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ORIGINAL RESEARCH PAPER

A Framework for Future-Oriented Assessment of Converging Technologies at National Level

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Abstract Converging technologies require intelligent policy-making as they have significant capabilities to develop disruptive innovations. In this regard, future-oriented technology assessment is vital given the great uncertainty about the consequences of and barriers to accessing these technologies. However, few frameworks have been developed to evaluate converging technologies, and most of those have neglected the unique dimensions of these technologies. Therefore, this study aims to provide a policy-making framework for converging technology development. Accordingly, the proposed framework is designed through a meta-synthesis of previous technology assessment frameworks by considering the feasibility, challenges, and achievements of converging technologies development pathways (CTDPs) as the key factors. Then, the framework is implemented in a case study of Iran and an appropriate strategy for each converging technologies development pathway is proposed based on a quadruple matrix of achievements and challenges. The results show that in Iran, biotechnology and cognitive technologies have the highest and lowest development horizons, respectively; and surprisingly, the combined field of biotechnology-cognitive is the most promising pair combination of converging technologies.

Keywords NBIC (Nanotechnology, Biotechnology, Information technology, and Cognitive science) · Converging technologies · Future-oriented technology assessment · Converging technologies development pathways (CTDP) · Iran

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Introduction

Despite the movement of systems towards modularity in the 1990s (for example, in computer and automotive development), the convergence of technology and services was introduced in scientific circles at the beginning of the twenty-first century [1]. Following the publication of Wilson's [2] efficacious work, NBIC (Nanotechnology, Biotechnology, Information technology, and Cognitive science) convergence was announced in 2002 in a World Technology Assessment Center report [3]. This movement continued through three annual conferences held on NBICs foresight in the USA [4]. In that period, Roco emphasized the need for policymaking and governance of these technologies by publishing numerous reports and papers on various aspects of converging technologies [5–10]. These efforts gradually led to the publication of documents on NBICs by international organizations and institutions such as the European Commission [11], Rand Institute [12], OECD[1] [13], and UNIDO[2] [14].

NBIC converging technologies (further referred to as converging technologies in the article) are the technologies developed through the paired, triple, or quadruple combination of nanotechnology, biotechnology, information technology, and cognitive science. Integration and synergy are the two key features of converging technologies; this means that these technologies, by establishing a new platform and taking a holistic approach to technology development, lead to the creation of new opportunities, products, and capabilities that go beyond the separate application of their capacities. Furthermore, during the process of convergence, the components of converging technologies become integrated [15] as nanotechnology experts formulate the ideas of cognitive scientists, and these constructs are used in the field of applied biotechnology through the guidance and empowerment of information technology [16].

Notwithstanding that the converging technologies are in the early stage of their life cycle, these technologies have experienced tremendous growth during this period; for instance, based on the study of inventions from 1995 to 2011, the integrated use of converging technologies led to the creation of added value beyond the individual application of these technologies [17, 18]. Studies have also shown that the economies of developed countries will see significant development in the coming years due to innovations based on converging technologies, and will move towards the sixth long economic wave during the 2018–2050 period [19]. The convergence of technologies even affects the decisions and expectations of customers in terms of the integration of different product features, so customers will expect multi-purpose products in the long term [20].

In summary, the role of NBICs in economic development in the coming decades, on the one hand, and the need for intelligent support of their development and dissemination, on the other hand, lead to the development of policies that exploit the benefits of converging technology development and also take the necessary actions to tackle the probable risks of these technologies. Although various studies have addressed the importance of future-oriented analysis of converging technologies, especially through life cycle assessment, only two governance models in the field were found, one for the USA [7–9] and another for the European Union [11], which were too specific and context-dependent. Most scholars studied just one of the NBICs, disregarding its convergence potential with the others. The few studies regarding the convergence of the NBICs either focused on a very particular converging field (nano biosensors in [21]) or addressed the issue on a macroscale while neglecting the Converging Technologies Development Pathways (CTDP) [22]. Furthermore, these studies mostly focus on the future achievements of converging technologies, while the possible consequences and risks of these technologies are currently more or less unclear. In other words, policymakers make their decisions in a state of uncertainty about the conditions and consequences of converging technologies, so the use of future studies can be helpful. The lack of a future-oriented framework for the analysis of the converging technologies at the national level has therefore been identified as the literature gap. This framework should address the unique characteristics of the converging technologies based on previous experiences regarding the future studies of various technologies.

Over the last century, different techniques have been established and utilized for the anticipation and guidance of forthcoming technologies [23]. Future-oriented technology analysis (FTA), the term that was coined for such studies, explores the effects of emerging technologies on the environment and vice versa [24]. As FTA consists of various practices including technology foresight, forecasting, and assessment [25], many scholars refer to it as a toolbox rather than a uniform and proven methodology [26]. Therefore, the differentiation of FTA techniques is misleading as most studies apply a combination of them to achieve further insights.

Technology assessment (TA) is one of the major fields of FTA that illuminates the effects of technology and proposes appropriate policies for dealing with it. New generations of technology assessment are mostly policy studies about the social and environmental impacts of the dissemination of emerging technologies (such as NBICs) in society, guiding the policymaking process in the form of public decision-making and resource allocation through a set of alternative options and anticipated consequences [27, 28].

[1] Organisation for Economic Co-operation and Development

[2] United Nations Industrial Development Organization

It also implements a warning system to track, control, and change the route of new technologies development and dissemination by encouraging public participation in the challenges and social issues of science and technology, paving the way to better technology governance [29, 30].

The purpose of this paper is to design a universal framework for the future-oriented assessment of converging technologies at the national level, providing strategic suggestions for the planning and development of these technologies based on future research studies on various dimensions of NBICs technology convergence. Future-oriented technology assessment is defined as future-oriented technology analysis with an emphasis on technology assessment as the key to impact assessment. Thus, FTA studies of NBICs technologies are critically evaluated in the "Literature Review" section, while in the "Research Method" section, by using a meta-synthesis research method, a framework is proposed based on a systematic review of previous FTA frameworks (with an emphasis on technology assessment). Then, in the "Case Study" section, the framework is implemented for Iran (as the case study), and at the end, in the "Conclusion" section, the findings and results are discussed.

Literature Review

Future-Oriented Studies of NBICs

For a thorough analysis of the literature, the Scopus articles regarding the "analysis, assessment, forecasting, and foresight" of "nanotechnology, biotechnology, information technology, cognitive science, NBICs, and converging technologies" have been reviewed. Accordingly, 9 out of 1964 articles have been identified as relevant studies through the title-abstract-full-text filtering (Table 1).

The literature review indicates that although many scholars suggest that a new framework is vital for converging technologies assessment, which departs from technology-based, traditional, and exploratory forecasting to science-based, biology-based, normative, rapid, and robust planning [40–47], few researchers have assessed NBICs interdisciplinary aspects with a solid methodology. While most national foresight studies have studied each converging technology separately, international reports (such as [48] and [14]) have described technological applications of interdisciplinary converging technologies and suggested fruitful but proofless policy recommendations. Therefore, the research contributes to the literature by addressing the lack of NBICs technology assessment with a focus on the interdisciplinary aspects of the converging technologies. It should be noted that although the previous studies have not explored the aforementioned research question, their findings can guide this research in two ways:

1. The possible achievements of and barriers to the development of the converging technologies are widely discussed (e.g., the role of converging technologies in a smarter health and wellness future [49]) which are later reviewed to better understand the dimensions of the converging technologies.
2. The innovation pathways of converging technologies are referred to both in forecasting literature (e.g., nano biosensor technology applications [50]) and technical articles (e.g., biosynthesis of nanoparticles [51, 52] and quantum cryptography [53]), which are further explored for the development of CTDPs.

