In Search of Sectoral Foresight Methodology: Bridging Foresight and SIS

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Foresight helps decision makers understand complexity, and anticipate and prepare for future challenges. In the transition to a new paradigm, foresight should find a response to the fundamental changes in evolution and be sensitive to the main policy challenges that together drive the transition and call for the implementation of chaos, complexity and evolutionary theories as a basis for future exploration. These theories serve as a departure point for the methodology.

Sectoral technological foresight "produces" technological priorities for the sectoral system of innovation and production (SIS), which can reframe the system fundamentally. Future technologies also call for supporting actions built into the SIS. However, the concept of the sectoral system of innovation and production and foresight methodology are not linked, although they should complement each other. This is another challenge to the foresight methodology and to the concept of the sectoral system of innovation and production, and the emphasis in this paper.

The paper concentrates on three issues:

(1) How to design foresight to respond to fundamental changes;

(2) How to bridge foresight and the sectoral system of innovation in order to identify the transformational changes in the system that are necessary for embedding future technologies in the SIS, and developing an action plan for their support;

(3) How to develop an innovation policy that would be "tuned" to the transformational changes generated by future technologies and would be sensitive to rapid changes in environment.

The developed methodology "brings" foresight into SIS and a wide policy process and revises the approach to the assessment of the sectoral innovation system to make it sensitive to future technologies and transformative changes, generated by them. All actors, who could impact policy development and implementation today and in the future, are involved in foresight. The methodology responds to the increasing complexity and rapid changes, to the growing role of global and social challenges in the SIS development and future paths of technological trajectories, as well as changing role of various actors.

Keywords: foresight, sectoral system of innovation and production, global and social challenges, knowledge base, future technologies

Introduction

Foresight methodology is in the transition to a new paradigm. From this perspective, foresight, first of all, should find a response to the fundamental changes in evolution, to which the author refers the growing complexity of problems and systems, the accelerating rhythm of evolution, the changing role of various actors in policy development and implementation, as well as the growing role of global and social challenges, multisectoral and multidisciplinary nature of both emerging technologies and problems. In addition, foresight should be sensitive to the main policy challenges, the most critical of which are the adaptation to rapid changes and growing uncertainties, the mobilization of resources for the implementation of the shared policy agenda. Fundamental changes and policy challenges drive the transition to a new paradigm and call for the implementation of chaos, complexity and evolutionary theories as a foundation for future studies and decision making; in the paper a combination of these theories serves as a departure point for the building a sectoral foresight methodology and bridging it with the sectoral system of innovation concept.

Sectoral technological foresight fulfils the function of building technological priorities for sectoral innovation systems. Novel technologies can reframe the system fundamentally, change competitiveness, goals, and even its role in the economy. In addition, actions oriented at supporting the emerging technologies are required. However, the concept of the sectoral system of innovation and the sectoral foresight methodology develop in parallel and do not intersect. This is another branch point that is in focus in this paper.

The paper focuses on three methodological issues:

(1) How to design foresight methodology to respond to fundamental changes in evolution;

(2) How to bridge foresight and SIS to explore the potential reconfigurations in SIS to meet emerging technologies and develop an action plan to support them;

(3) How to develop shared policy actions to ensure SIS competitiveness and sustainability as well as its adaptability and sensitivity to rapid changes.

Methodology

Towards a new paradigm, the concept of sectoral systems of innovation and the foresight of the knowledge-based economy increasingly rely on evolutionary, chaos and complexity theories [1]. In the past, system analysis played (and continues to play) a special role for both.

The new theoretical basis makes it possible to move away from linearity, to look at SIS as an open, co-evolving, self-organizing system where small changes, passing through loops of feedbacks, can fundamentally transform the system and where the scientific and technological paradigm serves as an attractor and sets the corridor boundary for the development of the knowledge base of the system within a long-term cycle.

Based on new assumptions, the methodology explores three issues: the building of a knowledge-base, the development of the foresight methodology, the designing of a methodological approach to bridge foresight and SIS assessment, and the development of innovation policy to support future technologies and transformative changes, generated by future technologies.

