

# Foresight-Research for Green IT Engineering Development

Igor Shostak, Mariia Danova and Yuliia Kuznetsova

**Abstract** It is given the basic principles and directions of Green IT Engineering development, as well as the principles of ecological research in the software industry. It is performed the generalized procedure for foresight-project implementation to determine scientific-technical development Green IT Engineering perspective directions using the proposed information technology. It is proposed the approach to construction of foresight technology system model in the form of the two-level hierarchical system consisting of the functional and methodical levels. As a formal basis, methods of bibliometrics and scientometrics (calculating the number of publications, analysis of citing), multi-criterion decision-making problems (t-ordering, Pareto optimality) and patent analysis (trace analysis of the dynamics of inventive activity) are chosen. The result of the foresight-research implementation will be a number of priorities for Green IT Engineering development. In future members of foresight-projects will implement the theoretical development in the form of interactive decision-making support system.

**Keywords** Green IT engineering · Foresight-research · t-ordering · Pareto optimality · Priority directions development

## 1 Introduction

In the era of globalization, one of the fundamental priorities of scientific-technical and innovation policies in most countries include ensuring global leadership in high-tech industries and innovative technologies. At that, the efforts of the states are aimed both to promoting research and development activities in the advanced fields of science and technologies and setting national priorities for scientific and technical development. Practically all developed countries periodically create special programs that set priority development areas of science and technology. The

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methods used in development process of these programs proved to be the most effective tool of choosing the priorities in the field of science and technologies.

The concept of “foresight” arose in the 1950s in the “Rand” American Corporation that solved the problems of determining the perspective military technologies. In view of insufficiency of traditional predictive methods (quantitative models, extrapolation of current trends, etc.), “Rand” experts developed Delphi method [1], which became a basis of most foresight-researches. During the 1960s large-scale operations on predicting were carried out by Naval and Air-Force establishments of the USA. Since the 1980 the foresight has already been used in the European countries [1]. The foresight reached its peak as an analysis method in the mid-nineties within national programs of technological prediction, which still remain the main scope of application of foresights. For today, the foresight is used as a system instrument for future development that allows one to consider changes in all areas of society, namely science and technologies, economy, social and public relations, culture.

### ***1.1 Background of the Work***

Today, in most countries of the world (USA, Japan, Great Britain, France, Sweden, Russia and others) and in Ukraine, in particular, the foresight technology proved to be the most effective tool for selection of priority directions in the field of science and technology.

In Japan since 1971 the foresight results determine the development forecast of science and technologies in the country for the next 30 years [2]. Thus, the results are “adjusted” each 5 years. The main stages of foresight in Japan included the analysis of trends in the world of science and technology; making the list of perspective “subjects” of economic, scientific, technical and social development; two-round survey of experts according to the Delphi method; ranging the chosen subjects according to the extent of their innovative importance; making the list of national scientific and technical priorities as well as critical technologies.

In the USA in recent years the main efforts at the federal level were aimed to drawing up a list of technologies that are critical to the national economy. Due to the fact that the researches are not general one of the most difficult challenges facing the US government in the analysis of foresight research was bringing together the different lists of critical technologies and identifying similarities between them, as different researches used techniques different in the level and quality (survey of experts, expert panels, technology road maps), which were often formal and were not the result of original research [3].

In Great Britain there were carried out three foresight-programs organized by the Government [4]. “Foresight-1” (1994–1999) program took into account only the technological and market prospects. “Foresight-2” (1999–2002) and “Foresight-3” (2002–2004) are characterized by the integration of technological, market and social problems, as well as the involvement of a wide range of participants. The

Government committee heads the program that includes representatives of 17 ministries and departments. Each program consists of three interconnected stages, namely the analysis, distribution of information and application of results, preparation for the following program. As a result the state priorities are set in scientific and technical programs, in staff training and methods of state regulation. The budgetary priorities are formed based on five-year plans and since the 1990—with regard to long-term (15–30 years) forecast priorities of foresight and scenarios. The main mechanism of implementation is a LINK program of promotion of the cooperation and the methods are Delphi, expert panels, scanning of technologies and scenarios.

