2) "the appropriability model" (Devine et al., 1987; Gibson, Smilor, 1991), (3) "the dissemination model" (Rogers, Kincaid, 1981), (4) the "knowledge utilization model," (5) the (Gibson, Smilor, 1991) model, (6) the "contingent model" (Bozeman, 2000; Bozeman et al., 2014), and (7) the "interactive-recursive model" (Eckl, 2012). However, empirical evidence on implementing these models is still being determined.

Furthermore, the TT process focuses on commercializing R&D results from the academic staff and students in the university context. The process encompasses two paths, (1) dropping the discovery off at the technology transfer office (TTO) for acquiring licenses and (2) embarking on the entrepreneurial journey with a spin-off company (Nilsson et al., 2010). Meanwhile, in PRIs, licensing the technology through TTO became the most popular strategy to push the R&D results into innovation (Buenstorf, Geissler, 2012). Although the commercialization options between PRIs and universities differ, both entities have a similar pattern in the TT generic process.

As TT literature evolved, it became rich in the relevant country's characteristics. The production of knowledge regarding TT flows from developed countries into developing ones. The developing countries have different settings and provide vast opportunities to be explored for TT conceptualization. As one of the developing countries in Southeast Asia, Indonesia has some peculiar traits regarding TT processes at the PRIs and universities. Contemporarily, Indonesian PRIs and universities faced the same problem as the US in the 1980s, as most produced patents could not be commercialized. For example, among the 1,226 patents registered with the Indonesian Institute of Sciences (we now call National Research and Innovation Agency - BRIN), less than 2% have been commercialized (until the end of 2021). The most common technology transfer model these organizations adopt is the dissemination model. However, the application involves prominent actors such as the technology transfer office (TTO) and science-techno park (STP). This model relies on the supply push transfer direction, where the technology producer starts the transfer process to push the technology toward the market (Lane, 1999). This classic model needs to be revised as it makes PRIs underperforming in terms of commercialization (Choe, Ji, 2019). It is suitable for the nature of technology production of Indonesian PRIs and universities. Hence, there is an urgent need to renew the current model while adjusting to the nature of existing innovation processes.

Further, Indonesia has enacted Law No. 11 of 2019 concerning the National System of Science and Technology[1]. This law renews the structure of government science and technology-related agencies and integrates several PRIs into a single super body (BRIN). It also regulates the technology transfer process, yet it does less comprehensively. Thus, deficiencies need to be addressed by developing a model and mechanism of technology transfer and this study intends to investigate several models of technology transfer implementation at PRIs.

The Seamless TT model, when connected with many processes in Indonesia today, is one of the references that is based on the processes carried out at each PRI and university. The TT process's essence is based on research and development results. If the Seamless TT model is used, it will be an effective formulation as it considers several descriptions of each process, all of which are needed and interconnected. Generally, the processes carried out at PRIs and universities have various characteristics and factors, each part of an integrated and interdependent process in Indonesia. These TT practices have been repeatedly tested by referring to the characteristics and patterns of the sequence of processes adapted to the implementation in each place, no matter the principles. On the other hand, the TT Seamless model process has been adjusted to the conditions of technology empowerment, human resources, research and development products, product and technology users, and applicable policies and regulations so that the application of this model takes into account the conditions and situation in Indonesia and considers existing market needs.

Literature Study

Technology transfer is a process of the transmission or movement of knowledge (sometimes followed by physical infrastructure). It is intended for the use, further development, or commercialization by other parties, be it

[1] https://ap.fftc.org.tw/article/1589, accessed 17.06.2023.

between parties within the same organization, those at different organizations, or even between parties in different countries (Halili, 2020; Lavoie, Daim, 2020).

Technology transfer has six stages: "technology innovation, technology confirmation, targeting technology consumers, technology marketing, technology application, technology evaluation" (Risdon, 1992). Each stage involves several activities. For example, in technology development, activities begin with finding financial support, conducting research, discovering new technologies, protecting intellectual property, and appraising the technology. In the technology utilization stage, activities are continued with prototyping, finding counterparts, manufacturing, marketing, and others. The final stage, the return of benefits, involves distributing financial benefits (Asmoro, 2017).

Technology Production at PRIs and Universities

Public research institutes have become substantial sources of today's innovations, regardless of their numerous underutilized inventions and R&D results. Among those great inventions, only a few innovations with significant value became widely known. Commercializing these inventions is complex and difficult, as most are not market-ready products (Buenstorf, Geissler, 2012). In addition, developing commercial products from inventions and pushing them onto the marketplace is separate from scientists' regular jobs. Thus, it is common for PRIs to establish a technology licensing office (TLO) or technology transfer office (TTO) to do the job. The TTO has a dynamic relationship with the PRI and firms, acting as an intermediary between these entities (Min et al., 2020).

Conversely, professors and their students are the producers of innovations at universities. Their ideation processes are more fluid than those at PRIs. A university's commercialization path diverges into two streams, (1) outward licensing and (2) establishing spin-off companies. Public-private partnerships, open science initiatives, and entrepreneurial channels, such as student-based start-ups and related financing and mobility schemes, have complemented these paths.

Technology Transfer Model

The need to develop a technology transfer model arises from the recognition among researchers that technology transfer is naturally a complex matter (Garbuz, Topală, 2021; Necoechea-Mondragón et al., 2013). The early development of technology transfer models dates back to the end of World War II (Wahab et al., 2009). The Appropriability Model (AM) was developed from 1945 to the 1950s and stressed the quality of the research or technology and competitive market pressures to ensure the technology transfer (Gibson, Smilor, 1991).

The study of technology transfer models continued to expand along with the development of the Dissemination Model (DM) from 1960 to the 1970s, focusing on the diffusion of a technology from the experts to the willing user (Gibson, Smilor, 1991; Hamdan et al., 2018). According to Gibson and Smilor (1991), the model assumes that the technology transfer will effortlessly occur once the linkages between experts and users are established.

In 1971 another model called The Bar-Zakay Model (BZM) was introduced (Ramanathan, 2011). It describes several stages in technology transfer processes, including search, adaptation, implementation, and maintenance, which require an evaluation and joint decision between the sender and receiver to continue the transfer processes (Bar-Zakay, 1970; Steenhuis, Bruijn, 2005).

The progression continued to the late 1980s during the introduction of the Knowledge Utilization Model (KUM), which was the first to focus on the communication and mechanism of technology transfer (Gibson, Smilor, 1991; Hamdan et al., 2018). It raises two issues as the focal points in managing the technology transfer risks of communication, such as 1) the prominent role of interpersonal communication between researchers and users; and 2) the importance of identifying organizational barriers and facilitators of technology transfer (Lee, Shvetsova, 2019).

Furthermore, Gibson and Smilor's Model (GSM), introduced in 1991, presents the three-level prism to describe the technology transfer processes (Gibson, Smilor, 1991), such as the technological development process, the technology acceptance process, and technology application.

Additionally, Bozeman (2000) first proposed his Contingent Effectiveness Model (CEM) of Technology Transfer, which was further developed in 2015 by Bozeman et al. (2014). It emphasizes two important aspects, including 1) the determinants of technology transfer and 2) the criteria of technology transfer effectiveness (Arenas, González, 2018).

Finally, Eckl (2012) introduced the Interactive-Recursive Model of Knowledge Transfer (IRM), which was developed based on (Gibson, Rogers, 1994; Bozeman, 2000). This model describes knowledge transfer as a complex interactive, non-linear, and possibly recursive process consisting of three fundamental dimensions: knowledge creation; knowledge diffusion; and knowledge absorption (Eckl, 2012). Eckl (2012) structures the respective dimension with the processes, the involved actors, and the determinant factors of technology transfer.

Actors in Technology Transfers

Technology transfer is a process that includes actors from both public and private entities (Van Horne, Dutot, 2017). The interaction between and among the involved actors (Schiavone et al., 2014) and their roles (Flipse et al., 2014) will also determine the success of technology transfers. The actors in technology transfers perform their respective roles to ensure continuity in techonological implementation. Actors involved in the technology transfer process include advisory boards

(Weber, 2017), selectors (Min et al., 2020), intermediaries (Tunca, Kanat, 2019), and regulators (Alaassar et al., 2020). First, the advisory board determines the Key Performance Indicators (KPI). It provides directions that will impact the produced results. Furthermore, the advisory board is one of the important actors in forming an innovation ecosystem and technology transfer process in developing technology-based start-up companies (Weber, 2017). Policies made by the advisory board can be in the form of programs or strategies for technology development, thereby facilitating technology transfer activities (Chen et al., 2010).

Moreover, the role of the selector is to carry out the process of selecting and assessing the readiness of a technology to be developed and applied in the industrial world. This selection process is adjusted to the possibility of achieving the set targets and has to look at the technological and economic aspects. Developing a business and providing economic benefits is feasible (Min et al., 2020). The advisory board and selector actors are the main key actors in achieving the success of the TT process at R&D institutions involving PRIs and universities in Indonesia.

The third actor is the intermediary organization that can facilitate the flow of technology between the research organization or university and industry. The intermediaries are organizations active through all stages of technology transfer and mainly face the challenge of retaining partners (Van Horne, Dutot, 2017). The Technology Transfer Office's (TTO) activities often reflect its role as an intermediary organization in supporting technology transfer from technology-producing agencies to user partners. The TTO plays a vital role in forming an innovation ecosystem and is an actor that accelerates the spin-off process for new companies and the implementation of a technology. The TTO encourages incubation activities and facilitates cooperation agreements on the use of technology as a know-how development process (Tunca, Kanat, 2019).

Furthermore, the regulator is also one of the other actors with a vital role where policies are produced both from the agency and a higher (national) level. The policy made by this regulator will impact the development of the innovation ecosystem and the technology transfer process. The government acts in the policymaking and grant process stage and has to balance the needs of all parties to start the technology transfer (Van Horne, Dutot, 2017). Regulators need to see actual conditions in the field and pay attention to inputs from various parties and experts (social interaction) to determine policies supporting the development of an innovation ecosystem in Indonesia (Alaassar et al., 2020).

These four actors in the technology transfer process will create a non-linear model of innovation based on the relationships between the actors. The linkage between actors is needed so that the technology transfer process follows user needs, not only the interests of certain parties. The actors within each contribution have developed their structure and work cooperatively to facilitate technology transfer (Chen et al., 2010). Each actor does not have to contribute to the performance of other actors but only needs to carry out their duties according to their capacity and authority. The involvement of these parties will later make the innovation ecosystem work properly and be mutually sustainable to build an effective innovation system (Wonglimpiyarat, 2016).

Methodology

This study uses a multiple case study method with a comparative design based on the constructivism paradigm (Eisenhardt, 1989). The case study process includes (1) case selection based on PRIs and universities that have technology transfer offices/units, (2) data collection through in-depth interviews with managers from five PRIs and four universities that have carried out technology licensing, (3) data analysis that includes categorization, preparation of thick descriptions for each case, and the examination of patterns between cases in order to find the emerging trends and synthesize it into a new TT model, (4) validation of findings through triangulation, pattern matching (based on data saturation), and comparing with existing literature. This research uses the interactive-recursive technology transfer model developed by (Eckl, 2012) as the analytical framework. The model describes technology transfer as three related processes, including (1) knowledge creation (KC), (2) knowledge diffusion (KD), and (3) knowledge absorption (KA).

Technology Transfer (TT) in Indonesia: General Overview

TT in Indonesia refers to transferring knowledge, skills, and technology from research institutions to businesses, organizations, and the wider community for commercialization and social benefit. The Indonesian government has recognized the importance of technology transfer and has taken steps to support it.

The concept of TT in Indonesia includes various aspects such as identifying and selecting technologies with potential commercial value, protecting intellectual property rights, negotiating license agreements, providing technical assistance, and supporting commercialization efforts.

The Indonesian government has created several regulations to support technology transfer in Indonesia.[2] The government has issued guidance on patent man-

[2] Including Patent Law No. 13 of 2016 (https://www.wipo.int/wipolex/en/legislation/details/16392, accessed 17.06.2023), Trademark and Geographical Indication Law No. 20 of 2016 (https://www.wipo.int/wipolex/en/legislation/details/16513, accessed 17.06.2023) and Regulation No. 45 of 2016 (https://www.tilleke.com/print-insight/?post_id=36945, accessed 17.06.2023).

agement and trademark rights in the context of TT. In this provision, TT can only be done through a license contract between the technology owner (licensor) and the technology recipient (licensee). The license agreement must be made in writing and registered with the National Office of Intellectual Property.

This policy also stipulates the principles of remuneration in the TT process. The licensee must indemnify the licensor for the use of the technology. Compensation must be in the form of royalties or other payments, and it must be based on the value of the technology. During the know-how transfer, the licensor must transfer the know-how and provide technical support to the licensee to ensure that the technology is properly used and maintained.

Indonesia also has made various efforts to facilitate technology transfer, such as establishing technology incubators and science parks, funding research and development, and promoting partnerships between research institutes, industry, and the government. Overall, the concept of TT in Indonesia focuses on promoting innovation, increasing competitiveness, and generating economic growth through the development and commercialization of new technologies.

Technology Transfer at PRIs

KC Process

The multiple case study results at PRIs indicate two significant patterns in the knowledge creation processes (see Table 1). First, the typical internal knowledge production process derives from top-down research policy at research centers (RCs), resulting in a pool of technology that pushes into the next commercialization phase. Second is R&D collaboration, which rarely occurs due to specific conditions or incentives.

The first pattern starts with determining the research foci in each research center based on national policy. Then, research groups generate ideas based on their expertise and interest. The submitted ideas will be selected based on the quality of the idea and their relevance. Selected ideas will be executed within an annual timeline to generate knowledge in publications and intellectual properties (IP). Researchers drive these processes' key performance indicators (KPI) and funding.

The second pattern only happened in some research centers which conducted applied research and frequently had R&D collaboration. The researchers in these research centers have established a more personal relationship with their industry counterparts. Hence, the collaborative knowledge creation started with informal discussions among them. In some cases, these collaborations lead to a very successful innovation process. On the other side, such collaboration is hard to establish in research centers with basic science and a lack of experience in working with industries.

KD Process

Based on our investigation, the TTO became a standard unit that led the diffusion process at PRIs. The process starts with (1) readiness selection, (2) IP registration, (3) valuation, (4) development, (5) promotion, and ends with a signed (6) contract of license. This process often goes back and forth and can skip between TTO, research centers (or researchers), and industry counterparts. For example, in the process of readiness selection, the TTO will conduct due diligence regarding R&D results that are being 'pushed' from the research centers. They use a readiness selection framework such as technology readiness level (TRL) to assess the R&D results.

KA Process

Absorption concepts involve the actors in Academics-Business-Government (Triple Helix ABG). The absorption of knowledge and technology from existing actors depends on the success rate of the diffusion of existing knowledge and technology. The absorption level of knowledge and technology can accelerate the process of adoption, diffusion, and the achievement of collaboration in technology transfer.

In addition, this absorption rate influences the determination of the potentially applicable technologies, the potential to generate licenses and royalties or other incentives for inventors and innovators, the potential for spin-offs of the new technology-based companies, and the potential for spin-offs of the new technology-based companies' determination of the potential for sustainable collaboration. Regulatory support and competency improvement based on market needs. The process of absorption of knowledge and technology is also strongly influenced by the behavior of the involved actors (Erosa, 2012). The entire process of technology transfer in PRIs has been summarized in Table 1.

Technology Transfer at Universities

KC Process

According to a comparison of four universities' technology transfer cases, several notable results can be highlighted. The knowledge creation processes are mainly based on the lecturers' research interests in line with the university's vision. The submitted research ideas that are successfully selected could continue to the development stage. This development process usually involves lecturers and students across departments or faculties. In some cases, it also involves an industrial partner.

The involvement of partners during the knowledge creation process is relatively minimal. In some cases, it increases the success rate of the invention since the product market has been identified from the beginning. However, we found that one university (UNI-2) started initiating an Ideation Forum to explore the needs of industrial partners as guidance to formulate R&D ideas.

Similar to PRIs' cases, KPIs and funding also play a prominent role in the knowledge creation process within universities. KPIs make the inventor more focused on the invention quantity while paying less attention to quality. Meanwhile, funding availability is crucial for the sustainability of the R&D program, especially for a long-term development project.

KD Process

Similar to PRIs, the TTOs at universities also play a significant role in the diffusion process. At the beginning of the diffusion process, they are responsible for assessing the readiness of the available inventions. This process is usually also carried out together with experts in related fields. The invention with six readiness levels is prepared for the IP protection and promotion stage. The inventions that have obtained partners will continue in the contract management process.

As the processes are facilitated by the TTO, having a qualified TTO is essential for the success of the diffusion process. They should possess sufficient skills and competencies, such as marketing, negotiation, and technology valuation skills.