Knowledge base for foresight and SIS assessment

The knowledge base is the accumulated information about the past and the information that throws the bridge from the past to the future. This is a «knowledge depositary» that feeds all stages of foresight and SIS assessment. The knowledge bases for foresight and SIS assessment intersect; we can say that foresight and the assessment of sectoral innovation systems share a common knowledge base. Both need information about trends, actors, problems, weak signals, so many methods can be used for both studies. The activity that focuses on the sectoral actors' mapping is specific for sectoral systems' assessment is. The SIS assessment relies on surveys of organizations, interviews with key actors, SWOT and benchmarking in great degree, but technological foresight is based on Delphi and technological roadmaps as key methods. However, many methods might be used for both studies.

Environmental scanning plays a special role in identification and monitoring of trends, events, problems, actors, and weak signals that can challenge past assumptions and transform the system or its part fundamentally. It can take the form of an open search or a focused scan. Environmental scanning is actually an umbrella that brings together various methods and tools for systematic scanning and capturing information from various sources. However, it is always a problem: what combination of methods should be used, and what issues they should be focused on.

We believe that bibliometric, patent analysis, regression models, survey of organizations, interviews and SWOT are useful for the evaluation of trends, correlations, capturing structural shifts, and mapping actors, networks and S&T fields. They can also be useful for detecting emerging technologies and actors, for mapping technologies according to their possible contribution to solving global and social challenges, and featuring of cross-sectoral migration of technologies. Semantic technologies are more useful when it comes to the identification of emerging technologies, actors, problems, although they also might be coupled with bibliometrics and big data.

Big data open a new window of opportunities. Big data represents the information assets characterized by such a high volume, velocity and variety that they require the specific technology and analytical methods for their transformation into value [2]. Big data philosophy encompasses unstructured, semi-structured and structured data, however the main focus is on unstructured data [3]. Big data uses inductive statistics and concepts from non-linear system identification to infer laws (regressions, nonlinear relationships, and causal effects) from large sets of data with low information density to reveal relationships and dependencies, or to perform predictions of outcomes and behaviors [4]. It is clear that the big data is a paradigm shift regarding what information we can use to foresee and strategically plan, where and how we can find this information and how we can analyze the information in order to get an idea of the interrelated changes in the economic, social, technological areas, structural shifts, and the like. In order the big data not to repeat the "small data results", it is necessary to delineate areas where their application can be extremely valuable for foresight and SIS assessment, and where other tools cope with difficulty. We believe that the identification of changes in the value system, cultural barriers in the usage of emerging technologies, possible negative consequences of the application of novel technologies can be promising. Big data are practical in identifying clusters of emerging technologies and their interrelationships with basic technologies of interrelated sectoral innovation systems. Hopefully, they will help to outline the nonlinear relationships and dependencies between social, economic and technological trajectories.

Weak signals and other findings of big data and semantic technologies can be tested using Real time Delphi (RTD) or an interview, depending on what insight is required for their application in foresight and decision making, that is, they can be used as an input to RTD. Delphi can also be convenient for the assessing events that have occurred in the past, but could impact future paths of development. This information is useful mostly for scenario development.

Global challenges have started to play a new role in SIS trajectories and technological paths. No standard methodology is available for the assessment of their impact. We believe that it might be designed like a multistep process, using a combination of methods like Delphi, brainstorming, and trend impact analysis.

The combination of outlined methods can bring nonlinearity to the evaluation of historical paths of development and their impact on the future. A key problem in future studies is the linearity of methods and thinking about the past and the future. The knowledge base mainly includes trends and problems formed in the past. The interplay between different levels (global, national, regional), fields (technology, economy, social issues) as well as emerging values, actors, problems usually fall out of sight. The combination of outlined methods will provide a comprehensive picture of trends, problems, breakthroughs, emerging technologies, weak signals in economic, social, technological and geopolitical fields.

Foresight methodology

With increasing complexity and accelerating changes the selection and combination of methods is a challenge for the foresight. As far as any method has its advantages and weaknesses the combination of methods makes the findings and recommendations more robust. The challenge is to design a combination of methods and tools that would complement each other and allow us to respond to rapid changes in the system and its environment, and to meet the growing complexity of knowledge, innovations, global and social challenges as well as problems, which decision-makers face.