In Germany, two rounds of Delphi were carried out in 1993 and 1998 [5], the results of which were used in the formation of national research and development policy. Their initiator was the Federal Ministry of Education, Science, Research and Technology, and Institute of systems and innovative researches Fraunhofer carried them out in Karlsruhe. The general objective of these researches was not predicting the future, but preparing possible scenarios and gathering information for decision-making, as well as preparing the scientific basis for national debates on the development of the country future. The result of foresight studies in close cooperation with Japanese colleagues (“Delphi-93” and “Delphi-98”) has become its own unique program FUTUR (another name—“The German Research Dialogue”) that allows one to create a strategic vision for the Ministry of Education and science for the next 20 years.

Implementation of technological foresight in France in 1999–2000 was carried out in four stages [6]. A distinctive feature of the French foresight involves its organization in two mutually parallel directions. The first of them was implemented by the Ministry of Higher Education and Research, and was carried out by Delphi method through most experts (about 3.5 thousand). Its strategic objective laid in studying important technological development in various areas that would interest economy and society. The second direction was in charge of the Ministry of Industry and its objective laid in studying the technologies that were critical for the French industry in the next 30 years. As a methodological basis of the research, there were used bibliometric and patent analysis, as well as expert evaluation.

The history of foresight-researches in Russia is nearly 15 years. Over the years, various departments and research groups implemented projects aimed at determining the prospects for the development of various scientific and technological areas, sectors of economy and regions. However, the long-term forecast of scientific and technological development in the Russian Federation for the period to 2025 prepared by the Ministry of Education and Science of the Russian Federation in 2007–2008 [7] became the most large-scale and rather complex research. The forecast was developed within the Federal target program called “Research and Development in the Priority Directions of Development of Scientific and Technological Complex of Russia for 2007 – 2012” with the application of the methods, namely “critical technologies”, “expert panels”, “scenarios”, as well as with the direct support of Federal agency on science and innovations.

The forecasting and analytical research carried out in Ukraine, within the State Program on Forecasting of scientific and technological innovation and development approved by Cabinet of Ministers involved more than 700 experts. The Ukrainian foresight methodology [8], which objective was forming state scientific-technological and innovative priorities provides implementation for a set of stages, by questioning a group of experts based on the Delphi method [9]:

- the first stage involves solving the problem of selecting of experts to participate in the foresight-research; when forming the group of experts the method of “snowball” is used;
- the second stage, using of expert surveys, as well as “benchmarking” (comparison with other countries or regions) involves forming a preliminary list of subject directions and the criteria for their evaluation of the main objectives of the country (scientific-technical development) STD;
- the third stage involves estimating by experts the obtained subject directions by the set of criteria. This procedure is carried out by means of Delphi method that assumes survey (questioning) of experts and organization of feedback (through carrying out three rounds of survey). Results of research include the evaluation summary for each topic, as well as analytical reviews of the subject directions;
- the final stage involves coordinating and approving the lists of subject directions of the country STD obtained in the previous stage.

## ***1.2 Work Related Analysis***

Recently a number of publications devoted to research of theoretical and practical aspects of the foresight (the technology of future development) is increasing [9–12]. The foresight was started to be used since the beginning of the 1990s by the governments of the U.S., United Kingdom, Germany, Japan and Australia, and by 2000 the number of such countries exceeded 30. At present this technology has been adopted not only in Western Europe, U.S. and Japan, but also in a number of developing countries and countries with economies in transition (Poland, Czech Republic, Russia, Belarus, Ukraine, etc.) [1–12].

The foresight is the systematic process that is aimed at identifying new strategic directions of scientific and technological achievements, which in the long run will have a serious impact on the economic and social development of the country [1]. The foresight technology has the following main characteristics: the foresight is a systematic process; the central place in this process is taken by scientific and technological directions; priorities are considered with regard to their influence on social and economic development of the country; time horizon is considered in the average and long terms.