KA Process

The implementation of the process of absorbing knowledge and technology through formal and informal interactions, both internal and external, where the innovative research and development results have high commercial value and are attached to user needs. The absorption process through several mechanisms, such as licensing, start-ups, and joint operations, takes place as well. This process includes industries, internal business units, and start-ups. The process of technology absorption is characterized by prospective industry partners already involved upstream, from ideas to

Table 1. **Summary of Process TTs Connected to Seamless Models in PRIs**

Samples	Process	Actor	Determinant
	KC		
PRIs-1	Priority Setting, Ideation, Execution, IP Registration, Valuation, Promotion, Contract.	Inventor, Intermediary, Internal Developer, Assessor, Partner.	KPI, Funding, Readiness, IP, Market, Engagement.
PRIs-2	Priority Setting, Ideation, Selection, Pilot Development, Value Capture.	Advisory Board, Inventor, Assessor, Partner.	Policy, KPI, Readiness, Market, Engagement.
PRIs-3	Priority Setting, Ideation, Selection, Readiness Selection, Valuation, Market Discovery.	Selector, Inventor, Intermediary, Internal Developer.	KPI, Readiness, Market, Engagement.
PRIs-4	Ideation, selection, Execution, Valuation, Acquisition, Market Discovery, Value Capture.	Inventor, Intermediary, Partner.	Funding, Readiness, IP, Competence, engagement.
PRIs-5	Priority Setting, Ideation, Acquisition, Value Capture.	Advisory Board, Inventor, Intermediary, Partner.	Readiness, IP, Market, Engagement.
	KD		
PRIs-1	Ideation, Selection, Valuation, Pilot Development, Market Discovery,	Inventor, Intermediary, Partner.	Funding, Readiness, IP, Market, Engagement.
PRIs-2	IP Registration, Execution, Valuation, Co-Development.	Advisory Board, Inventor, Intermediary, Partner.	Readiness, IP, Digital Media, Market, Engagement.
PRIs-3	Selection, Execution, Readiness Selection, IP Registration, Pilot Development, Market Discovery.	Inventor, Intermediary, Internal Developer, Partner.	Readiness, IP, Digital Media, Market, Engagement.
PRIs-4	Ideation, Readiness Selection, Execution, IP Registration, Co-Development, Market Discovery.	Intermediary, Internal Developer, Partner.	Funding, Readiness, Human Resource, Market, Engagement.
PRIs-5	Execution, Readiness Selection, IP Registration, Valuation, Promotion.	Inventor, Intermediary, Partner.	Digital Media, Market, Engagement.
	KA		
PRIs-1	Ideation, Selection, Execution, Pilot Development, Market Discovery.	Inventor, Intermediary, Partner.	Readiness, Human Resource, Competence, Engagement.
PRIs-2	Execution, Readiness Selection, Acquisition, Co-Development,	Selector, Inventor, Intermediary, Internal Developer, Partner.	Market, Competence, Engagement.
PRIs-3	Execution, Readiness Selection, Promotion, Co-Development, Value Capture.	Inventor, Intermediary, Partner.	Policy, Human Resource, Competence, Engagement.
PRIs-4	Valuation, Pilot development, Contract, Acquisition.	Intermediary, Partner.	Readiness, IP, Human Resource, Market.
PRIs-5	Priority Setting, Execution, Pilot Development, Market Discovery.	Intermediary, Partner.	Readiness, Funding, IP, Market.

Source: authors.

the implementation of research. The entire technology transfer process at universities has been summarized in Table 2.

Involvement of Actors and Determining Factors

Based on the elaboration of the aforementioned cases, we identified several important actors and their involvement in every technology transfer process, as shown in Table 3. According to Table 3, each stage of the technology transfer process mostly requires involvement of multiple actors. Therefore, collaborations among these actors are essential to ensure the effectiveness of the technology transfer. Moreover, each should also be involved in several different processes, regardless of its knowledge dimensions and where the process belongs. This finding is relatively dissimilar when compared with the proposition presented by Eckl (2012) in the Interactive-Recursive Technology Transfer Model.

Our contrasting finding shows that actor A3 (inventors), the key actor in the knowledge creation dimension, should also remain involved in the diffusion and absorption processes. Similarly, actor A4 (intermediaries) plays a significant role in knowledge diffusion. Moreover, they need to be involved in processes within other dimensions, such as in the process P2 (ideation), to become partners for inventors to provide input related to technological developments and the latest market needs.

Furthermore, our study also identifies the determining factors that need to be considered in each technology transfer process, as shown in Table 4. Meanwhile, as in the process-actor relationship, the process-determinant mapping also shows findings quite different from those presented in the Interactive-Recursive Model by Eckl (2012). This study found that the determining factors can be essential in different technology transfer processes and knowledge dimensions.

Model Conceptualization

The authors propose the Seamless Technology Transfer Model, which describes the technology transfer models at R&D entities governing the achievement in technology collaboration/licensing utilized by users (stakeholders). This model focuses on the need for special attention by involving various actors in the transition process between (1) the process of knowledge creation toward knowledge diffusion, (2) the process of knowledge diffusion toward knowledge absorption, and (3) the process of knowledge absorption toward the next knowledge creation.

The 'seamless' model holistically explains where the dimensions of knowledge creation, knowledge diffusion, and knowledge absorption are closely related. First, the transition process when assessing applicability after a piece of knowledge/technology is generated requires the direct involvement of researchers, intermediaries, and assessors. That in turn requires researchers to understand field conditions better when their research results are applied by direct users, supported by intermediaries and assessors to assess the possibility/success of the technology being applied. Second, the technology acquisition process after the licensing cooperation agreement is created due to the technology diffusion process. In this transition process, it is necessary to involve inventors, intermediaries, internal developers, and industry partners. The third is the transition process for determining the priorities of subsequent research. After the technology is successfully absorbed and exploited, industry partners may have input for further research as a form of refinement or meeting other new technology needs.

Repetition can occur in every component of the process in each dimension, wherein several stages (at least two) allow for it. After the knowledge absorption process succeeds (or fails), input is generated for iteration in the priority-setting process. The process is described in a streamlined and sequential manner, but a reversal can also occur if a failure or obstacle occurs at a particular stage.

There are 14 processes, nine actors, and ten determinants depicted in this model. In contrast to the Interactive-Recursive Model (Eckl, 2012), which separates the components in each dimension, this model provides flexible constraints on the actor and determinant components. So several actors can play a role in several processes in different dimensions. Likewise, the determinant component can affect several processes in different dimensions. The seamless model of technology transfer is shown in Figure 1.

Discussion

The Comparison Between Eckl's Model and the Seamless Model for Technology Transfer

The new model was developed by translating the stages of implementing technology transfer into either knowledge creation, diffusion, or adsorption, which are adapted to field conditions from each R&D entity. The primary factors of knowledge transfer are determined by the interactions of knowledge creators, knowledge disseminators, and knowledge consumers. Key stakeholder groups in each dimension are critical for the success or failure of knowledge transfer. The outputs or outcomes of their actions in each dimension produce the determinants of knowledge transfer, which center attention on the analysis of the transfer process.

The interpretation of the recursive interactive technology transfer model includes the transformation of the three basic dimensions of knowledge transfer to reveal the related characteristics of the knowledge transfer process. Moreover, it should not be considered a uni-

Table 2. **Summary of Process TT Connected to Seamless Models in Universities**

Samples	Process	Actor	Determinant
KC			
UNI-1	Ideation, Selection, Execution.	Inventor, Intermediary, Internal Developer, Assessor, Partner.	Market, Funding, IP, Engagement.
UNI-2	Ideation, Selection, Execution, Readiness Selection, Valuation, Market Discovery,	Advisory Board, Inventor, Intermediary, Partner.	Policy, Readiness, IP, Market, Engagement.
UNI-3	Priority Setting, Ideation, Execution, Market Discovery.	Advisory Board, Inventor, Intermediary, Partner.	KPI, Funding, Readiness, IP, Market, Engagement.
UNI-4	Ideation, Selection, Execution, Valuation, Promotion.	Advisory Board, Selector, Inventor, Intermediary, Internal Developer, Partner.	KPI, Funding, IP, Market, Competence.
KD			
UNI-1	Readiness selection, IP Registration, Valuation, Pilot Development, Promotion, Contract, Acquisition.	Advisory Board, Selector, Inventor, Intermediary, Assessor, Partner.	Readiness, Human Resource, Market, Competence, Engagement.
UNI-2	Ideation, Execution, IP Registration, Pilot Development, Contract, Acquisition.	Selector, Inventor, Intermediary, Internal Developer, Partner.	KPI, Funding, Readiness, IP, Market, Engagement.
UNI-3	Ideation, Selection, Execution, IP Registration, Contract, Acquisition.	Advisory Board, Selector, Inventor, Intermediary, Assessor, Partner	KPI, Funding, Readiness, IP, Market, Competence, Engagement.
UNI-4	Ideation, Selection, Readiness Selection, IP Registration, Valuation, Promotion, Contract	Advisory Board, Selector, Inventor, Intermediary, Co-developer.	Policy, Funding, Readiness, IP, Market, Competence, Engagement.
KA			
UNI-1	Execution, Readiness Selection, IP Registration, Valuation, Contract, Acquisition.	Inventor, Intermediary, Internal Developer, Assessor, Partner.	Readiness, IP, Market, Engagement
UNI-2	Ideation, Execution, Pilot Development, Acquisition, Value Capture.	Inventor, Intermediary, Internal Developer, Partner.	Funding, Readiness, IP, Market, Competence, Engagement.
UNI-3	Priority Setting, Ideation, Execution, IP Registration, Valuation, Contract, Acquisition.	Inventor, Intermediary, Internal Developer, Assessor, Partner, Co-developer.	Policy, KPI, Funding, Readiness, Human Resource, Market, Engagement.
UNI-4	Priority Setting, Ideation, Selection, Execution, Value Capture.	Inventor, Intermediary, Internal Developer, Partner, Co-developer.	Policy, Funding, Readiness, Human Resource, Market, Engagement.

Source: authors.

directional sequence but should be understood non-linearly and recursively since it has no real beginning or end. It does not begin with knowledge generation or end with its use. It is not be equivalent to a linear motion, as had been prevalent for a long time (Wahab et al., 2009).

From the synthesis and interpretation of the data obtained, several stages can be used as derivative elements of the model proposed by Eckl (2012). Furthermore, it is a new concept generated from field findings by looking in a structured manner at what factors can affect the governance model of technology transfer at R&D entities in Indonesia and used as a reference in the management of technology transfer, especially in Indonesia.

The evolution of this derivative model from Eckl (2012) is a new model that illustrates the stages of technology transfer implementation by looking at the elements of Knowledge Creation, Knowledge Diffusion, and Knowledge Adsorption adapted to the field conditions of each R&D entity. It presents the formation of three fundamental dimensions and has the advantage of combining the benefits of a the now obsolete linear model with the epistemological requirements of a recursive model by describing the process of knowledge transfer without linear biases. The interactions of knowledge creators, knowledge spreaders, and knowledge consumers determine the primary factors of knowledge transfer. The output or outcome of their actions in each dimension determines the factor of knowledge transfer that is at the center of attention in the analysis of the transfer process. For the success or failure of knowledge transfer, a key stakeholder group in each dimension is essential.

The "seamless" model holistically describes where knowledge creation, diffusion, and absorption are closely related. It has several similarities and differences from the model upon which it is based. The seamless model focuses on the need for special attention on the involvement of various actors in the transition process between (1) the process of knowledge creation to the diffusion of knowledge, (2) the process of diffusion toward absorption, and (3) the process of absorption toward creation. Processes can be described in a streamlined manner and sequentially, but there can also be reversals in the event of failure or resistance at some stage. In contrast to the Interactive-Recursive Model, this model removes barriers between dimensions so that actors can have several roles in creating, diffusing, and absorbing knowledge.

Table 3. **Actor's Involvement in Technology Transfer Processes**

Process	Participant								
	A1	A2	A3	A4	A5	A6	A7	A8	A9
P1	√		√						√
P2			√	√			√		
P3		√							
P4			√				√		
P5				√		√			
P6			√	√					
P7				√		√			
P8			√	√	√		√		
P9			√	√					
P10				√			√		
P11			√	√			√		
P12			√	√				√	
P13				√			√		√
P14				√		√			

Source: authors.

Note:

Process

P1 – Priority setting
P2 – Ideation
P3 – Selection
P4 – Execution (collaboration)
P5 – Readiness selection
P6 – IP registration
P7 – Valuation
P8 – Pilot development
P9 – Promotion
P10 – Contract
P11 – Acquisition
P12 – Co-development
P13 – Market discovery
P14 – Value Capture

Participant

A1 – Advisory Board
A2 – Selector
A3 – Inventor
A4 – Intermediarist
A5 – Internal developer
A6 – Assessor
A7 – Partner
A8 – Co-developer
A9 – Regulator

Table 4. **Determinant Factors of Technology Transfer Processes**

Process	Determinant									
	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
P1	√	√	√							
P2		√	√							
P3		√	√							
P4		√	√	√	√		√		√	
P5				√	√	√		√	√	
P6					√		√			
P7				√	√	√	√		√	
P8		√	√	√	√		√		√	
P9			√	√	√	√	√		√	
P10				√	√					√
P11			√		√		√		√	
P12		√	√		√		√	√	√	√
P13	√					√	√	√	√	√
P14	√							√		√

Source: authors.

Note:

Determinant

D1 – Policy
D2 – Key Performance Indicators (KPI)
D3 – Funding
D4 – Readiness
D5 – Intellectual Property (IP)
D6 – Digital media
D7 – Human resource
D8 – Market
D9 – Competence
D10 – Engagement

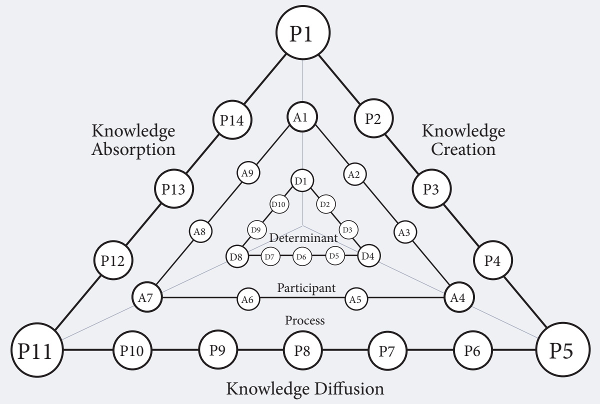
The Comparison between the Seamless Model and Other Models in Technology Transfers

This section compares the seamless technology transfer model with several previous models, mechanisms, processes, actors, and determinants. The technological context in our proposed model corresponds to the idea that technology transfer does not only manifest the physical artifacts of technology as described in most traditional models such as AM, DM, and KUM. However, it also incorporates the movement of know-how and technical knowledge from one organization to another, as in Bozeman (2000) and endorsed by Eckl (2012).

Several possible transfer mechanisms have been revealed in various studies, which Arenas and Gonzalez (2018) have summarized into two categories, i.e., formal and informal. In line with (Arenas, González, 2018; Mendoza, Sanchez, 2018), this research accentuates the formal mechanisms, especially license agreements through which patents or prototypes and joint ventures are created. We do not consider informal mechanisms such as talent recruitment, paper presentations, and informal discussions as do (Arenas, Gonzalez, 2018) in our model. However, such activities might occur across PRIs and universities. Furthermore, according to the Indonesian context, the formal mechanisms still require considerable interventions to yield significant impacts in encouraging national economic development.

Furthermore, the seamless model strives to more clearly illustrate the complex processes within technology transfers compared to the previous traditional models. The traditional models express the technology transfer process as linear, easily understandable, and effortlessly applicable, regardless of the current situation (Bustamante et al., 2021). For example, the AM only emphasizes the need to develop high-quality technology and ensure that the technology transfer will occur spontaneously. Technology transfers can be conducted without deliberate attempts within AM since the suitable technologies sell themselves (Gibson, Smilor, 1991; Hamdan et al., 2018; Wahab et al., 2009). The same is true for DM and KUM. According to Gibson, Smilor (1991), DM and KUM consider technology transfers to be merely simple, unidirectional, and unilateral technology movements from experts to users. There are a series of essential processes to deter-

Figure 1. **Knowledge Creation, Diffusion, and Absorption Process in Seamless Technology Transfer Model**



Note:

Process	Participant	Determinant
P1 – Priority setting	A1 – Advisory Board	D1 – Policy
P2 – Ideation	A2 – Selector	D2 – Key Performance Indicators (KPI)
P3 – Selection	A3 – Inventor	D3 – Funding
P4 – Execution (collaboration)	A4 – Intermediarist	D4 – Readiness
P5 – Readiness selection	A5 – Internal developer	D5 – Intellectual Property (IP)
P6 – IP registration	A6 – Assessor	D6 – Digital media
P7 – Valuation	A7 – Partner	D7 – Human resource
P8 – Pilot development	A8 – Co-developer	D8 – Market
P9 – Promotion	A9 – Regulator	D9 – Competence
P10 – Contract		D10 – Engagement
P11 – Acquisition		
P12 – Co-development		
P13 – Market discovery		
P14 – Value Capture		

Source: Author's Interpretation of the Seamless Model for Technology Transfer.

mine the R&D focus according to the user and market needs, protect and promote well-developed technologies, and maintain good relationships with potential users. Therefore, the seamless model attempts to describe the dimensions of KC, KD, and KA in several detailed stages, starting from priority setting activities and encompassing end consumption.

Unlike most traditional models (e.g., AM, DM, and KUM) and BZM, which suggest two key actors (i.e., transferor and transferee), we enrich our model by involving several important actors. We aim to adapt to the complex processes of technology transfer where many stakeholders are involved and are responsible for determining its success.