To avoid the limitations inherent in any method the methodology is based on the configuration of the following interconnected methods (see Figure 1):

(a) Future sectoral technologies: action oriented Delphi-Dialogue, technological roadmaps, brainstorming and interviews.

(b) Backcasting and exploratory scenarios.

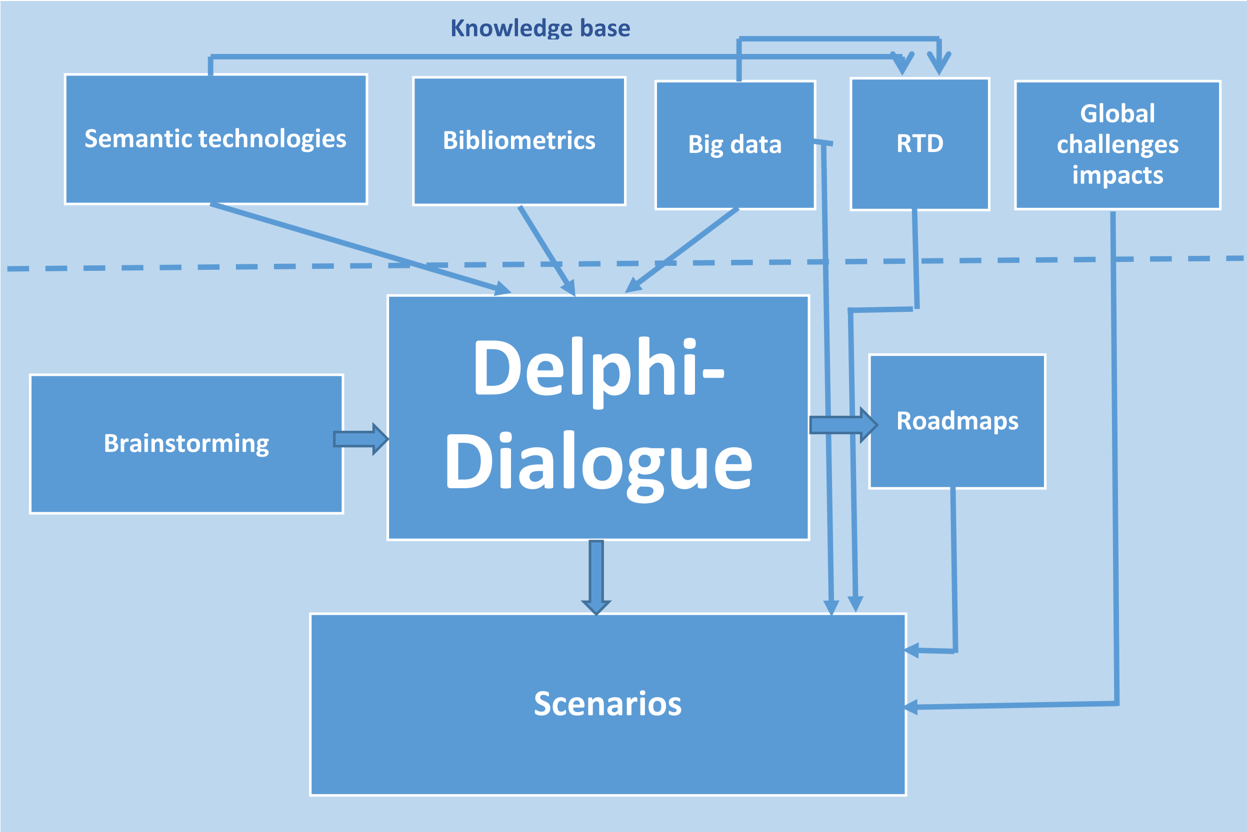

Figure 1. Foresight methods

Delphi plays a key role in the exploration and assessment of future technologies. Delphi can be used for different purposes in various domains. Since the very beginning, its key features were the preservation of anonymity in expert panel's responses and iteration of the questionnaires. A key benefit of participation was the ability of individuals to participate in group communication process asynchronously at time and places convenient to them [5]. Delphi is a method for the structuring of group communication process [6].