In the framework of foresight there is a question about an assessment of possible prospects of innovative development connected with the progress in science and technologies, as well as about possible technological horizons that can be reached

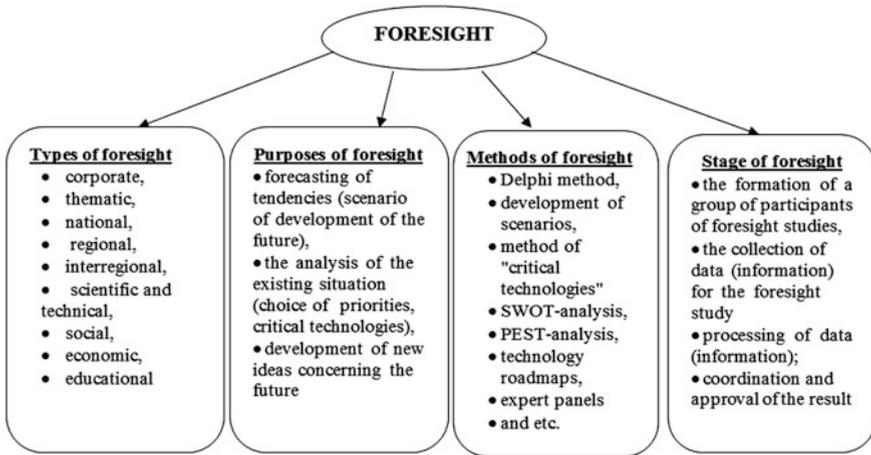


Fig. 1 Structural elements of technology foresight

in case of investment of certain funds and organization of systematic work, and probable effects for economy and society.

In practice, there are various types of the foresight [1, 13] as each foresight-project differs from others in various parameters: the contents, depth of analysis, scales, time frames, territory of coverage, number of participants, available resources, etc. Because of the analysis of the foresight in different world countries, it is possible to allocate its basic structural elements (Fig. 1).

Analysis of the publications from domestic and foreign sources [1–15] devoted to the study of theoretical and practical aspects in foresight methodology application showed that there was a need for further study of the problem related to the automation of foresight technology. The authors analyzed the way of automation for each stage in the national foresight-project [8, 14]. As a result of the analysis it was offered information technology support of foresight projects in Ukraine [15], based on the specialized techniques for selecting the priorities [8]. The adoption of specified technology will allow increasing the efficiency of national foresight-projects due to their complete computerization based on formal methods.

### 1.3 Goals and Approach

A **goal of the paper** is to consider the generalized procedure for foresight-project implementation to determine STD Green IT Engineering perspective directions using the proposed information technology. The result of the foresight-research implementation will be a number of priorities for Green IT Engineering development. As a formal basis, methods of bibliometrics and scientometrics (calculating the number of publications, analysis of citing), multi-criterion decision-making

problems (t-ordering, Pareto optimality) and patent analysis (trace analysis of the dynamics of inventive activity) are chosen. The complex automation approach of foresight-projects is expounded. In future members of foresight-projects will implement the theoretical development in the form of interactive decision-making support system.

The technology of carrying out the foresight-research consists of the following steps:

1. Formation of expert panels, i.e., number and structure of expert members participating in forecasting based on the evaluation of their competence level is formed.
2. Forming the initial list of the Green IT Engineering directions. It is necessary to analyze the status and prospects of Green IT Engineering development using methods of bibliometrics (calculating the number of publications), scientometrics (analysis of citing) and patent analysis (trace analysis of the dynamics of inventive activity). Then, for the obtained lists of trends of the Green IT Engineering development it is calculated value of criteria for their assessment provided by technique of foresight-researches. Thus, all “leading” directions have quantitative assessments for each of the criteria, which will help to determine the number of priority.
3. Selection of priority directions for Green IT Engineering development. Initial data for the selecting of priorities is a list of directions of Green IT Engineering, as well as a set of values of criteria assessment for each direction. The procedure for the selection of priority directions of Green IT Engineering development is in ranking these directions criteria using the Pareto optimality principle and t-ordering method.
4. Coordination and approval of Green IT Engineering priority directions. In accordance with the current technique the strictly regulated procedure for coordination and approval of priorities is carried out.