Furthermore, as their communications are established, the two above actors play a relatively passive role in technology transfers. Even though DM suggests the importance of link between transferors and transferees, this relationship is quite unilateral and lacks user involvement in technological development. AM even puts forward the passive role of the transferors who only need to publish their research results through passive media such as research articles (Gibson, Smilor, 1991). The BZM concept seems different in that the interactions between the two actors already exist. Ramanathan (2011) stated that they should be involved in the collaborative decision process at every stage of the technology transfer.

Meanwhile, the seamless model refers to these actors as inventors and partners. They contrast with the actors described in AM and DM, while in line with BZM, our model suggests that inventors and partners, along with other actors, play an active role as they can be involved and responsible for accomplishing the same stage within the technology transfer process. In addition, the term 'partners' refers to the fact that they are not solely involved in the downstream as the recipients of R&D results but are supposed to be involved in the initial project and the research funding collaboration.

Moreover, several studies have mentioned the need for complementary actors in technology transfer, such as TTOs and policymakers (Arenas, González, 2018). We postulate the role of intermediaries, which have similar responsibilities as a TTO. As for the policymakers, we describe them as the advisory boards responsible impacting the business environment and playing a role at the national level.

Our model also proposes several determining factors for a successful technology transfer. That is in line with the concept of KUM, which was the first model attempting to understand the factors and sub-factors that influence the technology transfer process (Hamdan et al., 2018). Another model, as the CEM, highlights these environmental factors, which Bozeman (2000) refers to as the effectiveness criteria.

Conclusion

Technology plays a significant role in supporting national economic growth. Technology transfers began to impact the performance and productivity of the industrial sector as the commercialization of innovation began to meet market needs. The role of technology transfer in supporting product commercialization depends on sectors that have strategic value derived from equipment, skills, knowledge, processes, and practices. By encouraging technology transfers, national strategies can be reinforced and relationships between key actors and consumers can be developed.

The "Seamless" Technology Transfer Model describes a governance model within R&D. It holistically illustrates how the dimensions of knowledge creation, knowledge diffusion, and knowledge absorption are closely related. This model focuses on the need for particular attention to the involvement of various actors in the transitions between:

1. Knowledge creation moving toward diffusion,
2. Knowledge diffusion toward absorption
3. The move from knowledge absorption toward the creation of new knowledge.

Unlike the Interactive-Recursive Model, this model eliminates the barrier between dimensions so that actors can play several roles in creating, diffusing, and absorbing knowledge. Some key actors (inventors, intermediaries, and industry partners) can be involved in several processes in all three dimensions. As with actors, some determinants can strongly influence technology transfer processes in all three dimensions. To be able to implement this model, a radical enough strategy is needed to be able to strengthen the linkage between technology transfer actors, especially at R&D entities, namely:

1. Changing the concept of inventor KPIs that rely on individual performance to publish or create IP into a more collaborative team KPI concept oriented toward the creation of innovations;
2. Involving inventors and partners (industry partners) in every dimension of technology transfer (knowledge creation, knowledge diffusion, knowledge absorption) so that research and development is determined based on industry- or market-driven needs;
3. Increase the competence of intermediaries to build networks (with inventors, partners, and government institutions) and commercialize knowledge;
4. Provide funding for the development process (internal development and co-development with partners) to increase the preparedness of inventions that still have a high risk of failure so that they can be adopted and mass-produced by industry partners;
5. Digital media is needed to exchange information related to technology development and connect the relevant actors.

In the context of using the seamless technology transfer model in Indonesia, it is highly recommended to accelerate the use of products derived from research and development. This model has been adapted to the TT process patterns and encompasses the best practices carried out by PRIs and universities.

Regarding future research, the role of current and former key actors in technology transfers linking the exploitation and possible commercialization of new knowledge, particularly at PRIs and universities remains unexplored. Acknowledging this role and understanding the driving factors and the main barriers could prove a particularly fruitful direction for future research.

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The Role of Universities in the Innovation Systems in the Developing Countries

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Abstract

There are no universal rules for improving the contribution of universities to the development of regional innovation systems. Much depends upon the context of the country, resources of a specific region and socio-cultural specifics. This article explores the given topic using the example of a technological university in India, located in a large region with established traditions and a culture of production. In the implementation of the third mission of the university, a special proxy-organization played a key role, providing effective communication between stakeholders, the involvement of different segments of the population in the innovation system and joint development of technologies. The authors propose an interactive model that allows universities to develop new technological solutions for enterprises.

Keywords: third mission of universities; regional innovation system; strategies; new technologies; economic development; textile industry; technological university; local communities; entrepreneurship; India.

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Introduction

In recent years, there has been growing interest from various parties - the educational and research communities, as well as the public sector - in the implementation of the third mission of universities - the production and use of knowledge to stimulate socio-economic development (Johnston, Wells, 2020). A number of empirical studies have been carried out in this direction, most of which were carried out based on the material of developed countries, in which universities are the key producers of knowledge and innovation (Benneworth et al., 2009; Trippl et al., 2015; Acosta et al., 2016; Martin, Trippl, 2017). However, the impact of universities on regional economies in developing countries has not yet been sufficiently studied (Thomas, Pugh, 2020). Using a variety of approaches, universities integrate all segments of the population into innovation systems, offering each group its niche (Grobbelaar et al., 2017). In developing economies, it is crucial for universities to collaborate with rural traditional industries that rely on less sophisticated technologies and encounter significant obstacles in acquiring technologies (Theodorakopoulos et al., 2012; 2014). Sánchez Preciado et al. (2016) state that low and intermediate technologies are simple and less expensive than advanced technologies imported from developed economies. However, the mechanisms of such transfers and the interactions of its participants have not yet been sufficiently studied. Universities find it difficult to maintain a balance between the commercial and non-profit components of their activities. The increase in the commercialization of knowledge makes universities inclined toward university-industry networks, undermining university-community networks and neglecting the social elements of innovation. The transfer of knowledge to industry has been studied in some detail, but the same cannot be said about universities promoting local communities (Jacobs et al., 2019).

Our article fills this gap by showing how a technical university can expand opportunities for local community involvement in small businesses.[1] The focus is on assessing the role of the Indian Institute of Technology Guwahati (IIT Guwahati) in developing the innovation system of north-eastern India through the transformation of small businesses. We are talking about the development of the textile industry. This case is of interest because the Institute was founded on the demand of local communities to foster academic excellence in the region, which would influence the creation of new jobs (IIT Guwahati, 1999). Indian Institute of Technology (IITs), in comparison with other national universities, have a high degree of autonomy and actively establish connections with industry (Datta, Saad, 2011). There are growing expectations from the government and business in terms of enhancing the transfer of knowledge and technology by IITs into the economy and society (Krishna, Chandra, 2009). For this purpose, an intermediary organization has been created at the university - Rural Technology Action Group-North East, (RuTAG-NE) to promote the development of the regional economy by introducing scientific and technological developments into traditional industries (Saha, Ravi, 2019).

Literature Review

Regional Innovation Systems

A regional innovation system (RIS) studies the social interaction of local actors governed and guided by trust, responsibility, exchange, and cooperation (Cooke, 1998). RIS consists of two subsystems (Tödtling, Trippl, 2005). The first is responsible for research and knowledge generation in public research and technical institutes and universities. The second relates to the use of knowledge by local businesses, suppliers, and consumers. An important role in the development of RIS is played by the presence of dynamic research organizations, universities, and clusters and their effective communication among themselves and other actors (Karlsen et al., 2017).

In the last two decades, the role of universities has expanded (Marques et al., 2019) through the intensification of a third mission in response to the growing expectations of the government and society regarding the contribution of universities to innovation and economic development at the regional level (Salomaa, Charles, 2021). The concepts of the entrepreneurial, civic, and engaged university and the triple helix model have been developed to describe and stimulate this trend.

The functions of universities are viewed in terms of four key components of RIS: associative governance, regional agglomeration, human capital formation, and regional cultural norms (Gunasekara, 2006a). Within the framework of RIS, there are two main roles of universities - generative and developmental, which complement each other. The first involves the capitalization of knowledge in the course of cooperation with industry and the government to develop innovative strategies (implemented in firm formation/spin-off). The second has a long-term orientation and is to support social development through participation in regional networks and building institutional and social capacity. Developing a general methodology for assessing the contribution of universities to regional economic development is difficult due to the specific nature of public policies and education systems in different countries (Gunasekara, 2006b; Marques et al., 2019). Their contribution to regional development is determined by a number of factors, primarily territorial specificity,

[1] Family-run weaving and handicraft industries play an important role in India's regional economy. Despite this, they are characterized by insufficient capital costs and a lack of advanced equipment. Limited attention is given to this industry in the science & technology policy and it continues to operate in the informal sector.

the type of university (Boucher et al., 2003; Kohoutek et al., 2017), the institutional environment, the structure of the regional economy, and the strategic orientation of the university (Gunasekara, 2006a).

The Contribution of Universities to the Development of Small Businesses

Universities traditionally focus on developing international academic connections, while losing sight of another important function that they are expected to perform - the involvement of local communities in the socioeconomic system (Robinson, Hudson, 2013). The informal economic activities are often disconnected from the knowledge and innovation generated by universities (Gastrow et al., 2017).[2] The question arises: how can universities reverse this situation? The role of universities in integrating local communities into institutionalized innovation networks has not yet been sufficiently studied. In implementing their third mission, universities use various intermediary organizations (Villani et al., 2016) to transfer and diffuse technologies, organize and coordinate information flows, search for partners, and adapt existing solutions to user needs (Howells, 2006). Similar proxy structures, such as technology transfer offices and regional innovation agencies, form a space for cooperation and consensus among participants in regional innovation systems (Fernández-Esquinas et al., 2016). Despite the growing number of studies on such organizations, a substantial effort is still required to understand their role in knowledge transfer for traditional industries.

Our article contributes to the management of universities' roles in societal and economic development. Using the example of the textile sector of the North-East region of India, the influence of IIT Guwahati is explored through the proxy structure of RuTAG-NE on the development of traditional crafts, mechanisms for knowledge exchange and co-creation activities, and the main actors in this process are revealed.

Technological Transformation of the Textile Sector

Before moving on to the case of IIT Guwahati, it makes sense to look at how innovation at the forefront is changing the face of the textile sector in the world today. The textile industry is embracing digitalization, advances in materials science, and advanced manufacturing technologies to efficiently produce clothing using sustainable and ethical methods. New technologies are modernizing traditional textile production, giving new impetus to the development of related sectors, and expanding its potential to increase its contribution to the national GDP. With the advent of new technologies, the variety of types of fabrics, materials, textiles, and their areas of application is expanding.[3] The concept of sustainable textile production is being introduced, which involves minimal energy use in production and the possibility of recycling products at the end of their life cycle. There is a trend towards increasing the availability and economic efficiency of environmentally friendly textiles. Examples of eco-friendly technologies include fabrics made from bamboo and recycled waste. The technology of creating customized textiles is gaining momentum, allowing the customer to remotely select or create various designs and print them on fabric. Smart computerized looms allow you to quickly create complex patterns, laser scanners and computers create finished patterns without cutting the fabric itself.[4]

The possibilities for producing raw materials for fabrics are expanding. So, in 2023, a discovery was made - using genetic engineering it is possible to produce spider silk.[5] New advanced materials improve the functionality of textiles and introduce a "smart" component. In advanced laboratories around the world, clothing is being developed from robotic fabrics that act as external muscles. It functions as a soft exoskeleton, increasing the freedom of movement of people who have difficulty walking, and also provides a dynamic massage, improving blood circulation in the human body. This technology has a biomimetic basis, reproducing the hygroscopic movement of plants, and the source of energy is the heat of the human body itself.[6] Developments are underway to produce environmentally friendly fabrics from seaweed and crustaceans, which also have anti-inflammatory properties. Smart clothing based on ion-conducting fibers is gaining popularity; it performs thermal regulation functions, can automatically change color and, if necessary, turn on a reflective option, while also exhibiting durability.[7]

Along with aesthetic textiles, the Government of India is also promoting technical textiles, which have been in high demand in recent years.[8] Due to its return on investment, versatility, sustainability, and durability, the demand for technical textiles has skyrocketed on the global market. In order to position the country as a world leader in the field of technical textiles, the Government of India has supported its production with a view to application in wide areas such as agriculture, transport, medicine, infrastructure, clothing production, and so on. These trends can be a guide for universities in developing countries that have textile clusters and human capital with high motivation to transform their region into a thriving economic hub that can gradually embrace increasingly sophisticated technologies and development models.

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[2] The informal economy can be defined as economic activity that falls outside the scope of government regulation. This includes both the informal sector and informal employment in the formal sector.

[3] https://www.startus-insights.com/innovators-guide/textile-industry-trends/

[4] https://www.linkedin.com/pulse/technology-innovation-textile-sector-eastman-exports/

[5] https://www.newscientist.com/article/2392737-silkworms-genetically-engineered-to-produce-pure-spider-silk/

[6] https://www.startus-insights.com/innovators-guide/textile-industry-trends/

Case Analysis

Northeast Region (NER)

The region in question includes eight states: Tripura, Manipur, Sikkim, Assam, Mizoram, Nagaland, Meghalaya, and Arunachal Pradesh, and is characterized by linguistic and cultural diversity. A total of 45 million people live here. The economy of the NER is dominated by agriculture and the share of industry is insignificant (Sachdeva, 2000). Due to the slow pace of industrialization, surplus labor is concentrated in the agricultural sector without access to alternative sources of income (Hussain, 2004). The region's industrial development prospects are limited due to its landlocked nature (Bhowmik, Viswanathan, 2021). In order to change this situation, the Government of India has included infrastructure and industry development in the list of government priorities (Das, 2017). To develop the NER, a special ministry- the Ministry of Development of the North Eastern Region (MDoNER)-was created in 2001 to develop, implement and evaluate the results of relevant programs.

Textile Sector

Weaving and handicrafts, which are essential elements of textile making are practiced in all states of the NER, besides the commercial one, have a cultural dimension that contributes to the preservation of historical heritage (in some parts of the region it has been practiced since the pre-colonial period) (Dikshit, Dikshit, 2014). The sector is seen as a potential source of economic growth (the region's five states account for about 60% of the country's total handloom capacity) and roughly the same proportion of households are employed in it and related activities. The state of Assam holds a special position as it produces four different types of natural silk (Goswami, 2009). Micro-entrepreneurs lack awareness of copyright protection mechanisms such as *geographical indication,* (GI),[9] therefore, in other parts of India, traditional designs are copied or replaced with inferior products[10] (Thakur, 2010). The traditional process of designing and manufacturing such fabrics is complex and time-consuming, yet low-paying (Singha, Singha, 2020). The lack of advanced technologies negatively affects the competitiveness of textile clusters, which are declining.

Indian Institute of Technology Guwahati (IIT Guwahati)

The Indian Institute of Technology Guwahati (founded in 1994) is the only IIT in the NER. It includes 11 faculties, five schools, and seven interdisciplinary centers covering the main engineering, sciences, humanities, and management disciplines. IIT Guwahati consults and advises the public and state governments on industry, economy, and social growth with a focus on the NER.

In 2005, at the initiative of the Principal Scientific Adviser[11] (PSA) to the Government of India, the Rural Technology Action Group-North East (RuTAG-NE) was established, providing essential scientific and technological support for regional development (Bhattacharjya et al., 2019). In contrast to the conventional top-down approach, RuTAG-NE has embraced a bottom-up and integrated approach to technology development. This approach allows for the involvement of various stakeholders (academia, government agencies, non-governmental organizations (NGOs), regional experts, and micro-enterprises). Attempts are being made to upgrade existing technology to the needs of various clusters, but the process is complicated by the initially low level of technological competencies, implementation concerns, and affordability.

Methodology

Case analysis is a qualitative research method that allows for a deeper understanding of a particular social phenomenon, event, or scenario (Yin, 2018). It is used when there is little information about the subject of research or the theory is not sufficiently developed. On its basis, new theories, hypotheses, and concepts are proposed. For our case study, we analyzed secondary data from scientific reports, books, policy documents, and studies. Semi-structured interviews were then conducted, with participants selected using purposive and snowball sampling methods. From April 2021-November 2022 respondents were interviewed, online and by telephone (Table 1). The interviews lasted between 30 and 90 minutes and were conducted in Hindi and English. The questions were structured on the following topics: functions of RuTAG-NE IIT Guwahati, interaction with regional actors and businesses, specifics of textile enterprises, technology transfer, and problems. To ensure the reliability of the data, data source triangulation methods that involve collecting data from different kinds of individuals were employed (Carter et al., 2014). The resulting information was inductively coded using MAXQDA software, allowing one to uncover important connections between the data, emerging themes, and existing literature. The data were assigned codes of different orders. The first-order codes represented informant-centric phrases. The second-order themes were more abstract in nature, reflected researcher-centric concepts, themes, and di-

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[7] https://www.fibre2fashion.com/industry-article/9435/innovations-in-the-world-of-textiles

[8] https://www.linkedin.com/pulse/technology-innovation-textile-sector-eastman-exports/

[9] https://assamtribune.com/low-awareness-in-state-on-gi-protection

[10] https://www.sentinelassam.com/topheadlines/sualkuchi-silk-under-threat-from-evil-twin-industry-wants-gi-to-be-safe-533474

[11] The Principal Scientific Adviser, often known as the PSA, serves as a chief advisor to the government of India on issues that are associated with scientific policy

mensions, and finally one arrives at aggregate codes (see Figure 1). At the start, first-order codes were used. They assessed participants' observations regarding the role of IIT Guwahati in RIS (left side of Figure 1) and RuTAG-NE's activities in co-developing technologies for micro-entrepreneurs involved in small businesses. (right side of Figure 1).