Iran's Status Quo in NBICs Development

Since the framework is designed to propose policy recommendations, it should be implemented at the national level, which is why Iran was chosen for the case study. There are two reasons for this choice; on the one hand, Iran is one of the few countries which have a relatively adequate knowledge base in each of the NBICs' research fields. On the other hand, the publicly funded approach toward NBICs development in Iran has not led to significant technological and economic spillover yet and therefore a national strategy for NBICs development is not only necessary but also applicable. To validate these statements, a brief overview of Iran's status quo in NBICs development is presented:

1. Biotechnology: While Iran's development of biological sciences dates back to the 1920s, the establishment of the National Research Center for Genetic Engineering and Biotechnology (NRCGEB) brought Iran into the modern biotech-

Table 1 NBICs future-oriented studies

Technology field	Researchers	Aim and method	Case	Results
Biotechnology	You et al. (2014) [21]	Patent analysis with convergence index (CI) and market index (MI) for nanobiosensors	---	Most promising convergence fields: electronics/communication-measurement, electronics/communication-chemical, machinery-material, machinery-chemical, and machinery-measurement
Nanotechnology	Nazarko et al. (2022) [31]	Creation of roadmaps, technology mapping, prioritization of technologies, and development of technology characteristics sheets	Podlaskie, Poland	Key technologies: (1) nanomaterials and nanocoating in medical equipment; (2) nanotechnologies for cutting tools and wood processing; (3) composite materials for permanent dental fillings; (4) topcoat nanotechnologies for biomedical applications; (5) nanotechnologies related to special fabrics; (6) powder technologies for use in plastics processing, paint, and varnish compositions; and (7) nanostructuring technologies for metals and light alloys. 4 scenario according to R&D intensity and the effectiveness of regional collaborations
	Masara et al. (2021) [32]	Scientometric review of the nanotechnology publications on the Web of Science Core Collection throughout 20 years	South Africa	Strategic research fields: Material science, photoluminance and optics, medicine, catalysis, electronics, energy, biotech, magnetism, sensors, water, and communicable diseases
	Vishnevskiy and Yaroslavtsev (2017) [33]	Nanotechnology foresight using both traditional methods (priority-setting, future visioning, global challenges analysis) and relatively new approaches (weak signals, wild cards)	Russia	Nanotechnology priority directions toward Russia 2030: (1) construction and functional material; (2) hybrid materials, converging technologies, bio-mimetic materials, and medical materials; (3) computer modeling of materials and processes; and (4) diagnostics of materials
	Su et al. (2010) [34]	Delphi-based foresight study with expert discussion	Taiwan	Field with the highest maturity: Nano Bio Medicine Technologies with the highest competitiveness: nanocomposite material technique, nano optoelectronic, and optical communication, and nano storage

Table 1 (continued)

Technology field	Researchers	Aim and method	Case	Results
Information Technology	Hemmat et al. (2017; 2019; 2021) [35–37]	Using key technology approach to identify the most important health information technologies (HIT) (phase 1: mind map of HIT based on literature review and expert panel; phase 2: identify key HIT for Iran using semi-structured interviews; phase 3: Delphi study to determine the importance, expected time frame, impact, and barriers of the key technologies)	Iran	Key technologies: (1) NHIN, (2) electronic health records, (3) national cloud-based service center, (4) personal health records, (5) interoperability standards for electronic data exchange, (6) infrastructure for information sharing, (7) telemonitoring technologies, (8) large-scale remote health services, (9) m-Health and its related technologies, (10) clinical decision support systems, (11) social networks in the healthcare environment, (12) electronic health insurance system, (13) business intelligence, (14) the integrated electronic monitoring system, (15) infrastructure for NHIN, and (16) infrastructure for m-health
	Chen et al. (2012) [38]	Two-stage foresight approach (Stage 1: critical technologies identification and evaluation by nationwide experts through Delphi surveys; Stage 2: estimation of values impact on attainment of foresight goals using a system dynamics simulation model)	China	Top technologies ranked: (1) large-scale manufacturing of 10-nm linewidth semiconductor integrated circuit with a density of 1000 G transistors; (2) wide adoption and application of the 4G wireless telecommunication technology; (3) communication-wide adoption of mobile communication with a focus on the picture and video transmission service; (4) computer-wide application of grid computing; (5) network-wide application of wireless intelligent sensor network; (6) communication-wide application of personal wireless information terminals with multi-function and multi-mode; (7) microelectronics, optic electronics, and micromechanics Wide commercial application of LED lighting technology; (8) broadcast and television-wide adoption of high definition digital television broadcast; (9) information safety development of emergency management information system for societal safety; and (10) information safety development of large-scale network safety defending system

Table 1 (continued)

Technology field	Researchers	Aim and method	Case	Results
	Bañuls and Salmeron (2008) [39]	Delphi–AHP approach	Spain	Relative ranking in the key groups: (1) e-business: Security & Electronic Payment Systems (EPS), Business-to-Business (B2B), and Customer Relationships Management (CRM) applications; (2) Internet and networking the extranets: Internet communication tools and Virtual Private Networks (VPN); (3) strategic and tactical: Business Intelligence, Executive Information Systems (EIS), and Decision Support Systems (DSS); (4) operational: Enterprise Resource Planning (ERP) industry solutions, ERP modules integration, and ERP downsizing; (5) IT infrastructure: data storage and server scalability.

nology era in the mid-1980s, since which time the scientific community has built up significant capabilities in various related branches of biotechnology under the supervision of the Biotechnology Development Council (BIODC[3]) [54]. Accordingly, in 2014, Iran ranked fifth in biotechnology production among Asian countries and 14th worldwide in published articles. The Pasteur Institute of Iran (IPI), the NRCGEB, and the Royan Institute (established in 1920, 1989, and 1991, respectively) are the key research institutions in this field. The IPI produces biopharmaceuticals and diagnostic kits related to infectious diseases and vaccines. The NRCGEB undertakes state-of-the-art research which has led to various achievements including the production of a recombinant growth hormone and a recombinant DNA hepatitis B vaccine. The Royan Institute is a pioneer research center focusing on stem cell biology and reproductive biomedicine, with applicable accomplishments in infertility treatment [55]. The development of recombinant proteins and medicines, animal cloning, tissue engineering, and bacterial diagnostic tools are considered the key advances in Iranian biotechnology research [56]. Biopharmaceuticals are the leading area of biotechnological innovation, accounting for 172 of the total 377 new technology-based firms (NTBFs) in the field. The most prominent biotechnological NTBF in Iran is CinnaGen, which has already produced various products (mostly biosimilar) including Cinnovex, ReciGen (Interferon Beta-1a), Cinnal-f (follitropin alfa), and CinnoPar (Teriparatide). Iran has also diffused biotechnology in the environmental crises, with the development of biofilter technologies for water recycling/reusing and dust stabilization using biological mulches. Iran has planned to increase its share of the global biotechnology market to 3% (0.62% in 2017) to become the regional leader in biotechnology development by 2025 [57].

2. Nanotechnology: The development of nanotechnology in Iran began in 2001 with technology-monitoring reports from some expatriate Iranian scientists in the USA directed to the Technology Cooperation Office (TCO), which is supervised directly by the Office of the President and is responsible for technology development in the country. TCO therefore created a committee to carry out studies related to nanotechnology development policies which later led to the establishment of the Iran Nanotechnology Innovation Council (INIC[4]) and the Iran Nanotechnology Laboratory Network (INLN) in 2003 and 2007, respectively [58]. As a result of such proactive strategies, nanotechnology has attracted much more attention among Iranian researchers than other converging technologies, ranking 7th worldwide in publications as a result in 2015 [55]. However, nanotechnology research faces two main challenges; the small number of international collaborations which are evident given the small number of articles with both Iranian and non-Iranian authors, and the slow pace of patenting growth which is less than one-fifth of the nanoparticle growth throughout 2007–2013. On the other hand, nanotechnology is mostly diffused in health care and upper stream nanomaterials (with 27 and 23 firms out of the total 143 in 2013, respectively) and the number of industry researchers as the main human resource index has grown from 568 in 2003 to 20,966 a decade later [59]. It should also be noted that future studies were more welcomed in this field, which led to 2 strategy plans; the first (2006–2015) focuses on infrastructure, public awareness, human resources, technology development, and international collaboration, and the second (2016 to 2025) is focused on industrialization, commercialization, international marketing, and again international collaboration [60]. Such efforts had led to scientific outputs as well, with Ghazinoory et al. [61] and Ghorshi Nezhad et al. [62] as an example.