## **2 Research of Foresight Technology Structure as a Complex System**

For computer implementation of foresight technology it is necessary to formalize it, by development of the model, with a known level of adequacy reflecting all stages of the foresight-research. The foresight technology consists of a set of interacting components—subprocesses (foresight-research stages) and possesses the following row of the main properties:

- hierarchies—actions of subsystems of the top level depend on the actual execution by the bottom levels of their functions;
- discretizations—correlation between elements of system (subprocesses) is carried out sequentially;

- determinancies—all transitions between elements of system are strictly defined, i.e. transition to the next happens on condition of successful execution of the previous subprocess.

To select a special mathematical apparatus that would consider the selected main characteristics of foresight-researches, it is appropriate to conduct modelling which will allow to receive an holistic, systemic view model, allowing to reveal correlations of elements foresight technology, possible states of each element and the relation between them.

Foresight technology representable in the form of multilevel structure described from positions of systems theory [16]. This structure should reflect the most important characteristics of the simulated system, namely:

- that the foresight technology consists of interrelated subsystems, which have a right to make decisions;
- that these subsystems form a hierarchy.

On the assumption of that, theoretical-system model of foresight technology represented in terms of functional-method relations, in which a function is understood as subject needs for receiving some result, and a method—some process by which this result is obtained. In this case, the upper level of foresight technology is set by the functional part and the lower—the methodical.

On the functional level displayed the main purpose of the foresight technology (analysis of the existing situation (the selecting of priorities, the search for critical technologies), prediction of tendencies (described of development scenarios), etc.), which in turn can be decomposed into sub-goals (stages), depending on the type of foresight (national, corporate, scientific and technical, social, etc.). The methodical level reflects the transition way from the input to the output elements and contains as methods of achieving the purpose (set of methods for foresight technology), and conversion technology from input to output elements (certain methods and order for their implementation).

The provided description of foresight technology is initial for its formalized description on the set-theoretic level, at that the general problem statement of synthesis the models of computer implementation of foresight technology, given on the set-theoretic level of description, is similar in its structure and content to the general problems statement of decision-making problems in the conditions of a multicriteriality. A formal set-theoretic description is carried out using the following model:

$$\Phi = \langle \Theta, G, \Lambda, \Omega \rangle, \quad (1)$$

where:  $\Phi = \{\varphi_g\}$ ,  $g = \overline{1, m}$ —the set of types in foresight technology;  $\Theta = \{\theta_i\}$ ,  $i = \overline{1, k}$ —set of goals in foresight technology that indicate a given state of foresight technology;  $G \subset G_0 \cup G_1$ —set of initial  $G_0$  and final  $G_1$  states of foresight technology, at that  $G_0 \cap G_1 \neq \emptyset$ ;  $\Lambda = \{\lambda_q\}$ ,  $q = \overline{1, z}$ —set of stage in

foresight technology;  $\Omega = \{\omega_j\}, j = \overline{1, n}$ —plural sets of methods foresight technology.

For the description of dynamic properties by means of system model, we will enter the following concepts:

1. Time  $T$  is a linear ordered by the relation “ $\leq$ ” a set of time points  $t$ :

$$T = \langle T^0 = \{t\}, \leq \rangle : t \in [t_0, t], \quad (2)$$

where:  $t_0$ —initial time point in the interval  $[t_0, t]$ ;

2. The instantaneous state of foresight technology  $\Phi$  for a period of time  $T$ :

$$\Phi^T \subset \Phi \times T : \Phi^T = \{\Phi^t\} \wedge \Pi_T(\Phi^T) = \{t\} \subseteq T, \quad (3)$$

where:  $\Pi_T(\Phi^T)$ —projection of a set of the instantaneous statuses  $\Phi^T$  to a set of time points  $T$ .

$\Pi_T(\Phi^T)$  is understood as a set of those elements from  $T$  which are projections of elements from  $(\Phi^T)$  on  $T$ . For a couples  $\Phi^t = (\Phi, t)$  projection element  $\Phi^t$  on the set  $T$  serves the element  $t$ . Instant state of foresight technology stage  $\Phi \in \Phi^T$ —making in a time point  $t$  some event (e.g. appearance of data at the input or output of stage foresight technology), relating to this stage.

The initial  $G_0^T$  and final  $G_1^T$  states of foresight technology represent the sets, including prehistory of its instantaneous states for the period of time  $T$  to some initial and final time points.