In the methodology, the outputs of bibliometric, big data, semantic technologies serve like input to Delphi. To avoid the extrapolation of technological trends, it is important to couple Delphi with a multidisciplinary brainstorming workshop to outline what kind of scientific breakthroughs can occur and what novel technologies they can bring to the agenda. It is useful to apply Delphi for the identification of emerging technologies as well.

Although Delphi is used widely in technological foresight, the opportunities this method provides for exploring the future are not fully used.

With the changing role of various stakeholders in technological evolution, including innovation users, as cultural and even religious issues are starting to play a new role in technological paths of development, a dialogue between various stakeholders regarding future technologies has become a critical problem.

We believe that the Delphi boundary can be expanded, and this method can serve as a place for dialogue. To this end, we developed a technique for Delphi as a dialogue (and learning process) between stakeholders and named it Delphi-Dialogue [7]. This technique assumes that expert judgments are collected, and the average values are calculated separately for each stakeholder group. The results are addressed to members of all groups. Thus, each group can learn the expectations of other groups; corporations, for example, can learn the expectations of innovation users, government officials, scholars and other involved groups; this information is extremely important for learning the expectations of various actors and amending their own judgments and strategies. In addition, Delphi-Dialogue is designed:

- to detect technologies that potentially have a significant impact on the competitiveness of SIS, on the addressing of global and social challenges, and ensure economic and technological security if the latter are high on the agenda;
- to identify technologies with potentially negative impact on environment and population health;
- to bring out cross-sectoral technologies and, respectively, sectors of their implementation;
- to clarify the barriers for technology generation, transfer and implementation;
- to formulate policy mechanisms as a dialogue between various groups of stakeholders.

Thus, Delphi is oriented on *actions* (policy mechanisms) and the *dialogue* between various stakeholders to evaluate future technologies, identify technologies that are critical for providing competitiveness, ensuring economic and social security and responding to global and social challenges.

Delphi outputs are used for the first round of technology prioritization. For this purpose, the methodology assumes the implementation of the following approaches:

a) orientation on the consensus among different groups of stakeholders;

b) realization of four stages of technology mapping using the criteria of technology importance (in terms of providing competitiveness for SIS, contribution to the social and global challenges solution, impact on the other S&T domains' evolution, and importance for the provision of national economic and technological security) and the likelihood;

c) evaluation of possibility of technology implementation in different sectors of economy.

Delphi- survey outputs serve as an input for the development of *technological roadmaps.* Methodology proposes to use roadmaps for scenarios.

Scenarios play a special role; scenarios let us explore how technologies will play in alternative future worlds to help decision makers to comprehend the problems, challenges, and opportunities. It is also a powerful tool for the learning process.

It is important to accumulate information from different parts of the foresight program for scenario development. The scanning process can feed scenarios with information about geopolitical changes, economic, social and environmental trends and problems. Delphi produces helpful information on the expected barriers and proposed policy mechanisms. Technological roadmaps supply information on future technologies i.e. technological events that can change the paths of development.

Scenario planning helps to develop a deeper and more shared understanding of plausible paths of SIS transformation under the impact of future technologies. Backcasting is useful for disruptive technologies, when goals, vision, values, markets are changing fundamentally. Exploratory scenarios are practical for incremental innovations.

Backcasting starts with the design of a vision (desirable future). Translating vision into actionable policies, it is important to study how future technologies can contribute to the achievement of the goals, and what policy actions can support them.

In the methodology for the exploratory scenarios, we outlined the following steps in scenario building: 1) driving forces and scenario worlds; 2) scenario skeleton; 3) narrative scenarios; 4) scenario quantification; 5) scenario writing and discussion.

At the first step one has to draw a line around the alternative future worlds. We suggest starting the development of the scenario skeleton with the identification of key problems that will condition technology development in the future and are important for the decision-making. The development of the time scale of events is a special task; it would be helpful to use events, produced by RTD and technological roadmaps. The evolutionary model can be used for scenario building; it helps to detect events pushed by novel technologies, to build logic and the skeleton of scenarios.