3. Information technology: Although the earliest use of software in Iran dates back to 1962, IT was in widespread use at universities and offices in the 1970s. In the post-revolutionary period, software development expanded, with the creation of word processing in Farsi as a major example. In the 1980s, discussions led to the adoption of definite plans for the export of software, and later, with the adoption of the legislative mandate for development in 2003, a solid demand (mostly public) for software products was created [63].

[3] https://en.biodc.isti.ir/

[4] https://en.nano.ir/

Unlike other converging technologies, IT development was directed mostly on the basis of the market-pull innovation model agreed by both policymakers (including information technology, communication, and cybersecurity development council (ICTC[5])) and other actors, with the highest share of NTBFs (20.1%) in 2016 and the highest ratio of R&D investment to sales (7.5%) in 2012–2014. The financial analysis also approves the aforementioned development model, as the ICT and computer software has attracted significant financial support with 201 INIF[6]-approved knowledge-based projects and a 12.5% share of total INIF funding from 2012 to October 2016 (third field after biotechnology and electronics) [55]. This market-oriented approach has also affected the research realm given the decline of published articles after 2011 (Fig. 1). Information technology is also diffused in prominent industries, especially the automotive industry, natural gas and petroleum industry, and banking sector. The diffusion extent in the Iranian automotive industry is similar to that in European automobile firms. On the other hand, the insurance sector and the agricultural industries lag behind in the application of information technology [63]. All in all, Iran's digital economy share of GDP was 6.9% in 2020, which is less than one-third of the global average (22.5%) [64].

4. Cognitive science: Iran has started to pioneer brain and cognitive science studies in the region (2nd in the Middle East in terms of publications in the cognitive neuroscience field for instance) following the establishment of the Cognitive Science and Technologies Council (CSTC[7]) as a governmental infrastructure supporting scientific and technological efforts in this field [65]. However, considerable results have yet to be achieved. Two main Iranian research institutes focus on cognitive science; the Institute for Research in Fundamental Sciences (IPM) mostly investigates brain disorders, while the Institute for Cognitive Science Studies (ICSS) studies the interrelation of psychology and neuroscience [66].

A bibliometric analysis of the NBICs research is presented in Fig. 1.

The convergence of NBICs is not studied deeply in the Iranian context, with Jamali et al. [22] being an exception. That paper investigates the interdisciplinary relations (pairs and trios) of NBICs using different bibliometric techniques for all Iranian NBIC articles published in international journals from 2001 to 2015. The results among the pairs and trios showed that Nano-Bio, Nano-Info, and Nano-Info-Bio had the highest level of mutual interdisciplinary relations, while Info-Bio, Cogno-Bio, and Cogno-Nano-Info had the weakest [22]. Dominant convergence types are presented in Table 2.

According to the results of this literature review, Iran has a significant number of researchers with international publications in each of the four areas of converging technologies. However, it is difficult to find scholars who specialize in dual and/or triple combinations of converging technologies, and therefore are qualified to be referred to as experts.

Research Method

The framework of the research method is based on the three-stage meta-synthesis research method [67], which integrates the interpretations of the findings of previous studies on technology assessment in three stages: (1) selection of studies, (2) synthesis of interpretations, and (3) provision of combinations. Scopus was chosen as the database in the search phase of the meta-synthesis and the period of the search was until the end of 2019. The search query is presented in Table 3. (Related words to each keyword were also included in the search.)

The initial sources were further filtered through title, abstract, and full-text review. Reference backtracking [68, 69] was then used to finalize the accepted sources (Fig. 2).

Based on the review, interpretation, and synthesis of the final 19 sources, the "Proposed model" (last column of Table 4) was extracted. Also, the most similar frameworks are presented in Table 4 for further comparison.

Since contextual dynamics of the environment affects the potential CTDPs, attention to

[5] http://en.ictc.isti.ir/

[6] Iran National Innovation Fund

[7] https://cogc.ir/?lang=2

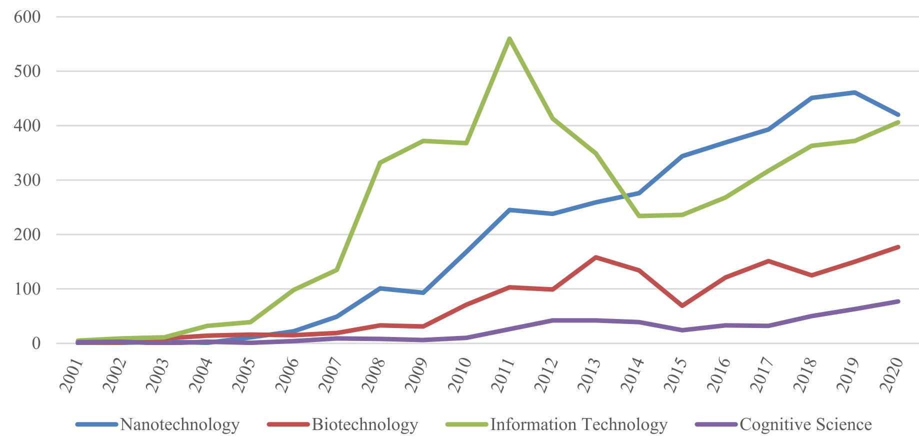

Fig. 1 Number of Iranian NBICs articles in Scopus throughout 2001 to 2020 (title, keywords, and abstract search)

socio-technical systems in the form of social achievements and barriers and challenges to the development of these technologies is essential; this is an important subject that has not been emphasized in any of the previous frameworks. On the other hand, all frameworks have a retrospective or present nature, while in the assessment of converging technologies, the emphasis is on the use of futuristic and exploratory methods. Thus the research framework, presented in the last column of Table 4 and Fig. 3, is designed to address the aforementioned gaps.

Case Study

In this section, the proposed framework for the future-oriented assessment of converging technologies (Fig. 2), which is the result of applying the meta-synthesis research method, has been implemented for the case study of converging technologies in Iran:

Defining the Problem of Converging Technologies Assessment

The purpose of this case study is to extract policy proposals for the development of converging technologies in Iran through future-oriented technology assessment. The geographical scope of this case study is Iran (national/ macro level), and the time scope is short-term, medium-term, and long-term. The possible beneficiaries of the future-oriented assessment are all actors in the field of science and technology policy-making in Iran, and the whole society at a higher level. The assessment dimensions will be social, economic, and environmental factors.

Understanding the Dimensions of Converging Technologies

After defining the problem, the dimensions of converging technologies are studied in the form of

Table 2 Dominant convergence types according to the bibliometric study of Iranian publications [22]

Pairs and Trios	Dominant convergence type	Examples
Nano-Bio	Materials	Graphene, fullerene, porphyrin, and dopamine
Nano–Cogno–Bio		
Nano-Info	Tools	Sensors and lasers
	Techniques	Neural networks and free vibration analysis
Info–Cogno		Retrieval and suppression
Info–Bio		NBO analysis, decision tree, and DFT calculation

Table 3 Search query for meta-synthesis of the future-oriented technology assessment framework

Keyword type 1		Keyword type 2		Keyword type 3		Journals (top journals in the technology and innovation policy field)
Technology OR Innovation	**AND**	Analysis OR Assessment OR Forecast OR Foresight	**AND**	Framework OR Model OR Guidebook OR Guidance OR Method OR Methodology OR Pathway OR Toolkit OR Decision-making	**IN**	*Futures* OR *Foresight* OR *International Journal of Forecasting* OR *Journal of Foresight and Innovation Policy* OR *Technological Forecasting and Social Change* OR *Technology in Society* OR *Technology Analysis and Strategic Management* OR *International Journal of Technology Management* OR *Technovation* OR *International Journal of Innovation and Technology Management* OR *Journal of Technology Management and Innovation* OR *International Journal of Innovation Management* OR *Asian Journal of Technology Innovation* OR *The Journal of Technology Transfer* OR *The Journal of Product Innovation Management* OR *R and D Management* OR *Research Policy* OR *Journal of Cleaner Production* OR *Science and Public Policy*