Participation in the RIS performs four functions: building regional networks, upgrading regional clusters, enabling academic staff in regional participation, and entrepreneurial and human capital development. Three main RuTAG-NE activities have been identified: analyzing technology needs; developing user-centric technology, and disseminating open-source technology. At the third stage is the formulation of aggregate code: university engagement mechanisms and contributions to the RIS.

Table 1. **Interview distributions**

Respondents	Number
RuTAG officials	3
Professors	4
NGOs	5
Local enterprise/fabricator	3
Regional experts	3
Government	4
Total	22

Source: authors.

Activities of RuTAG-NE

Analyzing Technology Needs

For the successful implementation of technologies, it is necessary to understand the needs of micro-entrepreneurs involved in small businesses, for which two or three regional seminars are organized annually with their participation and the presence of NGO representatives. The first step in the needs analysis was to assess the actual demand for a particular technology. Information collected by RuTAG-NE is reviewed at committee meetings that determine priorities for scientific and technological support. The identified problems are discussed from different points of view by IIT faculty, regional experts, and NGO representatives. Some committee members communicate with micro-entrepreneurs. Priorities are determined depending on the significance of the region, its resource base, the scale of the problems, the capabilities of IIT Guwahati, and the expected economic impact on the business. If necessary, resources are attracted from the national level. From the findings, it is proposed that the need identification process adopted by the intermediary organization enables universities to engage with different regional stakeholders, including local communities working in informal sectors.

Developing User-Centric Technologies

The selected problem statement is shared with IIT faculty members with the appropriate competencies. Additional studies are being carried out to evaluate development possibilities. Depending on the identified needs, existing technology is either adapted and modified (the preferred option) or a new one is developed. Under the guidance of IIT faculty, RuTAG-NE officials develop a prototype. According to one of the RuTAG-NE officials, it is an iterative process and getting adequate feedback is necessary. Due to limited resources and poor infrastructure, the technology developed is simple in design and easy for the local community to adapt. Field testing of prototypes is carried out jointly with end users (micro-entrepreneurs), whose feedback is taken into account during further development. If their requests are satisfied, the technology is considered ready for implementation. It is therefore proposed that a user-centric approach to product development by the intermediary organization facilitates the inclusion of local communities in the process of technology development, thereby enhancing technology adoption.

Disseminating Open-Source Technology

At this stage, local enterprises or fabricators are identified for collaboration. RuTAG-NE does not receive any royalties or profits and does not patent its technologies; the developed products are available to everyone. If necessary, training is provided to produce similar products locally. Technology implementation in regional clusters is usually done by NGOs through government agencies' funding or corporate social responsibility (CSR) funds. Considerable attention is paid to collaborating with banks and other related organizations to resolve financial issues. Thus, we proposed that developing a simple and open-source technology enables the intermediary organization to effectively transfer technology to local enterprises or fabricators and NGOs, who can then disseminate it in regional clusters.

A summary of respondents' opinions on each of the considered aspects is presented in Table 2.

Participation of IIT Guwahati in RIS

Building a Regional Network

RuTAG-NE managed to create a system for regular interaction with regional actors, providing direct communication between users and innovation developers. It serves as a collaborative platform to keep all stakeholders confident and alleviate issues emerging due to variations in culture, social norms, and work ethics and acts as a change agent to overcome resistance to innovation. However, the distribution of NGOs across the region capable of implementing S&T intervention remains uneven. From our findings, it is therefore proposed that:

In the periphery regions of developing economies, the presence of an intermediary organization enables the technical university to establish a regional network.

Upgrading the Regional Cluster

In the framework of the special ministerial program STINER, RuTAG-NE IIT Guwahati has developed several semi-automatic machines to raise the productivity of local textile clusters. The dissemination of technologies is carried out in individual families as well as by establishing common facility centers. Government co-financing plays an important role in the wider penetration of technologies, since the financial capabilities of RuTAG-NE, as a university intermediary, are limited. Most successful projects have been implemented jointly with the central government, while cooperation with regional or local government is not very active. It is therefore proposed that in developing economies, technical universities in peripheral regions are more likely to upgrade traditional industries by offering improved and easy-to-adopt mechanized technologies.

Human Capital Development

RuTAG-NE is interested in training and developing local enterprises or fabricators. RuTAG-NE technologies can be produced where demand arises if local enterprises are trained in that location. Some fabricators find themselves interested in collaborating and taking the products forward to disseminate in regional textile clusters. Further, to incorporate teaching and research and provide consulting services regarding various issues faced by the rural sector, the School of Agro and Rural Technology has been established. From the findings, it is proposed that in the periphery regions of developing economies, the presence of intermediary organizations not only enables technical universities to engage in knowledge and technology transfer but also enables the university to identify future academic units to support the local economy.

To involve academic staff in supporting regional development, RuTAG-NE informs faculties and students about the problems faced by the local community and encourages them to participate in the exchange of knowledge and the search for possible solutions. The faculty involved in RuTAG-NE activities is voluntary and they often spend their valuable time on field visits interacting with micro-entrepreneurs involved in small businesses. RuTAG-NE receives certain financial support from the Principal Scientific Advisor (PSA) (central government institution) to conduct its activities. It is therefore proposed that in the periphery regions of developing economies, the presence of university intermediary organizations enables academic staff to become aware of regional issues and encourages them to participate in regional engagement.

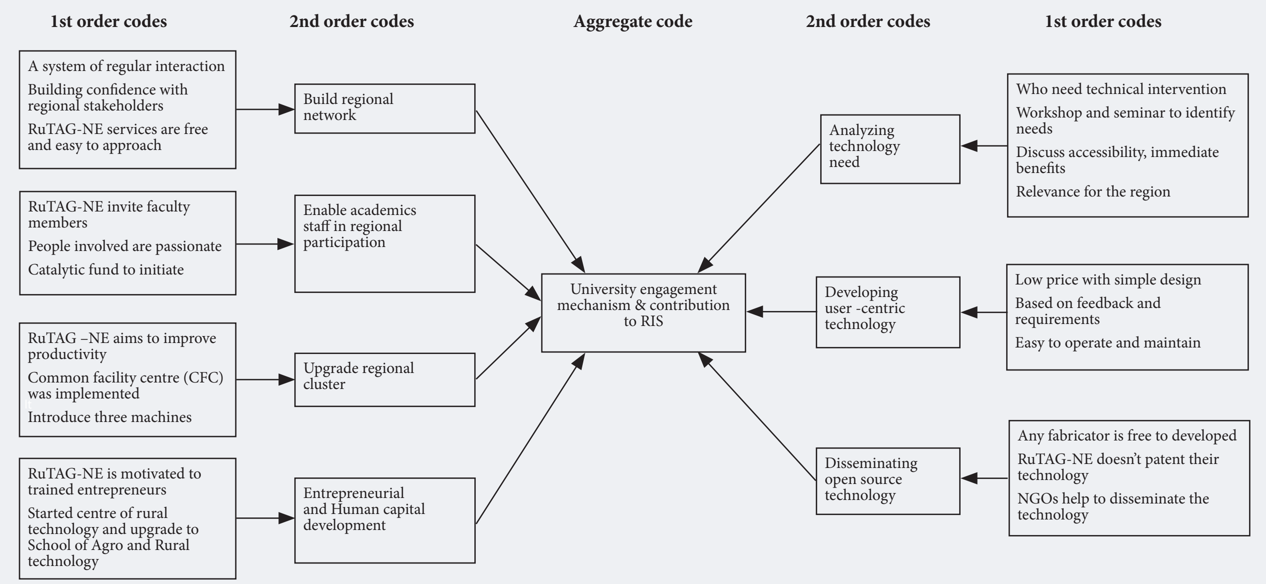
Table 3 shows excerpts from interviews with respondents on each of the indicated aspects of IIT Guwahati's participation in the RIS.

Discussion

The results of the study show that a technical university can play a key role in the socioeconomic development of peripheral regions in developing countries such as India. As part of the IIT Guwahati ecosystem, RuTAG-NE promotes the co-creation of technology and knowledge co-production and dissemination among regional actors.

This process allows for the involvement of the most diverse segments of the population and shares their needs and feedback to overcome challenges in upgrading the technology in the regional cluster and increase production. Figure 2 presents an interactive model of IIT Guwahati's participation in the regional innovation system.

Figure 1. **Data Structure**



Source: authors.

Table 2. **Excerpts from interviews with respondents regarding RuTAG-NE activities**

Dimensions	Citations from interview
Analyzing technology needs	What I'm saying is technology need analysis first things is that, what's the basic need of this particular technology... (Regional Expert # 1)
Developing user-centric technology	It is a learning process and the field trial is very important to get right feedback... (RuTAG-NE # 2)
Disseminating open-source technology	RuTAG-NE does not earn any loyalty or profit and neither patented these technologies... (Professor IIT Guwahati # 1)
Source: authors.	

Such a regional network, working on a "bottom-up" principle, makes it possible to quickly identify the technological demand of micro-entrepreneurs, strengthen the trust of stakeholders, and stimulate openness to innovation. University staff accompanies the entire process of development and technology transfer. By going beyond the conventional methods of technology transfer and commercialization, technical universities can enhance the potential of local enterprises or fabricators by sharing open-source technology, which in turn commercializes and diffuses the technology in regional clusters, such as the textile sector, to improve the productivity of microentrepreneurs working in this sector. In other words, universities are establishing a new balance between the commercial and non-commercial components of their activities in order to increase regional economic potential.

Policy Implications

In developing economies, technical universities can play a key role in the RIS of a periphery region, subject to appropriate national policies to support regional development (Gunasekara, 2006a). In addition, much depends on the type of university, on the willingness of its academic staff to voluntarily participate in the exchange of knowledge and experience with local entrepreneurs and other stakeholders (Gunasekara, 2006b; Salomaa, Charles, 2021). The availability of high-quality departments as a precondition for regional development is not mandatory. In developing countries, simple and less sophisticated technologies can serve as viable solutions to address the challenges of traditional industries (Theodorakopoulos et al., 2014).

The case of the north-eastern region of India represents a working regional ecosystem, where IIT Guwahati plays a central role, performing its functions through a proxy organization RuTAG-NE with the support of the PSA (central government agency). RuTAG-NE technologies are not subject to patenting and, as a result, easily transferable where demand arises. However, the conceptual framework of the RIS derived from our case study has its limitations when transferred to other contexts. RuTAG-NE is attached to academic institutions with a limited budget. At the same time, financial support is mainly from the central government, and the degree of involvement of regional and local authorities remains insufficient. In turn, the limited purchasing power of micro-entrepreneurs involved in traditional industries such as textile sectors further constrains the potential for the wider dissemination of technologies.

Conclusion and Further Research

This study expands our understanding of how technical universities can contribute to meeting societal needs and participating in RIS activities, especially in peripheral regions. The important role of the intermediary organization is emphasized, which organizes social learning and joint development of demand-driven technologies, expanding the range of segments of the population involved in the innovation system.

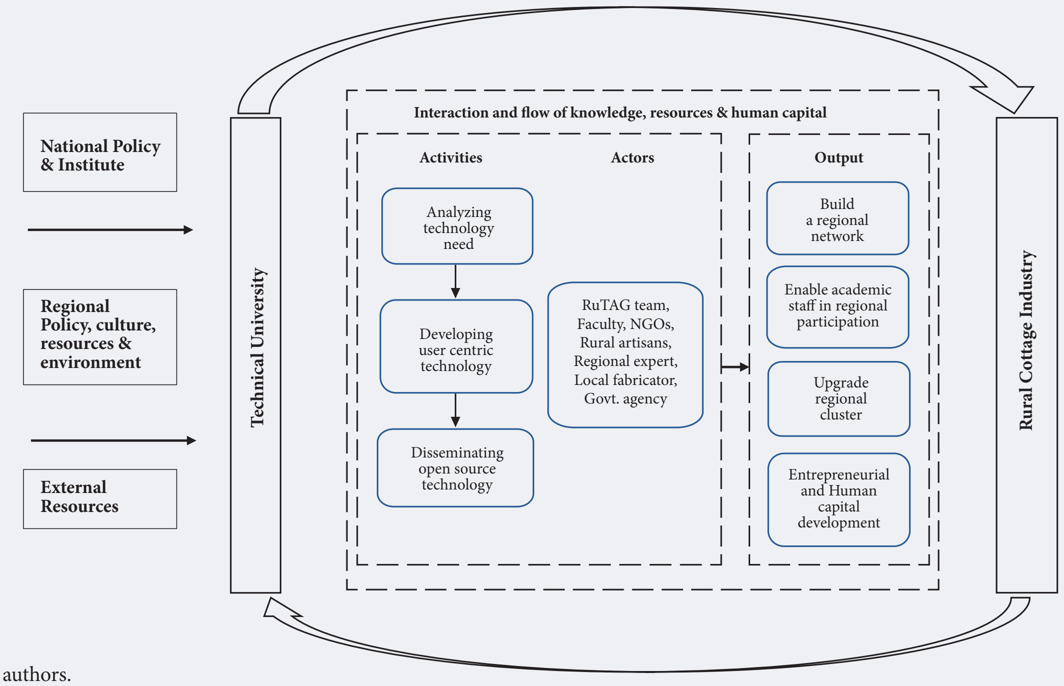
In terms of the transferability of the findings to other contexts, it is important to note that the main goal of case analysis is to provide a comprehensive illustration of the specific case under investigation (Stake, 1982). However, the information and conclusions obtained from such an analysis can be considered a working hypothesis for further research. The transferability of results depends on the degree of compatibility of the "sending" and "receiving" contexts (Mariotto et al., 2014).

A comparative analysis of the activities of other RuTAG centers (seven in total across India) will allow us to study their evolution, the effects of their activities, and the composition of regional stakeholders. The possibilities of using or replicating the presented interactive model in other technical universities or engineering colleges (besides IITs) in India and other developing countries can be explored. Moreover, in the case we examined, most of the university staff involved in RuTAG-NE activities are voluntary. Further research would benefit from exploring why and how academicians and scientists are involved in supporting regional development, what motivates them, and what policy initiatives and incentives might enhance such involvement.

Table 3. **Excerpts from interviews with respondents on the role of IIT Guwahati in the regional innovation system**

Building regional network
It is a good system of regular interaction with regional actors including, NGOs, villagers, and RuTAG-NE IIT Guwahati, as it helps to directly connect end users and innovators. (Regional Expert # 1) I say 'we' in RuTAG-NE because other stakeholders play a very important role even though IIT Guwahati is leading this centre. For example, when we started working on handloom and weaving issues, we had very limited knowledge of this sector. We learn and collaborate with other stakeholders and experts, such as the central silk board, to develop S&T intervention in this sector. Another thing we learn is that it is important to take other stakeholders into confidence to work together. In NER, there were hardly any NGOs who are involved in S&T implementations. At some point, we have to guide and train them. We build confidence with the NGOs and the NGOs use to build the confidence of the artisans or the villagers. (Professor IIT Guwahati# 1)
Upgrading regional cluster
A common facility weaving centre has been implemented in weaving cluster in Baksa district (Bodoland), Assam. The land was donated by six villagers to set up the centre; technology support was provided by RuTAG-NE IIT Guwahati. Weekly, around 120 women from six villages use the facility, and around 20 women use it on a daily basis in a routine manner. This not only provides weavers to increase their productivity but also allowed them to promote their traditional Bodo tribe textiles. The common facility is maintained by the community group (villagers) and later formed a cooperative society to commercialize the products and increase marketing and sales activities. The project was funded through central government Scheme of Fund for Regeneration of Traditional Industries (SFRUTI) project for rural cluster development and was completed in 2018. (NGO # 1) Sixty hank to bobbins machines were disseminated in weaving clusters in Nagaland. Around 200–300 people from nearby villages work in the cluster. Weaving technology was disseminated in the common facility centre as well as in individual families. Eri cocoon openers were also disseminated in Mizoram. We can disseminate our technology in the different north east region through the STINER project. (RuTAG-NE # 1)
Entrepreneurial & human capital development
I used to work as a steel fabricator, and later I developed an interest in textile machine manufacturing. I was contacted by RuTAG-NE IIT Guwahati in 2013 and gave a project to develop two machines, i.e. pirn winding machine and hank to bobbin machine. Since then, I have been working with IIT Guwahati. I started with an electrical background and got the inputs in manufacturing and mechanical engineering while working with RuTAG-NE. I got publicity through collaboration, and now my company is a government-approved supplier for textile machines. Knowledge transfer usually takes place informally. Since 2016 these machines have been delivered in different states in NER, including Sikkim, Nagaland, Assam, Mizoram, Arunachal Pradesh, and Tripura. (Local enterprise # 1)
Enabling academic staff in regional participation
My involvement in RuTAG-NE projects is mainly because of my passion to work for rural people, but I must say that getting involved in rural activities is not easy. It takes time to interact with them to understand their needs. It's not something you just design and build in the lab and give to them; many a time, rural technology fails when you don't understand their need and how they work. (Professor IIT Guwahati #2)
Source: authors.

Figure 2. **RuTAG-NE IIT Guwahati's interactive model to co-create demand-driven technology and contribute to RIS**



Source: authors.