Using the problem map, time scale of events, the scenarios are then described in sufficient detail. The time scale of events helps to “flow” from one event to another without losing consistency and plausibility of the scenario, and the problem map gives guidance on what problems should be in focus. The main trends, factors and motivations of different actors should be evaluated. Special attention should be paid to the branch points and to the factors and actors that cause drastic changes in the trajectory. After writing alternative stories in details, one has to develop the list of qualitative and quantitative indicators for scenario quantification and to put forward the issue of identification of strategic options.

Scenarios can be used to provide the second round of technology prioritization. We suggest giving the first rank to technologies that will play in all scenario worlds. We give a second rank to technologies that will address the key missions of SIS: improving competitiveness, addressing global and social challenges and providing security, and the third rank - to cross-sectoral technologies.

Finally, the changing role of actors puts forward an issue: who should be involved in the foresight. The solution should be based on the following principle: actors influencing policy development and implementation today, and those who will have an impact in the future should be involved in the foresight. The growing role of innovation users, environmental unions and an average citizen requires the consideration of their voice. However, we should not lose sight of emerging actors, whose impact is already visible, and foresee influential actors that may appear in the future, and may hamper or support policy measures implementation in the future.

The developed methodology helps to identify, explore and prioritize future sectoral technologies, i.e. sectoral innovations, which could change sectoral products and technologies evolutionarily or fundamentally.

Bridging foresight and sectoral systems of innovation

Technological foresight develops technological priorities for sectoral systems of innovation that can change the future paths of development, can transform the system slightly or even fundamentally. However, these two fields are not interrelated. In the search for solutions, we faced the problem that the innovation system concept is descriptive and static, and its static nature does not perceive the dynamic and forward-looking nature of foresight. To overcome this contradiction, we developed an evolutionary model of SIS, based on the main conclusions of evolutionary theory and regularities of SIS development in the framework of a long-term cycle (SIS live cycle) [8] (see figure 3).

The model gives an idea of how the system evolves, and what flow of interconnected changes in the system can be caused by technological innovations and global and social challenges. The sectoral system of innovation is regarded as an open system that is a part of higher-level systems (national innovation system, global SIS, national economy) that co-evolve. The evolutionary model can be used for the system assessment and for the embedding of novel technologies into the innovation system.

The sectoral system of innovation represents mission-oriented networks of organizations and individuals, focused on generation, diffusion and implementation of sectoral innovations to insure SIS sustainability and competitiveness. One can outline at least three SIS's missions:

- Providing the competitiveness of sectoral actors by means of knowledge generation, diffusion and implementation;
- Addressing global and social challenges through innovation;
- Providing security (economic, technological, environmental, defense) through innovations.

The evolutionary model consists of five blocks:

(1) *Mission and goals.* This block highlights the role and place of the system in the national economy and national innovation system, as well as its interplay with the environment. SIS should evolve in concert with interrelated sectoral innovation systems, which are suppliers or customers or have common targets for addressing global and social challenges. These are systems with mutually dependent trajectories of development. In the knowledge-based economy, a coordinated strategy with the system of education is of great importance for the successful and sustainable development. Environmental problems and the impact of environmental policy on the SIS trajectory call for the development of strategic actions to meet new requirements and constraints. This block determines the vector of SIS

development as a whole as far as the vector of transformative changes for all agents, institutions, knowledge base. At the same time scientific breakthroughs, new agents, priorities and changes in the legislative base impact SIS mission and bring corrections to the goals.