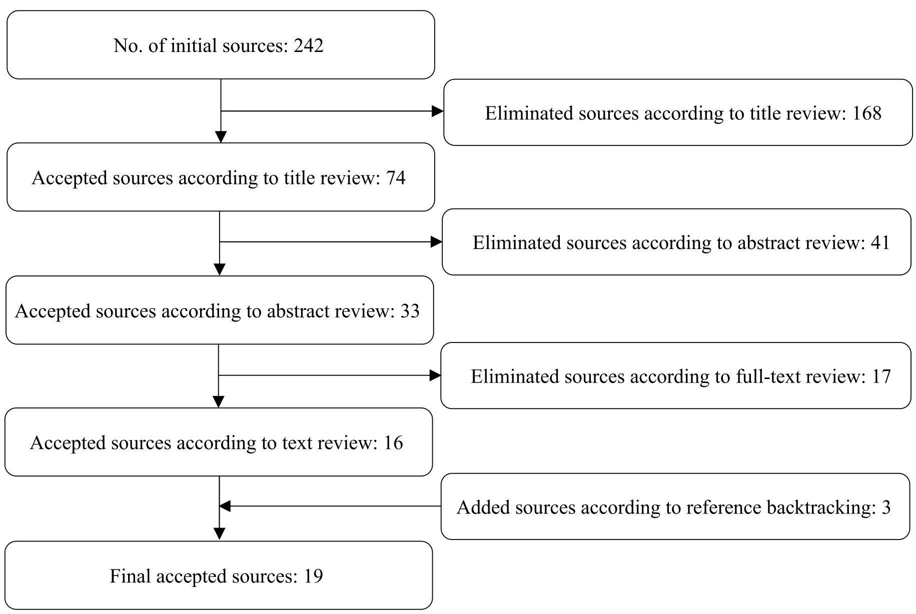

Fig. 2 Article selection process in meta-synthesis of the future-oriented technology assessment framework

achievements and challenges. For this purpose, in step 2–1 (Fig. 3), to identify the achievements of converging technologies in the context of society, various scientific databases are explored with related keywords, and the practical goals of converging technologies are classified in Table 5.

Then, in step 2–2 (Fig. 3), the challenges are extracted with the same approach as in Table 6.

Forecasting the Future of Converging Technologies

After realizing the different dimensions of converging technologies (achievements and challenges), the future CTDPs with a similar approach are first extracted from the literature to identify the potential applications of converging technologies, in step 1–1 (Fig. 3). Then, the pathways were completed in the form of 85 CTDPs and categorized based on the paired and triple combinations of converging technologies via exploratory interviews with eight experts (selected using a purposeful sampling method and considering maximum heterogeneity from the statistical population of experts with experience in at least three areas of converging technologies). Later, the combinations are verified by experts which resulted in 77 final CTDPs (presented in the Appendix and summarized in Table 7).

The viewpoints of a wider range of experts (45 persons) about the importance of each of the CTDPs at the national level are then gathered with a Likert questionnaire. The respondents are selected with the snowball sampling method from the experts specialized in at least one field of converging technologies, and experts from policymaking institutions in the field of converging technologies in the country (the demographic information is presented in Table 8). It should be mentioned that in the next steps and stages, the opinions of these experts (45 persons) were used to gather further information.

To ensure the normality of the data collected through the questionnaires, the Kolmogorov–Smirnov test was used, and the result confirmed the normality of the data with a confidence level of 95%. The responses were then analyzed by the *t*-test (population means values test). For this purpose, a test is designed as follows:

$$\begin{cases} H0 : \mu = 3 \\ H1 : \mu \neq 3 \end{cases}$$

Based on the test results, the null hypothesis for 77 CTDPs was rejected at a 95% confidence level (Sig. $<$ 0.05). Considering that the lower and the upper ends of the confidence interval of the difference are positive for all 77 CTDPs with 95% confidence, it can be claimed that the population of experts has recognized these 77 CTDPs as being of great importance. Thus, the possibility of achieving 77 CDTPs by Iranian scientists (out of a total of 88 CDTPs extracted from the literature in step 3–1) is confirmed by the experts. An example of the results of this process in the NI field is presented in Table 8, where the possibility of the attainment of all CDTPs was confirmed except for "computer simulations for modeling through the behavior of nanostructures" (row 9 of Table 9).

At the end of step 3–1 (according to Fig. 3), the required period of the emergence and implementation of CTDPs in Iran was determined based on the opinions of experts and in the form of three periods: short-term, medium-term, and long-term periods. The results of this process in the field of NI have been presented as an example in Table 10, where out of the 13 confirmed CTDPs in Table 8, it is predicted that 2 in the short term, 9 in the medium term, and 2 in the long term can be developed in Iran.

In steps 3–2 and 3–3 (Fig. 3), the experts' viewpoints on the impacts of different dimensions of converging technologies (8 achievements and 7 challenges identified in the previous step) on each CTDP have been evaluated with a Boolean (0/1) questionnaire to determine the number of effective achievements and challenges for each CTDP separately. Table 11 shows an example of this process for "Nanocapsules to generate portable energy source for soldiers" as one of the pathways to develop converging technologies in the field of NB.

Evaluating the Prospects of Converging Technologies

After examining the various dimensions of the development of converging technologies, in this stage, the graphic image of the future perspective assessment of the CTDP is presented. For this purpose, in step 4–1 (according to Fig. 3), the intensity of achievements and the intensity of challenges (extracted from the expert opinions in steps 3–2 and 3–3) respectively are shown on the horizontal and vertical axis. At the end of this stage and in step 4–2 (Fig. 3), the matrix of achievements-challenges is divided into four areas according to the high/low intensity of achievements and challenges of Fig. 4. As a result, for instance, the CTDP presented in Table 10 is located in area No. 2. Inspired by Vernet and Arasti [89], Morin (1985) [90], UNIDO [91], and Ghazinoory et al. [61], the clustering will further aid the development of the strategies in the next stage.

Table 4 Summary of the study of technology assessment frameworks and the proposed model resulting from the meta-synthesis of technology assessment frameworks

Jones (1971) [70]	**Coates (1976)** [71]	**Porter et al. (1980)** [72]	**Braun (1998)** [73]	**Coates (1998)** [74]	**Porter (2004)** [75]	**Koivisto et al. (2009)** [76]	**Kalbar et al. (2012)** [77]	**Robinson et al. (2013)** [50]	**Proposed model**
Determining the assessment framework and goal	Defining the problem Identifying the affected groups	Defining the problem	Determining the subject, scope, and time	Justifying the need for the assessment of the proposed technology	Determining policies, interests, consequences, and drivers	Describing the technology Determining the scope, subject, and methodology	Determining the appropriate technology	Defining the problem	1- Defining the problem of converging technology assessment: 1–1- Identifying and defining the problem, scope, and methods
Describing relevant technologies	Identifying system alternatives Identifying macro system alternatives	Technology description Technology forecasting	Technology description	Technology description (technology forecasting in the institutional context) Describing alternative systems			Determining the measures and indicators (life cycle assessment, system resistance analysis, etc.)	Understanding the technology (determining the characteristics of the technology, and analyzing the contextual and organizational determinants of technology management)	2- Determining the possible outcomes of converging technology development: 2–1- Identifying the achievements and goals of converging technology development 2–2- Identifying key barriers and challenges of converging technology development
Describing the society's status	Identifying external variables or events	Society description Society forecasting		Determining the societal trends and scenarios	Future analysis of the technology by the main stakeholders	Determining the risks of technology (determination of the probability of risk occurrence and potential consequences)	Determining the methodology of data collection and analysis		3- Forecasting the future of converging technologies: 3–1- Determining the potential applications of converging technologies 3–2- Analyzing the achievements of each CTDP 3–3- Analyzing the challenges of each CTDP
Identifying the affected areas	Identifying possible impacts	Identifying the impacts	Determining outcomes and potential beneficiaries Determining adverse impacts	Identifying influential partners and stakeholders Identifying potential impacts Screening and evaluating potential impacts Identifying relevant decision-makers	Determining findings, recommendations, and policies Presenting the results to other stakeholders	Risk assessment		Analyzing the characteristics of actors and innovative activities Determining the characteristics of R&D Mapping the innovative activities	