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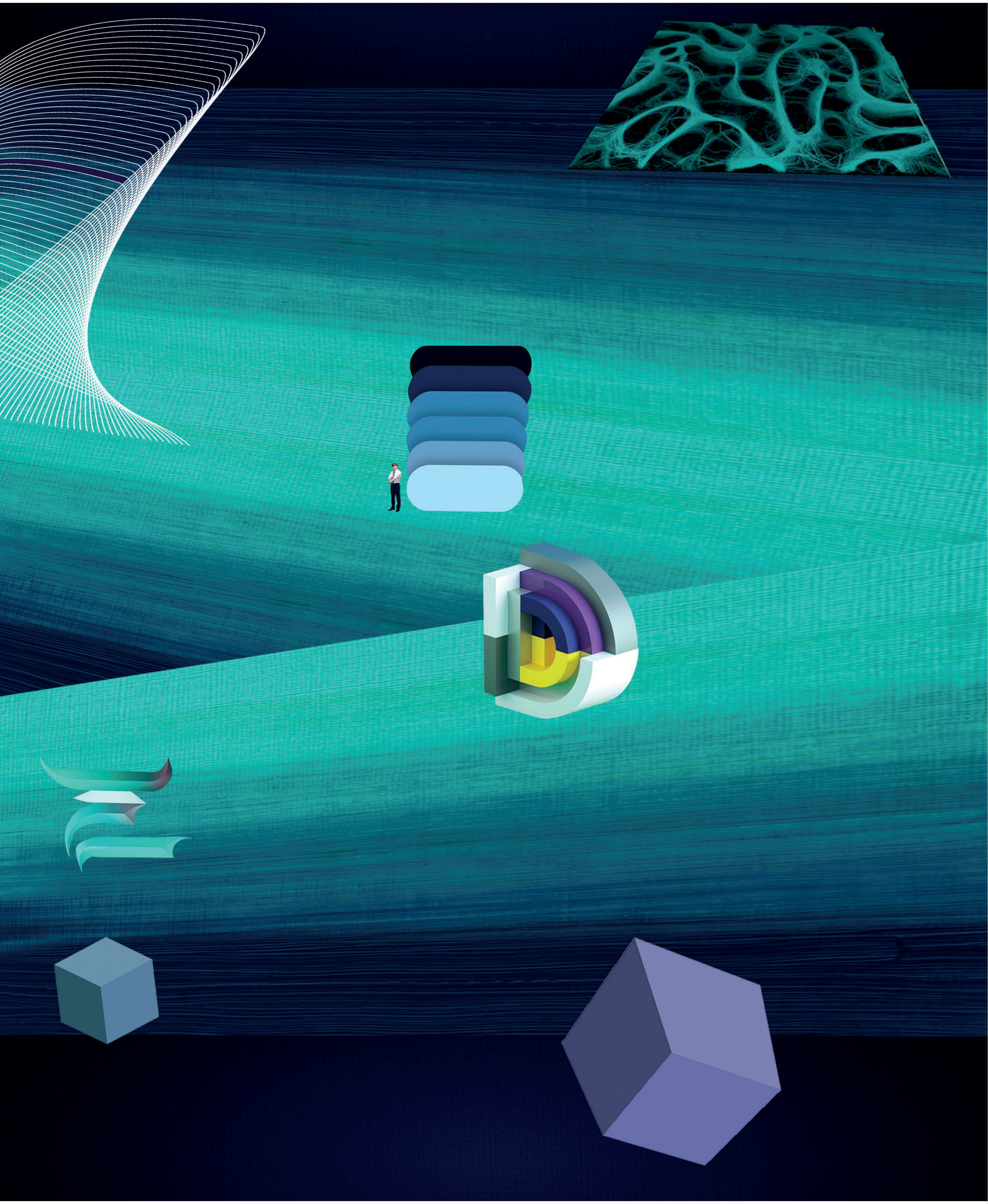

Evaluating the Performance of Foresight Studies: Evidence from the Egyptian Energy Sector

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Abstract

Foresight projects are expected to provide realistic scenarios for different future scenarios, which provides a better information base for relevant strategies. However, these expectations often turn out to be at least difficult to fulfill due to the uncertainty of the external environment and cognitive biases. Therefore, the idea of assessing each stage of Foresight is gaining relevance, which is of particular importance in the energy sector, which affects a variety of areas of life. This article analyzes the results of the Egyptian energy foresight study, Egypt LEAPS, in terms of process efficiency and forecast accuracy as well as the factors that influenced it, including cognitive biases. The authors conclude that for each stage of foresight, a thorough analysis of weaknesses and shortcomings is necessary. Therefore, from the very beginning, the foresight process should include reliable mechanisms for assessing results and a readiness for constant iterations. Consistent process adjustments that rely on new ways of dealing with complexity and uncertainty in dealing with the future help build trust among participants and consistently reduce the level of erroneous assumptions.

Keywords: foresight assessment; energy foresight; evidence-based policy; energy transition; renewable energy systems; strategies; futures studies; technology foresight; scenario planning; renewable energy; environmental aspects

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Introduction

The topic of assessing technological foresight studies to improve their quality has become increasingly relevant in recent years. This is due to the increased dynamics of change, as a result of which the influence of factors that determine the quality of forecasts increases many times over, determining the quality of decisions made and the effectiveness of strategies.

Research assessing the results of Foresight projects has intensified only in recent years and is not yet widespread. The assessment is of particular importance for Foresight studies in the field of energy, since this sector directly affects the socio-economic sphere.

The global energy sector determines the prospects for sustainable development, along with two other basic areas - the environment and the economy - which are constantly considered in Foresight studies, most often based on scenario planning (Rubio et al., 2023). There are many studies on scenario planning in the field of energy, such as projects by Shell[1], the International Energy Agency (IEA), the International Renewable Energy Development Agency (IRENA), the International Expert Council on Climate Change (IPCC), the European Commission, and several other European institutions (Guivarch et al., 2017). They have different coverage - from global trajectories (IPCC, 2014) to energy supply to local areas (Khosala et al., 2021). Horizons typically extend over the long term, for example, in the case of the IEA, up to 2100 (IEA, 2022).

For example, the European Commission and the Fraunhofer Institute for Systematic and Innovation Research ISI (European Commission, 2016; Fraunhofer ISI, 2014) are working on scenarios for the development of "low-carbon technologies" and renewable energy sources, assessing the prospects for their public acceptance and demand for them. The possibility of a 100% transition to electricity production based on renewable energy sources by 2050 has been assessed for 20 European countries and aggregated regions (Hainsh et al., 2022). The Danish Energy Agency is developing "Technology Catalogs" as data for scenarios. They contain the latest knowledge, technology development prospects, and forecasts until 2050 (Andersen, Silvast, 2023). As a result, different scenarios compete for influence on the development of the energy system.

Many such projects are currently undergoing the evaluation of their results, after which approaches to their implementation are revised in order to increase efficiency.

Egypt's first energy Foresight study, Egypt LEAPS, was implemented in 2017 and focused on two horizons: up to 2022 and 2027. In 2022, we attempted to contribute to the accumulation of "evaluative" Foresight work by conducting a similar analysis in connection with reaching the first horizon.

Egypt LEAPS focused on three core energy areas: solar energy, energy efficiency, and fossil fuels.

The purpose of our article is to analyze the first large-scale energy Foresight project in Egypt from the point of view of process and effects. The article begins by describing the main trends in the energy transition that set the context for the energy foresight study.

Then we will look at the potential of solar energy as the most promising direction for Egypt; forecasts for it turned out to be more accurate. We will also pay attention to the issue of selecting experts, the influence of cognitive biases on the results of the project, and finally present a case study of the project.

Energy Transition

With growing concerns about energy security and climate change, the energy transition, which changes the composition of the energy matrix, is a focus for many economies. A special role in this matrix belongs to renewable energy sources (RES), which are considered drivers for achieving the UN sustainable development goals until 2030. Despite the fact that it is still dominated by non-renewable sources (oil, coal, and natural gas) gradually the share of hydro, solar, wind, and hydrogen energy as well as biomass is increasing (Chen et al., 2019), the greatest significance of which was achieved China, USA, Germany, and Brazil.

The transition to a sustainable energy matrix requires greater dynamism, large-scale investment in renewable energy infrastructure, overcoming regulatory and political barriers, and managing the social and environmental impacts associated with certain technologies. The energy transition covers a wide range of aspects such as energy technologies, market behavior, environmental impacts, and policy development. In order to increase the share of new efficient technologies, it is necessary to study and coordinate energy and environmental policy issues, propose a regulatory framework for designing energy markets, and increase infrastructure investments. The number of similar studies in this direction is growing (Rubio et al., 2023). Many countries are trying to reduce dependence on fossil fuels by moving renewable energy sources to the center of government policy (Galvin, Healy, 2020).[2]

Scenario modeling must take into account not only emerging technologies, but also the structural interdependencies between policy development, energy infrastructure expansion, market behavior, environmental impacts, and security of supply (del Granado et al., 2018). It is about creating a coherent system that

[1] Shell has been developing global scenarios for over 50 years . Examines key trends around the energy transition, prospects for countries, regions and sectors.

[2] See also: https://www.wsj.com/articles/oil-gas-russia-renewable-energy-solar-wind-power-europe-11649086062, accessed 02/12/2024.

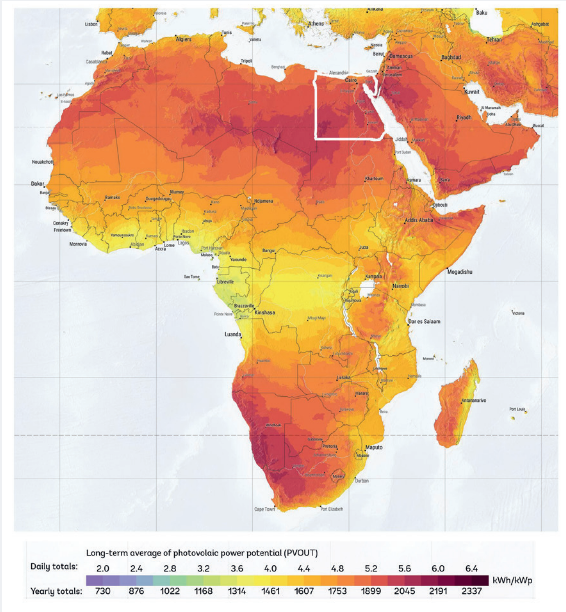
effectively balances economic, environmental, social costs, risks, and benefits (Sareen, Haarstad, 2018). A significant contribution to the development of renewable energy sources was made by solutions in the field of artificial intelligence and other technologies, which made it possible to implement individual projects of integrated energy systems operating on the smart principle Grid. Despite this, it was not possible to achieve a radical change or reformatting of the energy matrix. The reason is the lack of an integrated model of low-carbon development with clear goals (Luo, Lin, 2023). Its development is hampered by competition between different parties for influence, leadership without commitment, conflicting values, and a lack of strategic thinking focused on sustainability (Nwanekezie et al., 2022).

Potential for Renewable Energy Development in Africa

The development of solar energy is of great importance for reformatting the matrix of the energy system in Africa, which has a significant solar resource base (40% of the world's solar energy potential), but is in dire need of technologies for its development (Abdelrazik et al., 2022). Currently, the continent hosts only 1.48% of the world's total solar energy capacity (IRENA, 2021; Huard, Fremaux, 2020).

North Africa, the geographical area to which Egypt belongs, has an abundance of solar energy due to its ideal location in the Sun Belt region as shown in Figure 1.

Figure 1. **Distribution of Photovoltaic Capacity Potential for Solar Energy Development in Africa**



Note: The darker the color of the zone, the higher the photovoltaic capacity potential. Egypt (outlined in white on the map) is located in the "darker zones," which means the country has the highest potential for solar energy development.

Source: adapted by the authors on based on : WEF (2022) Africa is leading the way in solar power potential. https://www.weforum.org/agenda/2022/09/africa-solar-power-potential/, date appeals 16.01.2024.

A serious limiting factor to the development of renewable energy sources are financial, personnel, environmental, and technological problems (Dagnachew et al., 2020). There is an acute shortage of highly qualified personnel to design, maintain, and operate photovoltaic systems. Photovoltaic technologies have not yet become widespread due to the lack of supporting infrastructure. Frequent sandstorms lead to contamination of the surface of solar panels, which reduces their efficiency in converting solar radiation into electricity (Chanchangi et al., 2020; Othman and Hatem, 2022). In Egypt, however, the situation has recently improved due to the entry onto the market of KarmSolar, a leading provider of solutions in the field of renewable energy sources that brings together specialists with different competencies. The company was named the nation's fastest-growing player in 2022 and received international recognition by being named one of Fortune's "50 Companies Changing the World" list.[3] Another company, Efika, has become a pioneer in the solar equipment cleaning market.[4]

There are two main types of solar energy technology: photovoltaic energy (directly converts light into electricity) and concentrated solar energy (uses heat reflected from mirrors to drive heat engines). Concentrated photovoltaic cells increase the flux density of sunlight by an average of 200-1,000 times with the help of special lenses, hence they are considered the more advanced technology, since the proportion of solar energy converted into electricity reaches 42%. Based on the high potential of renewable energy sources, Egypt aims to achieve more than 40% of its energy generation from other sources in this category - wind and hydroelectric power plants (IRENA, 2018).

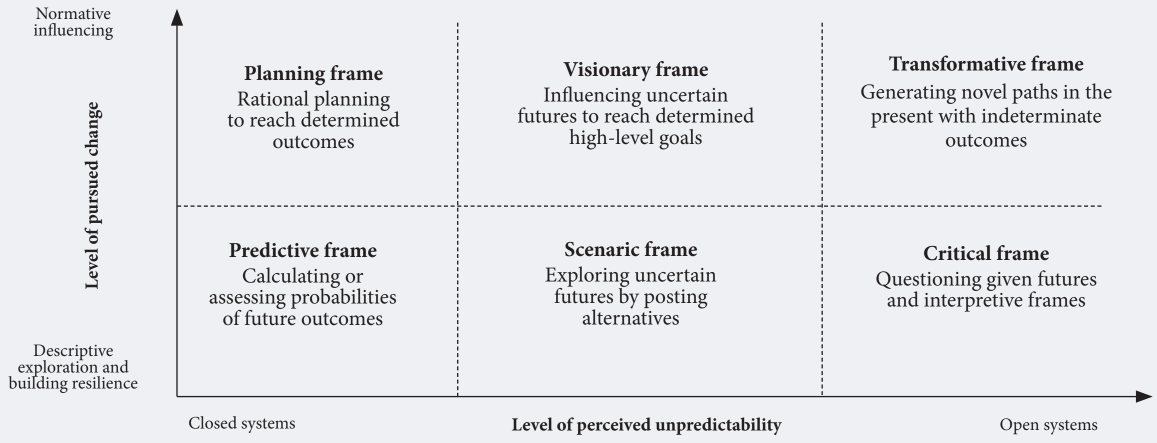
The introduction of new technologies is hampered by a lack of competence among policymakers, project planners, and potential users (Havila et al., 2014; Kimuli et al., 2017).

Modern educational programs in Egypt are mostly focused on academic research rather than on the practical aspects of power system design and operation. Only in recent years have educational programs begun to appear that train specialists with a wider range of competencies, including: the design of solar energy systems, taking into account the latest knowledge and technologies in this area, their maintenance and op-

[3] https://www.karmsolar.com/, accessed 02/15/2024.

[4] https://efika.company/, access date 02/15/2024.

Figure 2. **Matrix of Frameworks for Implementation and Evaluation of Foresight Projects**



Source: (Minkkinen et al., 2019).

eration, project management, and marketing. Among them are the programs of the Egyptian Youth Academy (Youth Academy Egypt)[5], British University in Egypt (British University in Egypt)[6], and the Ministry of Electricity and Renewable Energy of Egypt (Ministry of Electricity and Renewable Energy).[7] The generation of open knowledge transmitted in Foresight project reports makes its contribution.

However, not only the lack of competencies affects the "Foresight-strategy-decision-making" connection, but the cognitive biases of experts have a great influence on their content and results, even when competencies are present. Most Foresight participants omit many important aspects, concentrating, as a rule, on only one dimension of future development - reducing the cost of energy. Therefore, forecasts often turn out to be inaccurate due to their attachment to economic estimates of future energy demand (Paltsev, 2017; Stern, 2017; Trutnevyte, 2016; Nemet, 2021) due to their erroneous assumption that current trends will continue, not taking into account the dynamics of change and so on. Therefore, assessing Foresight studies in various areas becomes a necessary condition for reducing valuable resource losses and forming a more realistic picture of the future.

Evaluation of Foresight Projects

The first attempts to evaluate Foresight projects began to be made soon after their activation began in the 1990s, but so far the number of works devoted to their analysis remains insignificant compared to the total body of publications representing the Foresight process itself and its results (Ko, Yang, 2024). Foresight assessments were carried out most actively in Europe and the USA.

Figure 2 presents a classification matrix for the six frameworks of Foresight projects (Minkkinen et al., 2019). Most evaluation methodologies used in corporate practice and academia are based on only two of them: measuring the accuracy of forecasts and the degree of achievement of planned outcomes (Bonaccorsi et al., 2020). This is due to the fact that forecasting and planning deal with low levels of unpredictability. Accordingly, other areas (visionary, scenario, transformational, and critical analysis) are reflected to a lesser extent, as they belong to a zone of higher uncertainty and are more difficult to assess (Cuhls, 2003).