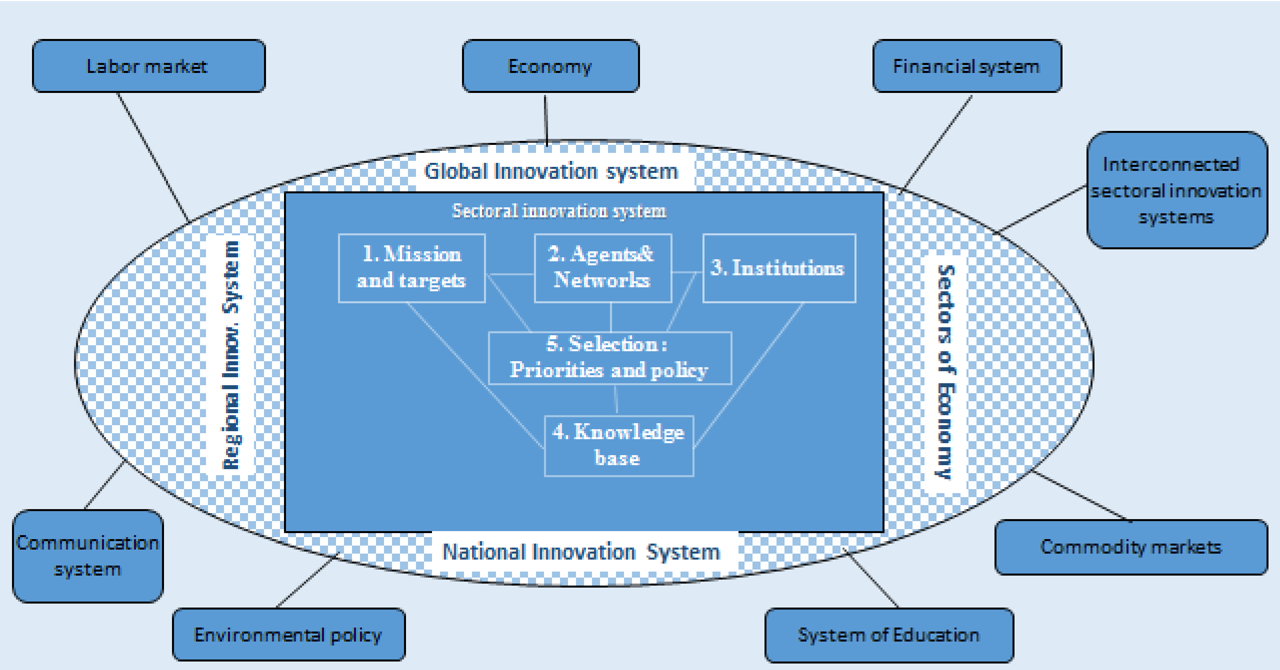

Figure 2. Evolutionary Model of SIS

(2) *Actors and networks*. Actors, organized in networks, fulfill the mission of the system; they generate changes in the system, and at the same time adopt to ongoing changes in the environment by developing shared strategies and action plans.

(3) *Institutions*. Institutions creates “rules of the game” for all actors and in this way decrease uncertainties. Formal institutions impact the directions of changes in the system. Informal institutions include mostly traditions and cultural issues.

(4) *SIS knowledge base*. Knowledge base consists of accumulated codified and tacit knowledge, including scientific knowledge and knowledge related to the performance of sectoral actors, the development of sectoral strategies and foresight programs, etc. The scientific knowledge serves as a basis for the development of SIS and its competitiveness. Incremental innovations bring evolutionary changes to the system, but scientific breakthroughs and, accordingly, the cluster of basic innovations can change the system fundamentally, and transform the knowledge base and its structure.

(5) Priorities and policy actions. Priorities (selection) reduce the level of diversity in SIS and prevent the inefficient use of resources. The mobilization of resources on priorities is the main task of innovation policy.

Changes in the system's mission can come from the outside (for example, climate change has transformed the mission of the energy sector towards meeting the goals for carbon emission and stimulated innovation in renewable energy, i.e. changed sectoral actors, the structure of the knowledge base and priorities), and from technological breakthroughs (for example, the implementation of technological innovations in the nuclear power sector for the production of medical diagnostic facilities resulted in the emergency of nuclear medicine and changed the border and mission of the sector).

If changes in the sector are generated by technological innovations, then the departure point for the analytical cycle of embedding future technologies into sectoral system is block 1 (mission and goals). To capture the changes, it is necessary to draw a line around the possible new markets (co-creating and co-shaping new markets) and asses the contribution to global and social challenges solution. The mission should be translated into concrete targets.

The next block is "actors and networks". A new mission may require new actors and networks or a reconfiguration of organizations and networks. The SIS institutional model can be used to map sectoral actors and identify gaps, which call for specific policy measures; these measures should determine the vector of transformative changes resulting from the vector of development of sectoral products and technologies [9].

In the block "institutions", the issues of the development of standards for the future sectoral products and technologies and the development of a legislative framework for providing the security of novel products and technologies for the customers and produces should be put on the agenda. In addition, the supporting measures for the generation, diffusion and implementation of novel products and technologies should be evaluated.