Using the introduced concepts, build the functional part  $\Phi^{\Phi^T}$  of a system model of the foresight technology as follows:

$$\Phi^{\Phi} \subset P(G_0^T \times \Theta^T \times G_1^T). \quad (4)$$

In the particular case  $\Phi^{\Phi}$  can be given mapping

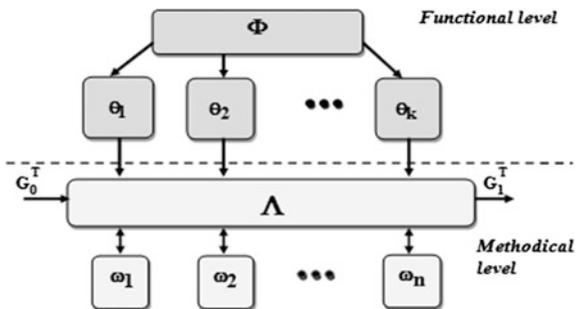
$$\Phi^{\Phi} : (G_0^T \times \Theta^T) \rightarrow G_1^T, \quad (5)$$

where:  $G_0^T, G_1^T$ —initial and final states of foresight technology for the time period  $T$ ;  $\Theta^T$ —set of foresight technology goals for the time period  $T$ .

Mapping (5) shows, that the final status of any of the stages of foresight—a function of its initial state and specified goal of this stage, specifying these states.

Methodical part of the model  $\Phi^M$  is intended to describe the possibilities on any stage in foresight technology to reach certain values of the output value for the fixed initial state and a specified goal, i.e. reflects a transition way from input elements to output:

**Fig. 2** Structural diagram of foresight technology system model



$$\Phi^M : (\Theta \times \Lambda) \rightarrow \Omega, \tag{6}$$

where:  $\Theta = \{\theta_i\}, i = \overline{1, k}$ —set of foresight technology goals that indicate a given foresight technology state;  $\Lambda = \{\lambda_q\}, q = \overline{1, z}$ —set of foresight technology stage;  $\Omega = \{\omega_j\}, j = \overline{1, n}$ —plural sets of foresight technology methods.

As a result, the system model (SM) of foresight technology will be the following:

$$\begin{aligned} \Phi &= (\Phi^\Phi \times \Phi^M) \\ \Phi^\Phi : (G_0^T \times \Theta^T) &\rightarrow G_1^T, \\ \Phi^M : (\Theta \times \Lambda) &\rightarrow \Omega \end{aligned} \tag{7}$$

where:  $\Phi^\Phi, \Phi^M$ —functional and methodical parts of foresight technology SM;  $G_0^T, G_1^T$ —initial and final states of foresight technology for the time period T;  $\Theta^T$ —set of foresight technology goals for the time period T.

Foresight technology SM is shown in Fig. 2. On the input of stage foresight technology when he is in some initial state, incoming input action in the form of given purpose, which upon reaching of it this stage should go to the desired finite state.

### 3 Approach to Complex Automation of Foresight-Projects Defining Scientific and Technological Priorities in Green IT Engineering

Results of conducted foresight—researches in majority developed countries of the world showed that one of the priority directions development are energy efficiency and energy saving, as well as decrease in negative influence on environment and improvement of an ecological condition of the planet. The volume of energy consumption is not only important indicator of economic development, but also scales of environment pollution, including of atmospheric air pollution. A main

objective of Green Engineering [17] is decrease in negative influence on environment at the help of science and equipment [18–20]. In [21] 12 basis principles of Green Engineering are given:

1. Designers need to strive to ensure that all material and energy inputs and outputs are as inherently nonhazardous as possible.
2. It is better to prevent waste than to treat or clean up waste after it is formed.
3. Separation and purification operations should be designed to minimize energy consumption and materials use.
4. Products, processes, and systems should be designed to maximize mass, energy, space, and time efficiency.
5. Products, processes, and systems should be “output pulled” rather than “input pushed” through the use of energy and materials.
6. Embedded entropy and complexity must be viewed as an investment when making design choices on recycle, reuse, or beneficial disposition.
7. Targeted durability, not immortality, should be a design goal.
8. Design for unnecessary capacity or capability (e.g., “one size fits all”) solutions should be considered a design flaw.
9. Material diversity in multicomponent products should be minimized to promote disassembly and value retention.
10. Design of products, processes, and systems must include integration and interconnectivity with available energy and materials flows.
11. Products, processes, and systems should be designed for performance in a commercial “afterlife”.
12. Material and energy inputs should be renewable rather than depleting.