Most often, results are assessed based on three criteria: transparency (proper use of public funds to achieve the main goal), validity (reasons for continuing Foresight), and lessons learned (methods for the most effective implementation are proposed) (Georghiou, Keenan, 2006). The biggest challenge is transparency, which requires organizing the complex manifold goals, interests, and experiences of different project participants. Falsity increases due to the need to apply the same unified tests to the assessment of Foresight projects as to other ones in state programs. The "lessons learned" criterion appeared later on the Foresight assessment agenda and its role in this process has so far received less attention. Meanwhile, this aspect is of great value, since it connects current problems with future ones, which increases confidence in Foresight (van der Steen, van der Duin, 2012). Giving it greater significance is constrained by the fact that going beyond "traditional values" is not easy for stakeholders in cognitive terms.

One of the Foresight projects, the results of which are assessed as very successful, is the initiative of the Institute of Advanced Science and Technology (KAIST)

[5] https://www.pdf-eg.com/node/75, accessed 02/07/2024

[6] https://new.bue.edu.eg/research-centers/center-for-renewable-energy-cre-bue, accessed 02/08/2024.

[7] http://nrea.gov.eg/test/en/About/Tranning, access date 02/08/2024.

of South Korea - "Forecasting and analysis of medium- and long-term future conflicts in order to prevent them" in 2019. It formed the basis of the national development strategy published in 2021.[8] The goal was to integrate Foresight into policy development by proactively analyzing the foundations for future conflicts. As of 2016, Korea ranked third in terms of conflict among the 34 OECD member states (Heo, Seo, 2021). Participants were aware of the existing gap between "knowing" the future and acting toward it in policymaking (Riedy, 2009; van der Steen, van Twist, 2013; van Dorser et al., 2020). The lack of "hard evidence", fallibility, and the problematic nature of a legitimate policy source contribute to the separation of Foresight from policy development (Riedy, 2009; van der Steen, van Twist, 2013). Understanding the how and why of stakeholders conceptualizing problems or strategies can increase decision makers' openness to new ideas and Foresight concepts (van der Steen, van Twist, 2013).

Indirectly, the project was also designed to build management capacity to make informed decisions. Even if these programs are not directly linked to official policy, the mandate itself allowed the Korean government to map a society in which the structure and intensity of conflicts are evident in order to prepare or adapt to sudden and unexpected changes (Calof, Smith, 2012; Vervoort, Gupta, 2018).

During the project implementation, strategies and methods "from present to future" (forecasting) and "from future to present" (backward forecasting) were simultaneously applied (Riedy, 2009). From the Korean case, it follows that the key condition for the successful integration of Foresight into the political agenda is the foresight of the government.

Cognitive Issues

Foresight assessment is closely related to the topic of cognitive science and the prejudices that largely determine the quality of projects. The influence of cognitive factors on the quality of expert assessments has been studied since the 1980s. (Hogarth, 1980; Hogarth, Makridakis, 1981; Schoemaker, 1993; Bradfield, 2008; Chermack, Nimon, 2008; Wright, Goodwin, 2009; Meissner, Wulf, 2013). There are many opportunities for error and bias that can affect the quality of future expectations at each stage (Bolger, Wright, 2017).

The classic problem is that experts have difficulty prioritizing and allocating the time and resources to contribute (Videira et al., 2009; Carlsson et al., 2015). Research in cognitive psychology and social psychology reveals why cognitive biases are so common and persistent among participants in Foresight projects. This issue is widely discussed in both general review analyses (Martino, 2003; UNIDO, 2004; Georghiou et al., 2008; Giaoutzi, Sapio, 2012) and when analyzing specific programs, for example, the German Delphi Project II (Blind et al., 2001). Experts tend to project cause-and-effect relationships observed in their field of activity onto other fields. A fairly common bias is increased optimism about the future development of a field or technology (Tversky, Kahneman, 1974; Tichy, 2004). Scenarios often show an erroneous pattern: short-term forecasts are characterized by an optimistic mood, while long-term forecasts are pessimistic (Linstone, Turoff, 1976; Winkler, Moser, 2016; Markmann et al., 2021). Instead of holistically covering alternative possibilities, experts most often rely on familiar (limited) rules of thumb (heuristics). As a consequence, cognitive biases arise that influence the development of strategies (Kahneman et al., 1982).

There is a point of view that "about 80% of all technology forecasts turn out to be wrong" (Golden et al., 1994). Cognitive biases are manifested in the discrepancy between the actual results that people's behavior produced and the results that would be expected if people followed the rules of rational choice and probabilistic reasoning.

Experts are faced with complex cognitive processes that reveal diverse cause-and-effect relationships, the dynamics of dozens of variables, and so on. The task is to build consistent ideas about possible future trajectories from complex, dynamic diversity. In technological forecasting, the result is distant in time and is often not formally assessed; the causal mechanisms are so complex that it is not obvious how to learn from the realized results.

The most common problem is overconfidence, which leads to an illusion of competence (Moore et al., 2015; Feld et al., 2017). Experts do not quite correctly determine the confidence interval of their own estimates (Lichtenstein, Fischhoff, 1977), overestimate or underestimate what can be achieved over a certain period of time (Kahneman, Tversky, 1979; Sharot et al., 2012), create scenarios based on the development of the present in the future, and at the same time focus on optimistic scenarios (Newby - Clark et al., 2000). They persist in this misconception even in the face of negative feedback (Buehler et al., 1994).

They make big mistakes in understanding exponential growth and formulate estimates that are largely inferior to the true values (Ebersbach et al., 2008; Levy, Tasoff, 2016; 2017). A related problem is the inability to identify rare events or low predictability events.

In this article, we cannot cover in detail the entire range of cognitive traps that participants in Foresight projects face. However, let us focus on solving the problem of cognitive biases. There is no single approach to overcoming them, so it is necessary to experiment with different combinations of methods. Strategies based on

[8] https://futures.kaist.ac.kr/en/?c=290, access date 02/12/2024.

Table 1. **Basic Cognitive Biases that Appear at Different Stages of Foresight and Ways to Overcome Them**

Foresight stage	Cognitive biases	Ways to minimize impact
Setting the project goal	Framing effect – an imbalance in semantic accents that affects the perception of context and decision-making. Experts focus on the benefits of a technology and underestimate the risks and costs of its implementation.	Expanding the diversity of participants - carriers of different points of view, which, through the exchange of them, form a collective, more balanced "mental template" regarding technology. To change an individual's perspective, it is also suggested that alternatives be considered.
Technology Trend Analysis	Social desirability effect bias - the desire to formulate a point of view in such a way as to correspond to the prevailing collective ideas.	Analysis of trends in an abstract functional space, without reference to the prevailing social perception.
Analysis of technological options	Advocacy bias is the tendency of an expert who is well acquainted with a technology to focus on its advantages and remain silent about risks and costs.	Expanding the diversity of participants - carriers of different points of view allows us to expand the range of technological options put on the discussion agenda and challenge the dominant options. Different options are compared in an abstract function space.
Drawing up a technology roadmap	Planning error (planning fallacy) - unfounded optimism and underestimation of the time required for the "maturation" of technology.	Regular review of the roadmap, deadlines, and costs, identification of potential "failures", and the decomposition of the problem into more specific tasks.
User analysis	The "false consensus" effect - the tendency to project an individual way of thinking onto others, which leads to an underestimation of the share of potential users and an overestimation of the scale of technology adoption.	Regular systematic analysis of the reasons why users reject technology
Technology Maturity Analysis	The social desirability effect is the degree to which technology maturity is underestimated and insufficient attention is paid to negative signals.	Regular system analysis of the technology's compliance with the declared functionality, assessment of potential failures at different stages of its life cycle
Market Analysis	Anchoring effect bias: rorecasts of the size of a new market are unreasonably tied to statistics on existing markets.	Creating an alternative "mental anchor" allows for a scenario in which the majority of users reject the technology.
Policy formation	Excessive confidence in one's own expert experience (overconfidence). It is expressed in a lack of understanding among politicians of how to apply Foresight results formulated by professionals.	Increasing the efficiency of communication between experts and decision makers and boosting their involvement in the Foresight process at the initial stages

Source: adapted by the authors based on (Bonaccorsi et al., 2020).

diversity, negation, and abstraction can mitigate biases that arise at any stage of the forecasting process.

Recently, tools have appeared that can directly or indirectly contribute to their leveling: full foresight, FAROUT, triangulation, and self-assessment. When evaluating Foresight studies, it is necessary to take a retrospective approach, comparing current indicators with the results of technological Foresight obtained in the past, which complicates the process.

In Table 1 we systematized the main types of cognitive distortions that manifest themselves at different stages of technological Foresight and suggest approaches to overcoming them (Bonaccorsi et al., 2020) (Table 1).

Based on this, our study attempts to evaluate the results of an energy Foresight study, Egypt LEAPS, in terms of the results achieved and the forecasting process itself.

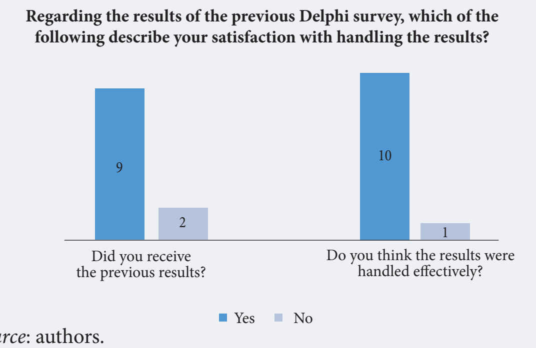
Foresight for the Egyptian Energy Sector

The first energy foresight study for Egypt - Egypt LEAPS - was initiated and implemented by the Academy of Scientific Research and Technology (Academy of Scientific Research and Technology, ASRT) in collaboration with Nile University (Nile University) and industry research centers (Rezk et al., 2019) in 2017. The national energy sector needed to develop scenarios, taking into account technological, legal, social, and political aspects. Two scenario horizons were defined - until 2022 and 2027. Implementation also took place in two stages. The first was a two-round Delphi survey, which examined about 180 topics, including technological and non-technological ones. They were distributed in 14 areas, including energy efficiency, creating an enabling environment, the use of fossil fuels and renewable energy sources. The timing of their technological "maturation", introduction to the market, and the beginning of widespread practical use in Egypt was predicted (Rezk et al., 2019).

For the interim assessment of the project's results, three of these areas were selected: solar energy, energy efficiency, and fossil fuels. The overall effectiveness of communication in Egypt LEAPS and the accuracy of forecasts obtained using the Delphi survey were assessed five years after implementation, upon reaching the first horizon (2022). To assess the effectiveness of the Foresight process, an online survey was conducted of experts who expressed their level of satisfaction with the communication and the results obtained. Then the level of implementation of the assumptions made about certain directions of energy development was measured. Initial statements regarding expected implementation times made in 2017 were compared with the times reported by respondents to our 2022 assessment survey.

On this basis, conclusions were drawn about the correctness of the Egypt LEAPS forecasts. Since the first of the horizons has already arrived, it became possible to conduct an intermediate assessment. If

Figure 3. **Respondent Views on the Handling of the Results of Previous Foresight Projects**



Source: authors.

Table 2. **Correspondence Scheme Adopted to Determine the Accuracy of the Original Foresight Statements**

Egypt LEAPS Prediction	Expert Opinion in our Study	Verdict
2022	2022	Success
2022	2027	Failure
2022	Not yet realized	Failure
2027	2022	Failure
2027	2027	Success
2027	Will not be realized	Failure

Source: authors.

the events predicted for 2022 did not actually take place, these forecasts were classified as erroneous. As for the second horizon for 2027, if respondents agreed with its feasibility, then the reliability of the developed forecasts was considered maintained. If it turned out that the forecasts in question were realized ahead of time, or their horizon should be revised (for example, postponed beyond 2027), then they were also considered not relevant. Table 2 shows the correspondence diagram used to evaluate the accuracy of the initial predictions.

Case Analysis Results and Discussion

Survey results were collected separately for each of the energy areas considered: solar energy, energy efficiency, and fossil fuels.

Our analysis of the Egypt LEAPS results included 28 experts. It is noteworthy that all of them were involved in the evaluated Delphi process in 2017, but after five years only 11 of them remembered that they took part when they were sent invitations, which confirms the relevance of the problem of cognitive factors raised in the previous sections. Such cognitive lapses give reason to doubt the reliability of other results.

The majority of the respondents (55%) in our survey confirmed that the research directions chosen for Egypt LEAPS were initially relevant.

Satisfaction with the level of organization of the project was expressed by 36% of the respondents, the degree of agreement with the final scenarios was 9%.

This may indicate that the participants did not have sufficient knowledge and preparation for such projects. Some of those who were truly involved expressed satisfaction with the experience. Almost all of them highly appreciated the degree of accessibility of the project results and in general characterized their processing as effective (Figure 2).

The effectiveness criteria themselves were assessed based on several answer options (Figure 3). It is noteworthy that the experts were not aware of the algorithm for processing the completed Egypt LEAPS questionnaires; there is no description of it in the final report. The document also does not mention the subsequent use of the Delphi survey results. However, since stakeholders did respond to our question, we believe that they expressed their personal opinion about the importance of the project results.

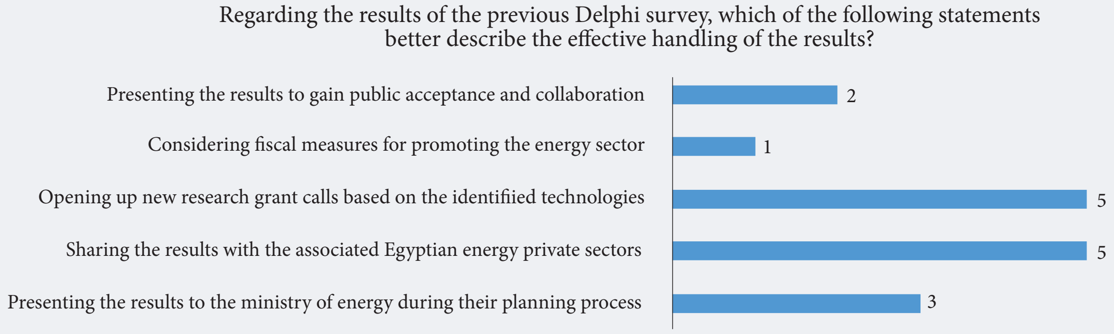
To evaluate the results of the Delphi surveys, a correspondence table was constructed between the initial forecast estimates of Egypt LEAPS, the actual data as of 2022, and the new assumptions from our survey participants. There were more accurate forecasts than incorrect ones, although not by much (33 versus 26), which suggests the relative success of Egypt LEAPS. However, more research is needed to identify the corresponding patterns (if any exist at all). An in-depth analysis showed that the majority of erroneous forecasts were related to energy efficiency (75% of those were not confirmed). Estimates for fossil fuel and solar energy use were more accurate (18% and 36% incorrect, respectively). This can be explained by the fact that improvements in energy efficiency are more difficult to predict. This area is characterized by a high degree of interdisciplinarity - its development depends on developments in areas, including those outside the energy sector (for example, materials science, electrical engineering, etc.). There was no significant spread of successful and erroneous forecasts regarding the timing of technological and social implementation (Table 3).

Table 3. **Number of Successful versus Failed Predictions on Foresight Project Results**

Type	Success	Failure
Technical	17	13
Social	16	13

Source: authors.

Figure 4. **Respondent Statements Assessing the Handling of Foresight Project Outcomes**



Source: authors.

In the Foresight project we studied, the level of involvement of politicians was insufficient, which caused the results to be disseminated inappropriately. As a result, they were unable to adequately influence decision-making. On the other hand, an unsatisfactory effect can be considered a starting point for rethinking approaches to organizing subsequent Foresight projects and communication between participants in order to achieve their deeper involvement.

Conclusion

In the context of accelerating technology development, Foresight is an important tool for effective development strategies. The objective of this study was to evaluate the results of the energy foresight project Egypt LEAPS, based on a Delphi survey.

We interviewed the experts who participated. They were asked to analyze the accuracy of forecasts made for a five-year horizon, which had already arrived at the time of our survey. In addition, respondents expressed their opinion about the effectiveness of the Foresight process within Egypt LEAPS. The following practical and policy conclusions can be drawn from the assessment.

Technological Foresight is a large-scale, expensive, and complex project that operates with a variety of methodologies and concepts that require the careful assessment of each stage for their manifestation, including the consideration of the cognitive biases of the participants. This is especially true for developing countries, where, due to insufficient institutional efficiency, there are further complications impeding the Foresight process.

To improve the effectiveness of future projects, it is necessary to understand what exactly happened after the implementation of the previous one. Our findings suggest that Foresight initiatives should include robust performance measurement mechanisms at the outset, rather than relying on ex-post approaches such as the one used in this study. We examined the potential of renewable energy in Egypt, primarily solar, and the practice of assessing Foresight, paying special attention to working with the cognitive biases of participants in such projects. For technology foresight to become an integral part of the policy development process and expert recommendations to be taken into account when policymakers make decisions, it is necessary to ensure an adequate level of participation of the latter in the foresight study. Measuring results and making incremental adjustments to the process are critical for building trust and motivation to reduce false assumptions, building on new ways of dealing with complexity and uncertainty in dealing with the future.