Finally, novel technologies can change the knowledge base and even the structure of the SIS knowledge base and its specialization. Using bibliometric and patent analyses, these issues should be considered in the block "SIS knowledge base".

If changes in the system are generated by global and social challenges, then one has to start the analytical cycle from the "knowledge base" and "actors and networks" blocks. The following interconnected issues should be considered:

(1) What knowledge base is available for the solution of global and social challenges (block "knowledge base")
(2) What new opportunities will be brought by future technologies (information from the foresight program should be used)
(3) Knowledge gap to respond to challenges
(4) How to mobilize sectoral actors to solve global challenges, what actors should be involved and/ or what new organizations should be set up, or what networks should be reframed
(5) What research infrastructure should be in focus and what are gaps in research facilities.

The development of the Internet of things will streamline the mapping of actors, facilities, and research infrastructure.

The identified gaps can serve as an input for a new foresight cycle.

The main policy objective is to ensure SIS competitiveness, sustainability, and adaptability. The policy focuses on the formulation of strategic goals, the selection of strategic technologies and the development of an action plan and policy mechanisms. The vision, scenarios, technological roadmaps and Delphi outputs form the basis for the policy.

The information from all blocks of the SIS evolutionary model should be accumulated in the "policy and priorities" block. It is important to link the action plan to the scale of events in scenario alternatives to ensure the adaptability and sensitivity of the policy to rapid changes. The action plan should be aimed at supporting future technologies and embedding them into the sectoral environment.

Conclusions

The main conclusion of the paper is that it is of crucial importance to splice the sectoral foresight with an assessment of the sectoral innovation system and the development of sectoral innovation policy, i.e. an integrated approach should be developed in which both activities are considered as complementary.

The first step in this direction is the development of the foresight methodology, which should not only form the answer to fundamental changes in evolution, but also should be linked to the mission of the system, since the future technologies should be aimed at the implementation of the mission, or they reconfigure it if it is about disruptive technologies. Bridging foresight with the mission of the system not only focuses future technologies on ensuring the system's competitiveness and on economic and social security, but also bind future technologies with global and social challenges (responding to global and social challenges is one of the mission of the system implemented by the system itself or in cooperation with other sectoral systems).

This finding serves as a starting point for building a bridge between the foresight and the sectoral system of innovation, on the one side, and foresight and global and social challenges, on the other. The Delphi-Dialogue technic, the developed approach to the first round of the future technology prioritization and the SIS evolutionary model give an idea how to bridge these studies.

Implementing this methodological scheme, we can set technological priorities that are oriented on global and social challenges that are broadly agreed to be of high social importance, and at the same time stimulate the private sector to invest. Global and social challenges will enhance the innovation dynamic, add speed to the generation and the use of future technologies.

The foresight is designed to spark dialogue among multiple scientific disciplines, across different sectoral innovation systems, and different sectoral actors to respond to global and social challenges, and to ensure the competitiveness and sustainability of SIS. There should be incentives to “think outside the box” to generate new solutions. Meeting SIS goals and missions through the generation and implementation of future technologies should be addressed by stimulating cross-disciplinary academic work with a focus on the intersection between natural and social sciences, collaborations between different sectoral innovation systems, and new forms of partnership between public, private sectors and civil society. Civil society organizations will be crucial to facilitate an open dialogue on future technologies and the practical application of solutions.

The methodology brings together a sectoral lens with global and social challenges focused lens and technology focused lens. Crucial to the implementation of technological priorities is the need to revise the institutional set up of the sectoral system of innovation. The evolutionary model of SIS can help us to find the right solutions and “immerse” future technologies in the sectoral environment. Thus, the vector of transformative changes in SIS is governed by future technologies and identified “failures” (institutional, infrastructural, interactional, capability failures) that inhibit the generation, transfer and implementation of future technologies.

The methodology brings together the supply-side policy with demand-side policy, and re-articulates the dominant policy analytical framework. Sectoral innovation policy is driven by future technologies, by global and social challenges, and response to the need to provide SIS competitiveness, economic and technological security.

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