Table 4 (continued)

Jones (1971) [70]	**Coates (1976)** [71]	**Porter et al. (1980)** [72]	**Braun (1998)** [73]	**Coates (1998)** [74]	**Porter (2004)** [75]	**Koivisto et al. (2009)** [76]	**Kalbar et al. (2012)** [77]	**Robinson et al. (2013)** [50]	**Proposed model**
						Determining the corrective actions		Providing a list of potential applications	4- Evaluating the future perspective of converging technologies: 4–1- Determining the future perspective of converging technologies by drawing a matrix of achievements—challenges 4–2- Clustering the CTDPs in 4 regions
Preliminary impact analysis	Impact estimation	Impact analysis Impact estimation						Technology assessment Defining the components of innovation Illustration of the alternative innovation pathways	
Identifying possible options for action Completing the impact analysis	Identifying the decision-making tools Identifying possible options and tools for action	Analyzing the policies	Analyzing the alternative policies	Policy analysis	Determining the achievements and applications Analyzing the outcomes, impacts, and policy decisions		Decision-making with multi-criteria methodology	Delineating the promising innovation pathways Identifying the leverage points Determining policy options	5- Analyzing and disseminating converging technology development policies: 5–1- Adopting a strategy based on scenarios designed for each cluster
	Conclusion and suggestions	Transferring the results		Conclusion and suggestions		Risk control and reduction Presenting the results in the form of a scenario	Announcing the ranking of the alternatives	Presenting the innovation pathways Determining possible policies and managerial actions	

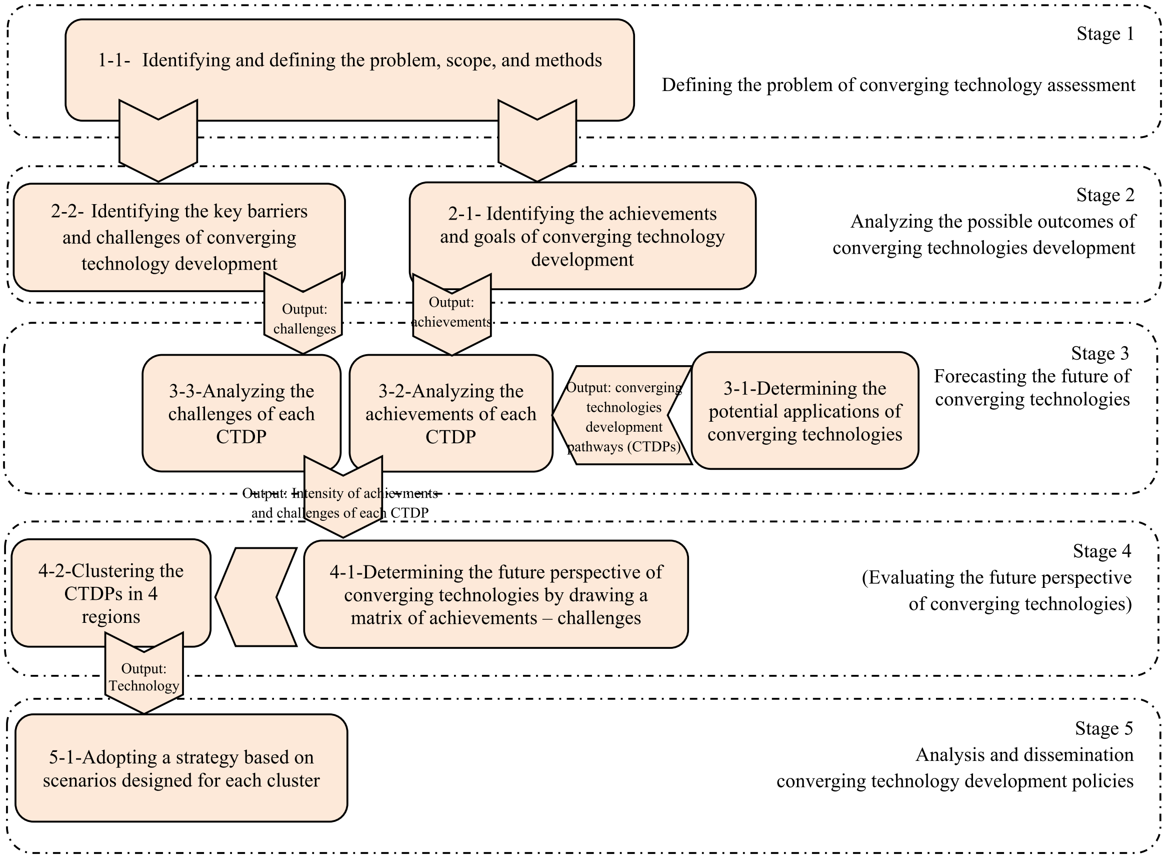

Fig. 3 Proposed framework for future-oriented assessment of converging technologies

Table 5 Achievements of converging technologies development

Achievements	References
Improving the quality of human life	[16, 78]
Improving and developing positive social outcomes	[79, 80]
Increasing economic growth	[12]
Increasing security and defense power	[10, 66]
Rapid scientific progress	[66, 80]
Achieving sustainable development	[5, 12]
Improving the country's innovation ranking	[10, 81]
Better environmental protection	[12, 82]

Analysis and Dissemination of Converging Technologies Development Policies

In the final stage, four scenarios for the development of converging technologies are proposed. For the development of the scenarios, similar technology selection matrices are reviewed. Inspired by BCG's model, Vernet and Arasti (1999) proposed an attractiveness-competencies matrix with star, cash, question mark, and cross zones [89]. Similarly, Morin [90] designed an ability–attractiveness matrix for technology planning, including 4 zones (position protection/development, replace/sale, selected improvement, and ignorance). Given the firm level of the previous frameworks, UNIDO (2004; 2005) developed a critical technology selection model for national policy-making, with attractiveness (social benefits and technological opportunities) and feasibility (research potential and societal absorption possibility) as the key parameters [91]. Finally, Ghazinoory et al. [61] proposed four scenarios for national technological strategy (replace/transmission, scanning, inception and development, and position protection) according to the capability-attractiveness matrix and then applied the framework in the case of nanotechnology

Table 6 Challenges of converging technology development

Challenges	References
Lack of culture in technology application	[83, 84]
Limitation of financial resources	[16, 85]
Lack of proper rules for technology application	[10, 86]
Ignoring stakeholders' opinions in the design and development of converging technologies	[12, 81]
Low social perception and acceptance of converging technologies	[80, 86]
Weakness in commercialization	[87, 88]
Excessive emphasis on the widespread use of the title converging technologies	[10, 81]

Table 7 Number of final CTDPs

Row	Combination of converging technologies	Number of initial development pathways	Number of approved development pathways
1	NB	16	16
2	NI	14	13
3	NC	5	3
4	BI	9	8
5	BC	18	15
6	IC	13	13
7	NBI	3	3
8	NBC	2	2
9	NIC	4	3
10	BIC	1	1
Total		**85**	**77**

Table 8 Demographic information of experts

Gender	Male: 22	Female: 17	Unknown: 6	
Education level	Ph.D.: 9	Ph.D. student: 10	M.Sc.: 20	Below M.Sc.: 6
Number of specialized areas of each expert	Single specialty: 18		Multiple specialties: 27	
Number of answered specialized areas (overlapping)	Biotechnology: 42	Nanotechnology: 34	Information technology: 33	Cognitive sciences: 36

in Iran. Given the wide use of the capability-attractiveness matrix in the context [92–94], it inspired the scenario development in this stage. Thus, four scenarios correspond to the achievements-challenges matrix in the fourth stage (Fig. 5):