Our findings highlight the need for sustained government support and active implementation of technology foresight studies in the energy sector and other critical industries to effectively stimulate long-term innovation and policy development. Technological Foresight should be a permanent priority of public policy, since some short-term initiatives quickly fade away, and their effect turns out to be very small or non-existent.

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Stakeholders and Their Participation in Foresight Projects

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Abstract

With the expansion of the scope of foresight research, the role and importance of various participants in the relevant projects and the users of their results - stakeholders - simultaneously increase. Whereas previously a significant part of foresight projects were carried out with the involvement of professional experts, in many recent studies the circle of their participants is becoming more diverse and an increasing role belongs to members of the public and other potential beneficiaries. This article explores the theory and best practices of applying the stakeholder analysis method in foresight projects, and an attempt is made to systematically characterize this approach. The place and role of various stakeholders in foresight projects are considered, the main problems, opportunities, and recommendations for using the method are assessed, and the features of its application in conjunction with other foresight methods are characterized.

Keywords: foresight project; stakeholders; stakeholder matrix; Foresight methods

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Introduction

According to the most commonly accepted definition, foresight is a systematic participatory process designed to integrate all knowledge and build visions of the medium-to-long-term future, it is aimed at informing present-day decisions and mobilizing joint actions (European Commission, 2002). Interacting and engaging with experts, representatives of various governmental, social, and business institutions, and creating networks are the most important features of foresight projects (Miles et al., 2016; Gokhberg et al., 2016; Saritas et al., 2013).

Foresight studies are not exclusively expert-based, they allow for the inclusion of a wider audience upon whom depends the solution of relevant problems — the stakeholders. Mutual knowledge exchange, training, and joint action by all foresight participants are necessary to expand the project's scope and find common ground on existing challenges and possible scenarios of the future. In recent years, the stakeholders' role in such projects has been growing as their involvement contributes to the knowledge base as well as the validity and practical implementation of the results (European Commission, 2015).

Stakeholder analysis has been used for a rather long time in addressing different aspects of selecting and involving foresight projects' participants. It was initially applied in 1930s during studies of corporate social responsibility (Lindborg, 2013). In 1963, the Stanford Research Institute suggested a term "stakeholders" for "groups without whose support the organization would seize to exist" (SRI, 1963). However, such an interpretation did not include questions of strategic management which were reflected in the book by Robert Freeman "Strategic Management: A Stakeholder Approach" (Freeman, 1984). The author noted that business solutions which do not take ethics into account might possibly lead to negative consequences, and was looking for an opportunity to include ethical aspects into organizational strategy.

After being integrated into the strategic management agenda, stakeholder analysis helped formulate principles of stakeholders' interactions and management (Harrison, John, 1996). This approach works as a set of instruments for managing stakeholders that includes descriptive and instrumental methods, but does not fall into one theory (Donaldson, Preston, 1995).

In recent years, the stakeholder analysis has been used on a larger scale. According to Scopus-based publication analysis for 2010–2022, for keywords "stakeholder analysis", the major areas of its application include corporate management, sustainable development, urban development, regional planning, information systems, agriculture, healthcare, and so on. (Figure 1). In these and many other areas, stakeholder analysis method is used for solving various tasks in many socioeconomic spheres, of which examples are provided in Table 1.

Stakeholder analysis is applied not only to study the present-day situation, as shown in the examples provided above, but to build foresight-based visions of a long-term future. Such an application of this approach is explored in this article. Although experts and stakeholders are posing as key participants in foresight projects, their roles are often overlooked, they are simply made note of in a list of other items of the process. Further, an attempt has been made to give a systematic assessment of this approach, to analyze stakeholders' place and role in foresight projects and evaluate the major risks and opportunities related to involving them.

Stakeholder Analysis Method

In the most widely accepted definitions, stakeholders are seen as parties interested in the project, who can affect or are affected by its results (Freeman, 1984; Body, Paton, 2004; UNECE, 2021). In further analysis, we will use these definitions as the ones that most fully reflect the different roles and positions of stakeholders when implementing projects, including foresight. With the help of this method, the following stakeholder features are considered: legitimacy, necessity, agility (Mitchell et al., 1997; Tsipes, Shadaeva, 2015; Mainardes et al., 2012); nature of influence on the organization (threatens or facilitates its activity) (Savage et al., 1991); and absence or presence of formal ties (Clarkson, 1995), etc.

Stakeholder analysis studies groups interested in implementing a project (participating in project development or affecting it), with the goal of adopting decisions that consider their opinion. Such groups may represent organizations form different spheres and areas of science, economy, government, and society. The results of applying this method are the identification of key stakeholder groups, their mapping,[1] making recommendations to interact with them and achieving desired outcomes.

The implementation of this method is a complex multistage process, where the number and types of participants depend on the objectives, tasks, and resource base of the project. Usually, the majority of projects try to involve a broad spectrum of participants subdivided into following types (Andersen et al., 2021):

1. Experts possessing professional knowledge and experience in implementing the project.
2. Representatives of organizations interested in project results (policymakers, potential beneficiaries of various project results).

[1] https://www.stakeholdermap.com/stakeholder-theory-freeman.html, accessed 17.03.2023.

3. Citizens and members of a wider audience with various degrees of impact upon project results.
4. Personal stakeholders — various individuals interested in the project.
5. Remarkable people having expertise, creativity, knowledge, but not necessarily participating in the project directly.

In the majority of projects, the first two or three types of stakeholders are taking part, a composition designed to reflect the full possible spectrum of representatives of socioeconomic and other spheres of society. In some cases, attracting personal stakeholders is highly advisable, for example, opinion leaders.

Stakeholders may work as experts and vice versa, but sometimes their roles differ. If the qualities of the stakeholders traditionally depend upon their interests and often intellectual rights on project results, the second are identified by formal qualifications, knowledge, and experience. However, these two categories could partially coincide, interchanging roles. Their specific place in the project depends on the work in which they are involved.

The implementation of this method usually requires specific supporting resources (finances, equipment, etc.) at all stages — from short-listing candidates for participation to analyzing the results received from collaboration with stakeholders. Involving the latter in a specific project helps in building a tailored structure for the problems at hand, outline possible solutions, develop measures to achieve the stated objectives on the level of individual projects, or on a sectoral or governmental level depending on the scale of the problem.

The key stages of a stakeholder analysis are provided in Figure 2.

Stakeholder selection and modes of working with them (workshops, interviews, surveys, etc.) is a labor-intensive process implemented under the guidance of a project's working group and formed at its initial stage. Let us take a closer look at each stage.

Preparation

The initial stage sets the objectives of stakeholder analysis and areas for applying the achieved results; a working group is formed; members of a working group receive training; and an action plan is composed. To prevent the possible distortion of results, the working group must represent the interests of various institutions. The greater objectivity of the results is secured by including members who do not have a vested interest in the project results. The working group develops specific stages and actions which are required for the analysis and works out an execution schedule.

At this stage a list of candidates to stakeholders is formed, where communication with many participants requires considerable efforts. Preparatory organizational work is conducted to prepare to workshops, interviews, and surveys. Going forward, members of the working group will coordinate arrangements with stakeholders and process the achieved results.

Identification of Potential and Priority Stakeholders

Depending on the objective of the project and available resources, the working group decides on the maximum number of stakeholders. Based on the corresponding sources of information, a first selection round is conducted to choose potential candidates who may be interested in the project. Then, after consulting with experts, the most relevant stakeholders are short-listed. Candidates are ranked during a preliminary assessment of their influence, and then following features are compiled:

- position and organization;
- affiliation with internal or external stakeholders (directly or indirectly related to project);
- understanding of the subject area of the project;
- stakeholder's interest in the project and the level of influence of project results upon the stakeholder;
- access to resources;
- level of stakeholder's influence on the implementation and results of the project;
- leadership qualities.

Interactions with Stakeholders

There are different foresight methods to receive the necessary information. The most widespread tools are workshops, interviews, and surveys; the Delphi method is rarely used.

When getting ready for the workshop, working materials include a detailed description of discussion topics and the workshop scenario is also provided. After that, invitations are sent to participants and their presence is secured. This helps the organizer receive more detailed information from participants and achieve consensus among stakeholders during their direct interactions.

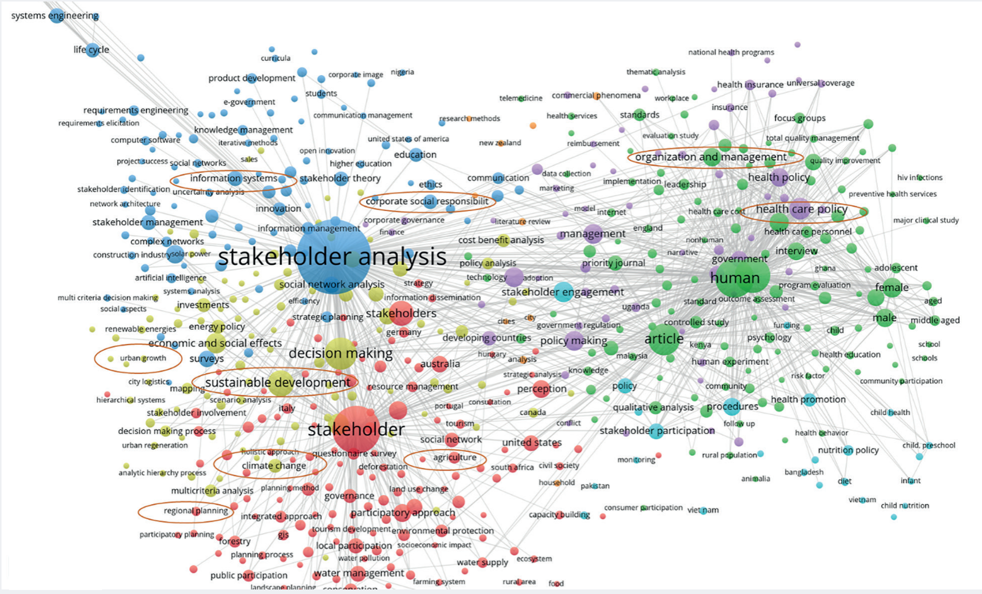
Before conducting the interview, its format is established — open discussion or formal questions. The duration of the interview is determined — from 20 minutes to two hours. The protocol that interviewer is required to follow is adopted by the working group. The questionnaire is tested on the candidates that were not included on the final list of stakeholders.

The survey is superseded by making a formalized questionnaire, and the gathering of information is conducted either in the form of interviews or by sending out questionnaires on paper or electronically and the processing of received data is subsequently conducted.

Gathering and Processing of Information about Stakeholders

Before starting an interview, a survey, or a workshop, gathering and studying secondary data about stakeholders takes place. Then, the working group com-

Figure 1. **Subject Areas of Publications Related to Stakeholder Analysis**



Source: built by authors with the use of VOSviwer based on Scopus publication analysis for 2010–2022, for "stakeholder analysis" keywords.

municates to all participants that they were selected in the order of their priority and invites them to discuss conducting an interview, a survey, or a workshop. All information is gathered in a unified database of the project for further analysis.

Stakeholder Analysis

At this stage the level of influence and interest of stakeholders is assessed. The results are shown in a stakeholder matrix (Table 2).

Under "Influence" we understand here a possible stakeholder's input into the achievement of stated objectives, and that input's influence upon decision-makers. Under "Interest" we imply the subjective value of the project results for the stakeholder from the point of meeting that stakeholder's interests and needs.

Apart from key indicators of influence and interest, the following additional information about stakeholders may be evaluated and analyzed:

- degree of awareness about the project;
- attitude toward the project;
- suspected pros and cons of the project;
- potential alliances among stakeholders, etc.

Development of Stakeholder Management Measures

Based on the conducted analysis, a stakeholder management mechanism is developed based on their ranking by level of Influence and Interest. If a stakeholder is either influential or motivated, then it is appropriate to engage him/her in implementing the project. If both attributes are present, he/she is considered a key stakeholder and should be involved in the coordination and implementation of the project to the fullest extent possible. Specific events to interact with stakeholders are organized bearing the specific features of each group in mind (Table 3).

Stakeholder analysis helps one identify persons capable of affecting the achievement of stated objectives; define potential barriers on this path; evaluate means, order, and principles of communication in the course of implementing the project; and make an action plan to get rid of the possible negative influence of stakeholders. In doing so, it is easier to optimize the implementation process itself, as well as fulfill planned events after its completion.

Then, using the example of a foresight study based on the shipbuilding industry, a stakeholder matrix is built (Slunge et al., 2017). There are 12 key stakeholders in the matrix that are being analyzed — governmental institutions, associations, groups of interests, research teams within and outside the country, companies, trade association, and others. They are distributed by the level of Interest and Influence (Figure 3). In this regard, ship classification societies[2], for example, constitute interested and influential stakeholders which ought to have maximum involvement in the project. National and open vessel registers have a high level of Influence, but low Interest, which is why their opinions are to be considered on an individual basis. Ship passengers and carriers have the lowest level of Influence

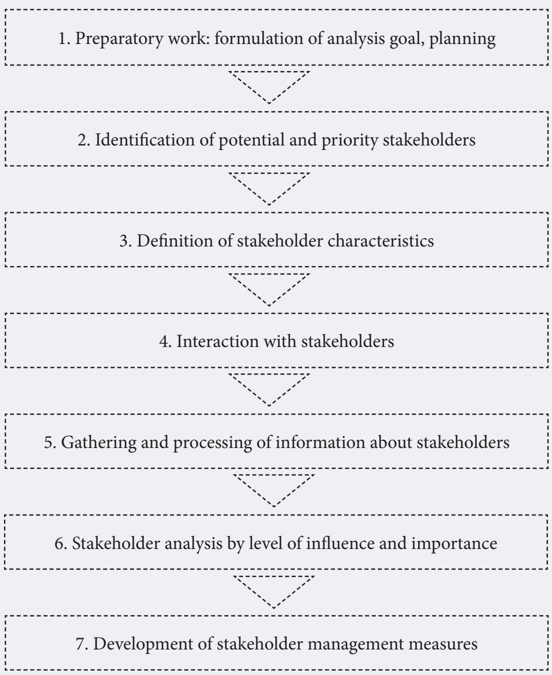
[2] Institution registering vessels and assessing their quality with the help of "ship surveyors" according to shipbuilding rules of various types.

Table 1. **Areas Where Stakeholder Analysis is Applied**

Application	Literature
Organisation management, corporate responsibility	
Corporate diversity management	Maj, 2020
Management of strategic decision-making	Slabá et al., 2020
Sustainable development, climate change	
Prioritisation of sustainability management measures in the socio-ecological system of a particular region	Guaita-García et al., 2022
Upgrading land resource management and environment conservation	Shantiko, 2021
Studying social aspects of sustainability in renewable energy sector	Afshari et al., 2022
Urban and regional development	
Formation of a transdisciplinary agenda through inclusion of citizens, experts, and stakeholders, which enables comprehensive consideration of aspects and possibilities of developing various urban economy sectors and formulation of a long-term strategy	Gudowsky et al., 2017
Optimisation of urban resource management and achieving higher living standards of the population	Pramono et al., 2022; Olander, Landin, 2005
Information systems	
Interactive use of management systems in IT projects	Mir, 2021
Innovation activity	
Study on the role of stakeholders in creation of new products by science and technology-based startups	Iglesias-Sanchez et al., 2022
Analysis of relationships between stakeholders and technological entrepreneurs in R&D-based startups	Kalayci, 2017
Agriculture	
Study on roles, organising capabilities, and forms of cooperation of stakeholders in the African agricultural innovation system	Chinseu, 2022
Healthcare	
Building long-term scenarios and forming key strategies of transferring to sustainable healthcare with multiple-stakeholder participation	Pereno, 2020

Source: composed by authors based on materials from provided articles.

Figure 2. **Key Stages of Stakeholder Analysis**



Source: authors, based on (Schmeer, 1999; Andersen et al., 2021; Reed et al., 2009).

on shipbuilding, so it has to be enough to simply keep them informed.

Apart from the stakeholder matrix, there are other data visualization tools to be used, in particular when it comes to Influence on and Interest in project results (tables, stakeholder circles, etc.).

In most cases it is expected that the role and meaning of stakeholders remains unchanged over the course of implementing the project. This is usually applicable to projects short in duration, where stakeholders' roles are outlined well enough and connected to fulfilling a limited scope of tasks. However, when it comes to large national or business projects related to acute socioeconomic issues or topical business issues, the Influence and Interest of any given stakeholder may vary significantly at different stages of project implementation.

We will illustrate this point by using a case of the Malmö–Gothenburg railway transformation from one-rail to two-rail (Olander, Landin, 2005). Its route passed through several settlements, including the city of Lund. The three stages of this project that superseded the beginning of its implementation were undergone from 1990 to 2003. The main project's stakeholders are given in Figure 4, as well as assessments of their Interest and Influence — on a scale from 1 (min) to 10 (max). As we see from the reviewed stages, both the composition of stakeholders and their indicators changed. The most interested were local residents and the national railway administration, and most influential — national railway administration, municipalities, and Sweden the government.

Since large long-term projects diversify the composition of stakeholders, their knowledge and requirements, their attitudes toward expected results and preferable communication strategies, an additional or multiple stakeholder analysis may be required for considering the possible dynamics of their features until the full completion of the project.