1- *Disregard scenario:* The high-risk and limited achievements of technology lead to low market attraction. Thus, ignoring along with planning to exit the market is suggested.
2- *Thought-provoking opportunity scenario*: Due to the limitations of achievements and challenges facing technology development, experts can—without the need for high investment or the allocation of research funds—keep up with the latest knowledge by following worldwide scientific and

Table 9 *T*-test for the development probability of NI CTDPs in Iran

Row	NI CTDPs	Test value = 3					
		t	df	Sig. (2-tailed)	Mean difference	95% confidence interval of the difference	
						Lower	Upper
1	Big data storage, management, and retrieving	7.000	3	.006	1.7500	.954	2.546
2	Ultra-thin electronic chips	7.000	3	.006	1.7500	.954	2.546
3	Ultrasensitive nanosensors for the detection of explosives	7.000	3	.006	1.7500	.954	2.546
4	Quantum cryptography	7.000	3	.006	1.7500	.954	2.546
5	Nanoelectronics	5.196	3	.014	1.5000	.581	2.419
6	Nanophotonics	7.000	3	.006	1.7500	.954	2.546
7	Detection of chemical agents based on photonic fibers or infrared nanoparticle quantum dot systems	5.196	3	.014	1.5000	.581	2.419
8	Internet-based distance analysis for modeling and simulation	5.196	3	.014	1.5000	.581	2.419
9	**Computer simulation for modeling through nanostructure behavior**	**2.611**	**3**	**.080**	**1.2500**	**−.273**	**2.773**
10	Faster data traffic in data centers with photonics technology	5.196	3	.014	1.5000	.581	2.419
11	Improvement of image quality and nanosensor systems	7.000	3	.006	1.7500	.954	2.546
12	Decoding with a complicated quantum computer simulator	7.000	3	.006	1.7500	.954	2.546
13	Network enhancement through the application of nanophotonics technologies in the construction of communication devices	7.000	3	.006	1.7500	.954	2.546
14	SERS, RERS, and SORS in Forensics	7.000	3	.006	1.7500	.954	2.546

Significance level is higher than 0.05, thus the achievement of the CTDP is not approved by the experts

commercial papers and easily enter a new field that looks promising.

3- *Lucky Benefit scenario*: The multiplicity of achievements and risks is one of the characteristics of a well-known existing technology. Thus conditional exploitation is recommended due to the appropriate market volume on the one hand and the instability of the current situation on the other.

4- *Pioneering scenario*: The existence of environmental opportunities, the positive status of macro indicators of technology, and the limitation of risks for the technology provide a unique opportunity for investors to pioneer the technology.

For instance, based on the challenges-achievements matrix, the required scenarios and related strategies for implementing the future development pathways of the paired/triple combination of a selected set of converging technologies (shown in Fig. 4) are determined in Table 12.

To summarize the results of the case study, the number of CDTPs with similar suggested scenarios is provided based on the required time duration for development in Tables 13 and 14.

Conclusion

The undeniable presence of converging technologies and their consequent effects on societies make strategic planning and futuristic thinking about technologies essential. Therefore, governments and policymakers, especially in developing countries, cannot remain indifferent to them. The complex interaction of life and new industries with advanced technologies has led and forced both scientists and managers to engage in the process of technology policy-making that paved the way for the emergence of interdisciplinary fields. Since decision-makers are not expected to be aware of the various aspects of each technology and its future development paths, there

Table 10 Time duration of NI technologies development in Iran

Short-term	Mid-term					Long-term
Nanoelectronics	Big data storage, management, and retrieving	Nanophotonics	Network enhancement through the application of nanophotonics technologies in the construction of communication devices	Improvement of image quality and nanosensor systems	Ultrasensitive nanosensors for the detection of explosives	Ultra-thin electronic chips
Internet-based distance analysis for modeling and simulation	SERS, RERS, and SORS in Forensics	Detection of chemical agents based on photonic fibers or infrared nanoparticle quantum dot systems		Decoding with a complicated quantum computer simulator	Faster data traffic in data centers with photonics technology	Quantum cryptography

Table 11 Intensity of social achievements and challenges in a CDTP of NB: "Nanocapsules to generate portable energy source for soldiers"

Social achievements		Challenges	
Description	No. of confirming experts	Description	No. of confirming experts
Improving the quality of human life	10	Lack of culture in technology application	6
Improving and developing positive social outcomes	6	Limitation of financial resources	4
Increasing economic growth	6	Lack of proper rules for technology application	5
Increasing security and defense power	13	Ignoring public/stakeholders' opinions in the design and development of converging technologies	2
Rapid scientific progress	4	Low social perception and acceptance of converging technologies	1
Achieving sustainable development	3	Weakness in commercialization	2
Improving the country's innovation ranking	5	Excessive emphasis on the widespread use of the title converging technologies	2
Better environmental protection	5		
Total votes of achievements	52	Total votes of challenges	22
Average for achievements (No. of Questionnaires: 26)	2	Average for challenges (No. of Questionnaires: 26)	0.85

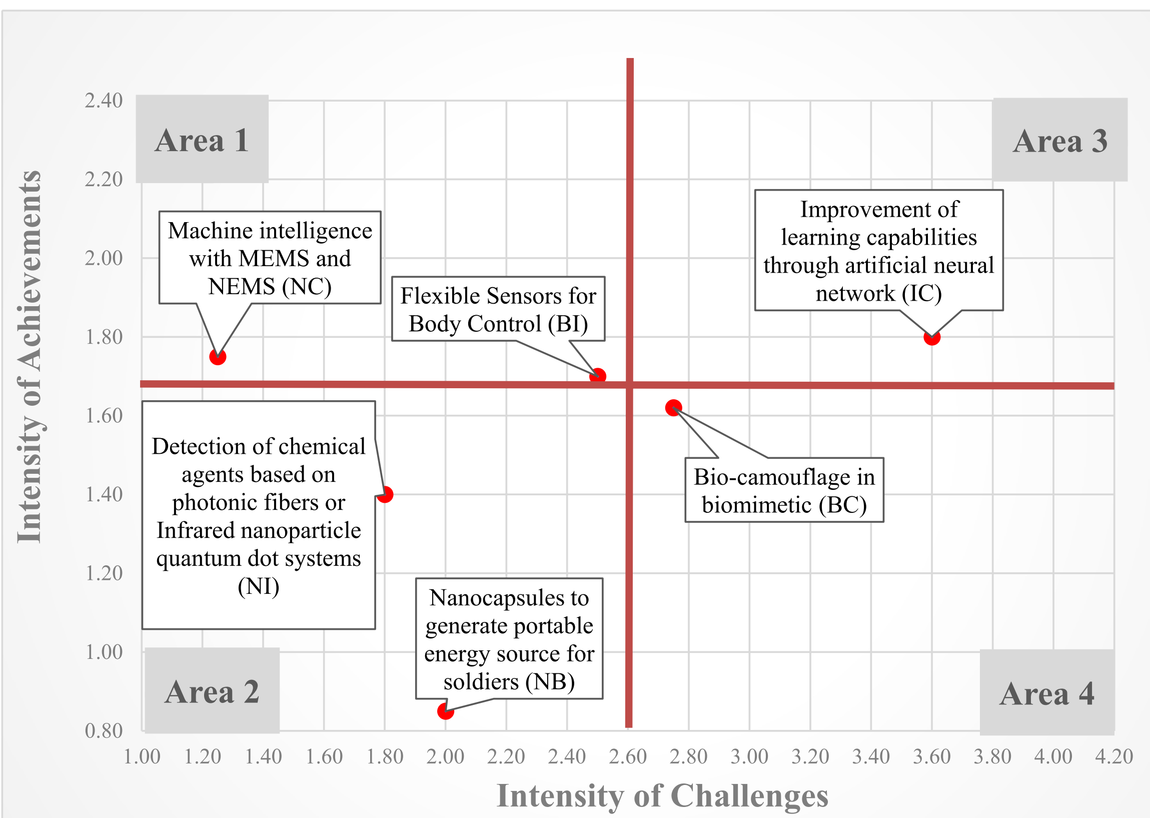

Fig. 4 Matrix of achievements-challenges for selected CTDPs

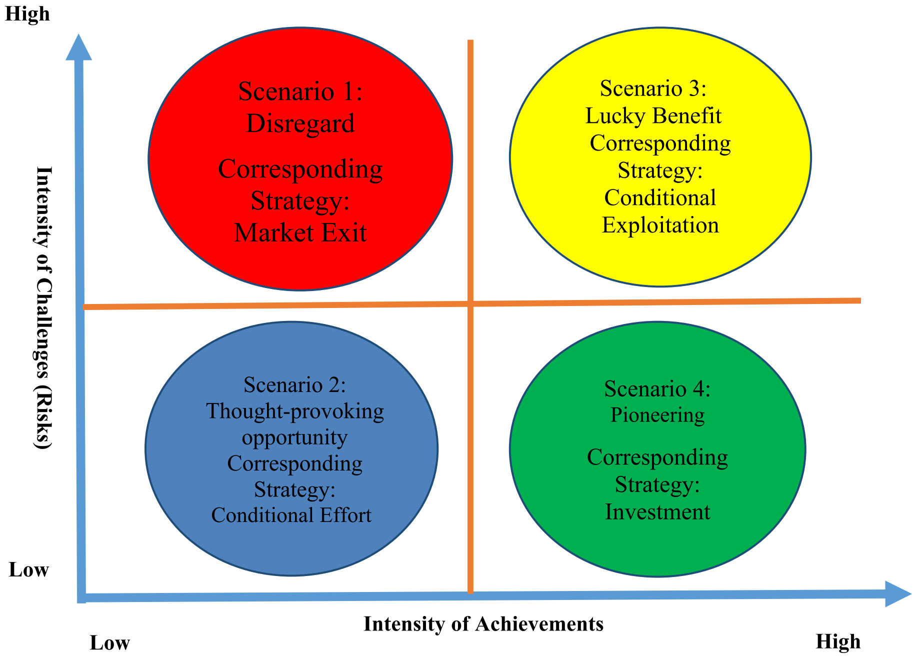

Fig. 5 Quadruple scenarios of converging technology development

is a need for systematic methods and tools that provide the required information. Accordingly, technology assessment provides this information to managers and policymakers. Technology assessment leads to the provision of the necessary resources for the comprehensive analysis of social, economic, and environmental capacities and for the development of new and creative options that were not possible before.

Accordingly, the main objective of this paper is to design a policy-making framework for developing converging technologies concerning their social challenges and achievements. Therefore, a model based on the future-oriented technology assessment was designed that evaluates future development pathways for paired/triple combinations of converging technologies and proposed appropriate strategies according to the level of achievements and challenges that each of the future CTDPs entails. To validate the proposed policymaking framework, the model was implemented for a case study (converging technology development policymaking in Iran), and the results were confirmed by experts. To implement the proposed framework (Fig. 3) for the case study, the achievements and challenges of the development of these technologies were first identified and classified into eight achievements and seven challenges. Then, 85 potential applications of future CTDPs for the paired and triple combinations of converging technologies were identified. In the next step, the feasibility of 77 CTDPs in Iran was confirmed and the timeframe for the accomplishment of the selected 77 CTDPs was determined by experts. Finally, a suitable national strategy for the implementation of each future CTDP was proposed based on the level of achievements and challenges of the technology development in future paths.

This research has three theoretical innovations:

1. The first innovation is to provide a specific future-oriented assessment model for converging technologies. Previous studies (Table 4) have provided general frameworks for technology assessment, but none of these studies has examined the future-oriented assessment of emerging or converging technologies. In the field of future-oriented assessment, Scapolo [95] has not provided a clear framework, although he has highlighted the role of the triple components of context, content, and process and emphasized the importance of context in foresight. Schaper-Rinkel [96] has only introduced a wide range of different tools for technology foresight, assessment, and fore-

Table 12 Suggested strategies for the development of selected CTDPs in Iran

Scenario	Strategy	Area	CTDP
Disregard	Market Exit	1	Machine intelligence with MEMS and NEMS (NC)
			Flexible sensors for body control (BI)
Thought-provoking opportunity	Conditional Effort	2	Detection of chemical agents based on photonic fibers or infrared nanoparticle quantum dot systems (NI)
			Nanocapsules to generate portable energy sources for soldiers (NB)
Lucky Benefit	Conditional Exploitation	3	Improvement of learning capabilities through an artificial neural network (IC)
Pioneering	Investment	4	Bio-camouflage in biomimetic (BC)

Table 13 Summarized result of case study for paired combinations of converging technologies

Scenario		Scenario 1: Disregard						Scenario 3: Lucky Benefit					
Long-Term	**2**	0	0	0	0	0	2	0	0	0	0	0	0
Mid-Term	**22**	0	3	3	4	2	3	1	0	0	2	1	3
Short-Term	**1**	0	0	0	0	0	0	0	1	0	0	0	0
Scenario		**Scenario 2: Thought-provoking opportunity**						**Scenario 4: Pioneering**					
Long-Term	**5**	0	2	0	1	0	0	0	0	0	0	0	2
Mid-Term	**37**	13	6	0	1	8	0	2	0	0	0	4	3
Short-Term	**1**	0	1	0	0	0	0	0	0	0	0	0	0
Paired Combination- Converging Technologies		**NB**	**NI**	**NC**	**BI**	**BC**	**IC**	**NB**	**NI**	**NC**	**BI**	**BC**	**IC**
Total CTDPs for Paired Combinations		13	12	3	6	10	5	3	1	0	2	5	8

Table 14 Summarized result of case study for triple combinations of converging technologies

Scenario		**Scenario 1: Disregard**				**Scenario 3: Lucky Benefit**			
Long-Term	**0**	0	0	0	0	0	0	0	0
Mid-Term	**5**	2	1	1	0	0	0	1	0
Short-Term	**0**	0	0	0	0	0	0	0	0
Scenario		**Scenario 2: Thought-provoking Opportunity**				**Scenario 4: Pioneering**			
Long-Term	**1**	0	0	0	1	0	0	0	0
Mid-Term	**3**	0	2	0	0	0	0	1	0
Short-Term	**0**	0	0	0	0	0	0	0	0
Triple Combination- Converging Technologies		**NBC**	**NIC**	**NIB**	**BIC**	**NBC**	**NIC**	**NIB**	**BIC**
Total CTDPs for Triple Combinations		2	3	1	1	0	0	2	0

casting, including scientometrics, scenario planning, and focus groups. Porter [75] and Kalbar et al. [77], although considered to have given a forward-looking assessment of new technologies, have provided a very general framework and neglected the positive and negative dimensions of new technologies (including the achievements and challenges). Koivisto et al. [76], despite systematic attention to risk assessment in the future-oriented assessment of converging technologies, have ignored the social and economic challenges and achievements of these technologies. The future-oriented assessment framework proposed by Robinson et al. [50] focuses only on innovation pathways in the specific field of nanobiosensors and ignores the challenges of acquiring these technologies. Thus in the field of converging technologies foresight, all studies (except Jamali et al. [22]) have examined converging technologies separately and also neglected the foresight of cognitive science technology. Accordingly, in this study, a stepwise future-oriented assessment framework was proposed for the first time that considers the achievements and challenges of development pathways of paired and triple converging technologies. Therefore, the research gap of previous frameworks, including the disregard for achievements and challenges, and the neglect of the paired and triple combinations of converging technologies, has been resolved.