Role and Place of Stakeholders in Foresight Projects

The most important outcome of foresight projects is applying their results in decision-making to achieve the objectives of socioeconomic and science and technology (S&T) policy. The stakeholder analysis method allows for choosing those participants who affect not only the development of possible recommendations but their implementation as well.

The key factor of successful project implementation consists in the active involvement of stakeholders with a high level of Influence. They are typically executives of professional agencies under the public authorities, which include large firms or research institutes and their deputies. A stakeholder's influence may manifest itself in the use the project results, raising awareness about the project, and the promotion of legal solutions facilitating its successful development.

The stakeholder analysis method and its individual components are effective during all stages of foresight projects — from setting an objective to preparing recommendations after receiving results. Only those capabilities that fully adhere to the desired results may be used: forming the vision, building scenarios, making a roadmap, and son on. In large foresight projects, stakeholders usually participate in all stages. Depending on the subject and objectives of a research study, they can be representatives of science, education, business, public authorities, or civil society.

The methods of working with stakeholders within foresight projects help:

- outline a circle of involved persons, including experts, and evaluate their role in the project;
- motivate stakeholders to achieve the stated objectives and engage them in making conclusions about project results and following up with recommendations afterwards;
- evaluate the input of certain stakeholders' actions in implementing recommendations.

In order to successfully implement a foresight project, it is necessary to answer the following questions: when, how, and in what measure do various project participants need to be involved in certain stages? What stimuli enable their involvement and increase Interest in success? What materials are required to be provided? How does one promote project results among all stakeholders (Saritas et al., 2013). The method under review in combination with workshops, interviews and surveys, scenario planning, and roadmaps, helps in answering the majority of these questions.

Table 2. **Stakeholder Matrix**

Level of influence	Level of appeal	
	N/A / Low	**Medium / High**
High / Medium	C	A
Low / N/A	D	B

Source: authors.

Stakeholder Selection

Any foresight project starts with selecting its potential participants and contacting them. Both recognized experts well acquainted with existing challenges and trends as well as potential recipients of the achieved results or developed recommendations may be engaged. At the stakeholder pre-selection stage, the reviewed method may be combined with a deep analysis of literature, bibliometric indicators, or patent analysis. Such a comprehensive approach enables the identification of key authors of publications and patents who could potentially participate as project stakeholders.

At the preparatory stage of the project stakeholders may make considerable inputs into forming the information base of the project, scanning the outside environment, identifying challenges and trends, and choosing the focus of the research subject.

Involving and Communicating with Stakeholders

At the main stage of the foresight project implementation, working with participants and gathering necessary information also suggests combining stakeholder analysis with workshops, interviews, and surveys. Stakeholders may participate in one or several workshops, and their number may vary from 10 to 30 people, in individual cases reaching 50 or more. The interviews may be conducted in an open or structured format, which lends higher flexibility to obtaining information from participants that have no exchange of information between them. Surveys are more formal. Receiving questionnaires from stakeholders usually requires more time and effort, and the efficiency from the data gathering point of view is lower, than when conducting interviews. Often stakeholder interviews (surveys) are conducted simultaneously with workshops: for example, before the first session, in-between them, or after they have ended — to assess the results.

Involving stakeholders helps enlarge the base of existing knowledge on the subject of the project and receive

Table 3. **Interaction Mechanisms with Various Stakeholder Categories**

Degree of Interest / Influence	Common interaction strategy	Set of measures
High / High	Maximum involvement	Key stakeholders contributing the most to achieving stated objectives. It is advisable to constantly increase the Interest of this group and satisfy its basic needs using partnership principles.
Low / High	Consulting	Coordination of important strategic decisions about the project using principles of consulting participation.
High / Low	Receiving support	Casual participation in the project that does not suppose obligatory direct involvement, only discussion of possible issues and support of important decisions.
Low / Low	Notifying	Informing and minimal involvement in the achievement of required tasks.
Sources: composed by authors.		

new knowledge. Working with stakeholders is the most important element when creating a vision, building scenarios, choosing alternative future variants, developing strategy, and receiving other end results. At the final stages stakeholders may help with providing recommendations after the results of the project and could facilitate their implementation.

A stakeholder's input into the results of a foresight project considerably depends upon the affiliation with a particular group: decision-makers, key experts, and business representatives lead in creating the common vision; experts make a contribution to developing possible results and their effects; ordinary members of business communities evaluate these results; and citizens discuss possible socioeconomic effects. Specific forms of stakeholder participation depend on the type of tasks at hand and desired results. For example, when forming scenarios, the efficient form of reaching consensus among stakeholders with opposing interests are workshops. Thanks to the professional moderators, the uncodified knowledge of workshop participants is formalized during such sessions and there is a transfer from the clash of opinions to developing a common vision reflecting various values and interests.

Below you will find a brief showcase of main possibilities of stakeholder analysis in combination with other foresight methods, structuring and optimizing the project implementation process itself, as well as the implementation of stated objectives after its completion.

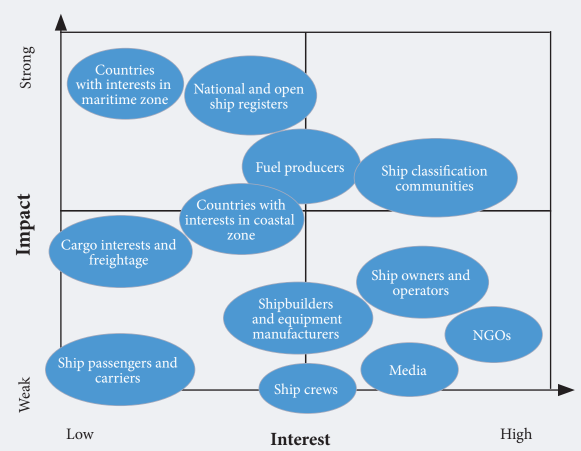
Creating a Vision and an Image of the Future in Working Groups

The advantage of holding sessions with working groups, and not interviews or surveys, lies in the direct interactions between stakeholders, which facilitate their common training, exchange of information, and create a feeling of co-creation concerning the received results. There is a series of workshops (on average from two to four) that are often conducted during the project implementation to develop, receive, and check the necessary information and jointly develop an image of the future.

A constructive case of utilizing such a method is a foresight study that applies blockchain technology in industrial transformation (Pólvora et al., 2020), which was implemented in 2017 under the order of the European Commission. There, the stakeholder analysis was applied in combination with workshops and several other methods.

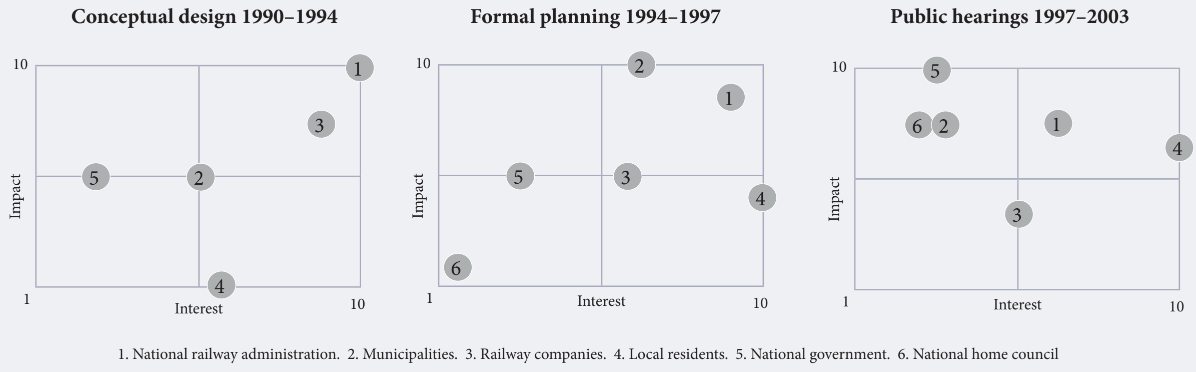
At the beginning of the project, there was a round of selecting a wider circle of stakeholders with different experience and interests, including technical experts and developers, researchers from socioeconomic sciences and law, blockchain-related business representatives, civil society, analytical centers, authorities at the city, regional, national, and supranational levels, including various services of the European Commission, European Parliament, UN, OECD, and WEF. After mapping, 270 individual and collective stakeholders were selected for the subject area of "blockchain", to whom invitations have been sent to participate in offline workshops and online surveys. Communication with them was performed in a series of three workshops with the same objectives and tasks, which helped to study and create a vision of the future opportunities for and applications of blockchain. The assignment to a particular workshop depended on the field of expertise and competence of participants.

Figure 3. **Stakeholder Matrix for the Shipbuilding Industry**



Source: (Slunge et al., 2017).

Figure 4. **Trends in the Positions of Project Stakeholders**



Source: (Olander, Landin, 2005).

The first workshop with 34 participants was dedicated to outlining actual and future challenges and opportunities for blockchain taking into account political, economic, social, technological, legal, and environmental aspects. The second workshop with 25 participants was dedicated to scenario planning for the manufacturing, dissemination, and use of blockchain applications in five sectors chosen during the first stage. At the final workshop with 23 participants, results from preceding stages were integrated with a focus on providing policy strategies for the digitalization of manufacturing and business processes and for the implementation of technologies and innovations by small and medium-sized enterprises.

The key project deliverable was obtaining a common vision, design, and creation of five prototypes implementing blockchain in advanced manufacturing, the energy sector, transportation, logistics, the health sector, and creative industries in the short and long term.

Scenario Planning and Stakeholders' Role

Common vision and other information received during workshops with stakeholder participation may work as tool for building scenarios immediately during the sessions or when implementing a project. Moreover, scenarios may be verified in additional workshops, interviews, or surveys with stakeholder participation.

During scenario planning stakeholders may be performing various functions, the main of which are presented in Table 4.

As an example of scenario planning with the involvement of various groups of stakeholders in combination with other methods (for example, panels of citizens and experts), we could study new governance models within the horizon of 2030 (JRC, 2019). It was focused on possible social, technological, and economic changes and factors prompting the appearance of new forms of governmental and societal management. A moderated dialogue between stakeholders was conducted in the format of working groups, where the base, structural elements, and development scenarios of future governments were being discussed, as well as in a format of a game that helped build and analyze participant interactions to evaluate possible forms of governance.

Prioritization and Development of Roadmaps and Support Mechanisms with Stakeholder Involvement

At the final stages of foresight projects stakeholders may be engaged to draw up a system of priorities, to develop roadmaps and support measures for the solution of existing problems, and to choose a trajectory of further development. Here, interacting with stakeholders is also done by way of workshops, interviews, and surveys.

Thus, in 2020–2023, the European Commission implemented a project evaluating the potential of key enabling technologies (KETs) and stakeholder preferences in this sphere. KETs are capable of significantly changing the daily lives of people, which is why it is important to engage a wider spectrum of participants in discussing them at various stages of the innovation process. Around 50 stakeholders have been engaged in the project from the manufacturing and public sectors, from spheres of business, innovation, research and development, and politics. The public was represented by citizens, NPO employees, trade unions, consumer rights protection organizations, and the media. New technologies have been discussed with them during interviews, as well as their influence on various spheres of life and the products created using KETs.

A foresight study dedicated to working out plant protection measures and food manufacturing development with the conservation of biodiversity and stable revenue for farmers was conducted by the European Parliament in 2020 (European Parliament, 2021). During the project, a plant protection measure (PPMs) analysis was conducted with the consideration of main stakeholders' opinions with regard to the development of support measures. The interests of various stakeholders interested in implementing PPMs were studied: consumers (private consumers, retail merchants,

Table 4. **Functions Performed by Stakeholders within Scenario Planning**

Scenario planning stages	Stakeholder functions
Scanning of environment	• Assessment of the present-day situation • Providing information about main challenges, trends, and factors influencing the future development
Ranking (prioritisation) of trends and challenges	• Identification of criteria for prioritising trends and factors • Defining most important development trends and factors
Creation of storylines, scenario generation	• Providing information to create storylines and develop scenarios • Participation in creating storylines and scenarios
Building scenarios	• Discussion of preliminary scenarios • Adjustment of preliminary scenarios • Prioritisation of scenarios
Formulation of methodology	• Identification of criteria to choose the measurement system • Determination of possible measures in accordance with identified criteria

Source: (Andersen et al., 2021).

representatives of food industry), manufacturers (farmers), suppliers (PPMs producers), and the public (citizens and NPOs). The analysis of stakeholders in any way related to PPMs was driven down to assessing the influence on them of the current protection measures and the potential transfer to alternative methods with consideration of existing and potential challenges in crop farming.

In 2014, the HSE University conducted a project with involvement of leading experts and decision-makers to update the priority areas and the list of critical technologies of the Russian Federation under the commission of the Russian Ministry of Science and Higher Education, within which recommendations were prepared to adjust the current lists of such technologies (Sokolova et al., 2018). A preliminary list was formed with the active participation of experts of the highest calibre — participants of federal executive authorities (FEAs), the Russian Academy of Science, development institutions, leading research centers, national research universities, and business communities.

At the next stage, a survey was conducted on the priority areas of science and technology, selected in accordance with the current list and top-level priorities of leading foreign countries. Among its participants were the representatives of all FEAs responsible for the support of the development of the main economy sectors and the decisions of the most important social tasks. The results of the survey and other expert procedures were brought up for the discussion in the working groups for each subject area and were summarized by an interdepartmental working group. After that the updated lists were cross-referenced with key stakeholders — representatives of the FEAs and the government.

In the study (Sajadi, 2019), a roadmap is prepared for the Iranian healthcare sector. Nine projects were being implemented simultaneously in different areas, one of which had two stages and a stakeholder analysis. The first stage consisted of identifying the barriers and drivers of the sector with the help of a focus group and brainstorming with research team members and several profile experts. At the second stage, some interests were identified that should be considered when implementing measures reflected in the roadmap. To study the influence, position, and interest of stakeholders, a specialized survey in the form of interviews was conducted. The selection criteria were: the level of stakeholders' expertise, their influence, and experience in participating in events dedicated to healthcare development. The results of the survey helped create a stakeholder matrix (based on parameters of Interest and Influence). At the final stage, some interaction strategies for each stakeholder group were proposed.

Conclusion

The reviewed cases and opportunities for attracting stakeholders into foresight projects prove that their participation adds to the relevance of the results and boosts the quality of adopted decisions, as it provides for a wider range of questions being discussed and a higher completeness of information available to (often in a nonformal way) governmental institutions, academia, business, and civil society. Such discussions allow for predicting and mitigating possible drawbacks. Other than that, the transparency of project implementation procedures due to plethora of stakeholders' opinions, increases the level of trust in obtained results and the relevance of the developed recommendations.

In order to implement a project effectively, it is prudent to attract stakeholders at all stages of the project, especially those initiatives characterized by a lack of information and a high level of uncertainty of the consequences of adopted decisions. Involving stakeholders of various types allows one to formulate tasks more accurately and choose optimal consensus-based approaches to solving them, as well as to increase the chances for the successful implementation of the project.

Along with that, one should keep in mind several peculiarities of this method. First of all, there is a chance of corrupting the results by improperly selecting representatives from any group of stakeholders: the guarantee of high-quality end results rests in the representativeness of analysis participants. The prevalence of some strata or their opinions increases the risk of shifting focus when assigning tasks, creating (prioritizing) visions of the desired future, and developing practical recommendations. For example, the views of economic efficiency argued by experts may conflict with the demands for social responsibility coming from members of the civil society. And if some group of stakeholders is under-represented, their interests and needs may not be reflected in project recommendations.

When organizing foresight projects, it is important to avoid pressures exerted by experts and opinion leaders on other stakeholders or allowing a lack of experience or the level of qualification of separate participants to impact the results. Experts' flaunting of their opinions, for example, in front of members of the public, may lead to a corruption of the results. That is why when organizing stakeholders' communications, it is necessary to make provisions for special mechanisms minimizing that pressure. The problem may worsen if stakeholders lack experience in discussing important informative or technical issues, so it is necessary to outline the list of topics prior to discussing them, with consideration of the background and interests of the various participants. Stakeholders often lose interest in the project if it is badly organized or if the actual possibility of influencing the outcome of decision-making seems insufficient to them. All mentioned aspects should be taken into consideration when working with various groups of stakeholders.

As shown above, stakeholder analysis is usually applied in combination with other foresight methods. The most popular approaches include working groups, interviews, surveys, and scenario planning, which secure a relevant selection of stakeholders and the organization of effective communication between them to aid in reaching targeted results. The methods of working with stakeholders are constantly advancing. Participants are subjected to an increasingly closer analysis according to various criteria (above all, by the level of their interest and influence), their coverage is increasing, which promotes and strengthens the practice-oriented aspect of foresight projects while maintaining their analytical and expert potential.

Reviewed cases and a publication analysis of recent years, including with a high citation index, demonstrate the expansion of objectives of and opportunities for applying stakeholder analysis. For example, in a study of ecosystem services, it helps to optimize natural resource management mechanisms (Zhuang et al., 2019). No less effective may be to study stakeholders' interest in and influence upon corporate social responsibility (Farmaki et al., 2020).

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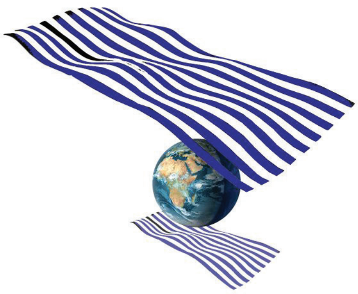

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