2. Another theoretical innovation of this research is the consideration of the contextual dynamics of social challenges and achievements, potential applications, and innovation pathways for the future-oriented assessment of converging technologies. The review of the literature in this field shows their neglect of the social achievements and challenges of the CTDPs. The social achievements and challenges of acquiring these technologies are studied in the different articles on a case-by-case basis. Also, the potential applications are only explored slightly in two studies (Roco et al. [10] and Song et al. [97]), where separate branches of NBICs are taken into account.
3. The last innovation of this research is to propose a matrix for evaluating and deciding on policies to deal with converging technologies by identifying four scenarios, which will be a guide in determining the strategies to deal with the CTDPs. Very few references pointed out the subject of converging technologies, and none of them suggested a framework for strategic planning. Roco [8, 9] discussed the governance of converging technologies but failed to provide any framework for dealing with them and only stated general concerns such as the need to consider the possible risks. Kaiser et al. [98] also outlined general concepts for the governance of future technologies. Regarding the aforementioned research gap, and inspired by the attractiveness-empowerment matrix as a well-known tool for evaluating and designing technology development strategy [61, 92, 93], two variables (social achievements and challenges) as two key uncertainty factors were considered for the first time in this paper. According to the clusters of different CTDPs, four scenarios were designed: (1) disregard (high challenges and low achievements), (2) thought-provoking opportunity (low achievements and challenges), (3) lucky benefit (high achievements and challenges), and (4) pioneering (low challenges and high achievements), and an appropriate strategy corresponding to each scenario was developed, respectively: (1) planning for market exit, (2) conditional effort, (3) conditional exploitation, and (4) investment.

According to the results of implementing the model for the case study of converging technologies development in Iran, the frequency number of proposed strategies for CTDPs in different periods is presented in Table 15. Based on the results, the highest frequency belongs to the conditional effort strategy, with market exit and investment strategies being the other suggested strategies.

Table 15 Frequency number of proposed strategies for CTDPs in Iran according to their predicted development periods

Period of development	Strategy			
	Pioneering	Lucky benefit	Thought-provoking opportunity	Disregard
Short-term	0	1	1	0
Medium-term	10	8	30	19
Long-term	2	0	4	2

Also, the frequency number of proposed strategies for CTDPs in Iran according to their general field of technology is presented in Table 16; accordingly, it seems that in Iran, biotechnology is the most promising technology in combination with the other converging technologies. Also, the strategy of conditional effort should be applied in the fields of biotechnology and nanotechnology, and the market exit strategy is proposed in many CTDPs in the fields of cognitive sciences and information technology.

To provide a more detailed analysis of the results of the implemented case study in Iran, the pair combinations of biotechnology (as the most promising converging technology in Iran) with other converging technologies in the medium term are discussed here. In the field of biotechnology-information technology (BI), none of the CTDPs has been selected for implementing the investment strategy, which means that experts do not currently consider any application of this combination as being ready for investment. Also, the most common proposed strategy in this field is the market exit strategy. Therefore, it seems that experts are relatively disappointed by the applications of technology development in this field. In the field of biotechnology-nanotechnology (BN), the disregard scenario has not been proposed for any of the CTDPs, which means that experts consider all CTDPs fruitful in this field. Also, the highest frequency of the proposed strategies in this field is to be found in the conditional effort and investment strategies, which indicates the promising status of technology development pathways in this field. Finally, in the field of biotechnology-cognitive sciences (BC), the investment strategy is proposed for four pathways of technology development (the highest frequency among the three subfields of biotechnology), which means that experts consider this field to be the main development lever of the country.

Like other matrices designed to assist decision-making, the suggested strategies for technologies located in the margins of the four areas could be challenged. Thus, the improvement of the framework with complementary fuzzy approaches is recommended to tackle this limitation in future research. Also, the usage of similar criteria could be misleading for some technologies (although vital for the comparison), and this can be referred to as another limitation of this research. The implementation of the framework in other countries is also suggested for further research as it aids the comparison of the results in different contexts.

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Availability of data and materials The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of Interest The authors declare no competing interests.

Table 16 Frequency number of proposed strategies for CTDPs in Iran according to their general field of technology

Technology	Strategy			
	Pioneering	Lucky Benefit	Thought-provoking Opportunity	Disregard
Biotechnology (B)	7	5	24	9
Nanotechnology (N)	3	3	24	10
Information technology (I)	6	6	14	14
Cognitive science (C)	10	4	11	13

Appendix

Table 17

Table 17 Verified CTDPs for Iran presented according to their suggested strategy (green for investment, yellow for conditional exploitation, blue for conditional effort, and red for market exit)

	CTDPs
BI Mid-Term	Biometric Sensors for the detection of pregnancy, addiction, diabetes, etc
	DNA processing in the body for the synthetic immune system and cancer control
	Telemedicine & bioelectronics
	Production of self-healing networks & biometric security systems
	Information processes in the biotic system for the development of DNA chips
	Disease detection using biorobotics
	Flexible sensors for body control
BI Long-Term	Emotion Controlling
NB Mid-Term	Application of nanoparticles for forensic investigations and latent fingerprinting
	Application of nanoemulsions for the absorption of chemical, biological, radiological, and nuclear (CBRN) contamination
	Application of nanoparticles or nanofibers for the adsorption, separation, and neutralization of chemical and biological contamination
	Biosynthesis of nanoparticles
	Investigation on nano-scale living things
	Genome synthesis of virus
	Biomolecular electronic devices (bioreceptors and biocomputers)
	Chemical nanosensors
	Self-cleaning skin cream
	Tailored materials
	Nanocapsules to generate portable energy sources for soldiers
	Continuous monitoring of physiological signs and telemedicine for the treatment of injured organs
	Compression of actual plasmid preparations and DNA sequencing reactions
	Enhancement of the mental and physical performance of soldiers
	Miniaturization of soldier weapons
	Improvement of the detection, identification, and neutralization of biological warfare agents
BC Mid-Term	Bio-camouflage in biomimetic
	Memory improvement and stress reduction in learning processes
	Optimization of the managerial decision making and the reduction of errors in evaluations
	Maximization of the cognitive abilities of students
	Microorganisms as biological weapons
	Biosensors
	Maximization of soldiers' awareness
	Response development through personality reinforcement
	Enhancement of the soldiers' capabilities to deal with sleep deprivation, fatigue, etc
	Bionics
	Management of biological data
	Stem cell therapy in brain trauma
	Perceptual-cognitive training
	Trained Animals as army forces
	National security (Food, Drugs, etc)
NI Mid-Term	Big data storage, management, and retrieving
	Ultrasensitive nanosensors for the detection of explosives
	Decoding with a complicated quantum computer simulator
	Detection of chemical agents based on photonic fibers or infrared nanoparticle quantum dot systems
	Network enhancement through the application of nanophotonics technologies in the construction of communication devices
	Surface-enhanced raman spectroscopy (SERS), resonance-enhanced raman scattering (RERS), and spatially offset raman spectroscopy (SORS) in Forensics
	Nanophotonics
	faster data traffic in data centers with photonics technology
	Improvement of image quality and nanosensor systems
NI Long-Term	Ultra-thin electronic chips
	Quantum cryptography
NI Short-Term	Nanoelectronics
NC Mid-Term	Internet-based distance analysis for modeling and simulation
	Artificial intelligence in small scale
	Machine intelligence with MEMS (Micro-Electro-Mechanical Systems) and NEMS (nanoelectromechanical systems)
	Enhanced sensing performance of sensors via nanostructures
IC Mid-Term	Automatic Systems
	Business advantages through advanced artificial intelligence
	Cooperative learning through human-computer interaction
	Cyber-Physical Systems and Internet of Things
	Effective computation
	Improvement of learning capabilities through the artificial neural network
	Nurse robots
	Insulin and Hormones monitorring
	Robots for dangrous operations (e.g. Bomb-Defusing)
IC Long-Term	Intelligent Feedback System in Tele-Learning Environment
	Business advantages through advanced artificial intelligence
	Automatic recognition of speech emotion
	Insulin and Hormones monitoring
Mid-Term Converging	Real-time monitoring devices for protein engineering (NIB)
	Gene chips (NIB)
	Fabrication of biocompatible piezoelectric or thermoelectric energy harvesters (NIC)
	Blood glucose monitoring (NIC)
	Save the lives of soldiers and support military equipment (NIC)
	Fabrication of biodevice for controlling and telecaring of physiological signs (NIB)
	Automatize unmanned military equipment (NBC)
	Integration of Nanotechnology, Biotechnology & cognitive science for forecasting threats and enhancing the mental and physical performance of soldiers (NBC)
Long-Term Converging	Augmentation of biological intelligence (BIC)

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