Thus, in order to harmonize economic, social and environmental factors affecting the sustainable current state of society and the satisfaction of its potential needs it is appropriate to study the processes of ecosystems that are software products. Application of ecological researches in the software industry shows that their distribution goes on the basis of three principles [20–22]:

- eco-efficiency—assumes a combination of the efficiency purposes in traditional sense with the ecological purposes and the direction of their achievement on improvement of life quality and reduction of environment influence, i.e. where and how the software has to be applied to reduce use of natural resources and to lower an adverse effect on environment;
- eco-equity—assumes distribution of resources between the living and future generations taking into account the concept of a sustainable development [23];
- eco-effectives—assumes creation of “pure” (waste-free) systems and technologies in which waste of one processes is sources for other processes and finally their application with advantage is carried out. An applying of the principle is directing on solution of the pollution problems by reducing waste.

As the directions for foresight-research of Green IT Engineering STD definition is expediently to use the following directions [23–25]:

- Efficiency improvements of the software and algorithms (“green” software development):

energy-saving green software—software, that focuses on the principles of software using, ensuring reduction of harmful effects (direct or indirect) on the environment;

green software engineering—software development with the least harmful effects on the environment;

software ecosystem—an artificial complex that includes the software, environment of its development, operation, maintenance and disposal, which are connected by sharing software and intelligence.

- Effective power supplies development (with high efficiency);
- Green telecommunications development;
- Use of the lowered supply voltage, voltage control and synchronization frequency of the equipment;
- Virtual calculations development and use of Plug computers.

### 3.1 Formation of Expert Panels

Expert members participating in forecasting—the key parameter defining quality of future forecast. Thus, for high-quality examination it is necessary to solve the following problems:

1. to assess the competence level of expert's;
2. to determine the number of expert's;
3. to form the final list of expert members participating in forecasting.

Denote by  $Q$  the experts set, then to evaluate the competence level of each  $i$ -th expert ( $i = 1, \dots, m$ ) will use the generalized indicator of the competence level ( $K_i$ ) given in [26], which takes into account both the professional activity, and personal qualities of experts:

$$K_i = \frac{1}{4} \sum_{j=1}^4 K_{ij}, \quad (8)$$

where  $K_{i1}$ —coefficient reflecting the level of professional training and knowledge of the  $i$ th expert (it takes into account the levels of qualification such as “Doctor of Science”, “PhD” etc., and is measured in points  $0.5 \leq K_{i1} \leq 1$ );

$K_{i2}$ —coefficient reflecting the level of the basic coherence of  $i$ th expert when decision making (it takes into account factors such as intuition, production experience, theoretical analysis etc., and is measured in points  $0.05 \leq K_{i2} \leq 1$ );

$K_{i3}$ —coefficient reflecting the personal qualities of the  $i$ th expert and on the basis of self-assessment is calculated ( $0 \leq K_{i3} \leq 1$ ):

$$K_{i3} = \frac{1}{n} \sum_{j=1}^n K_{i3j}, \quad (9)$$

where  $K_{i3j}$ —coefficient reflecting a self-assessment of the  $i$ th expert in existence of his  $j$ th personal qualities;  $n$ —number of expert personal qualities;

$K_{i4}$ —coefficient reflecting the personal qualities of the  $i$ th expert and by colleagues experts is calculated ( $0 \leq K_{i4} \leq 1$ ):

$$K_{i4} = \frac{1}{n \cdot m} \sum_{l=1}^m \sum_{j=1}^n K_{i4jl}, \quad (10)$$

where  $K_{i4jl}$ —coefficient given  $l$ th expert about existence of  $j$ th-personal qualities in the  $i$ th expert;  $n$ —number of expert personal qualities;  $m$ —number of experts participating in the assessment of the  $i$ th expert.

As a criterion for assessment of the required number of experts, the following formula is used:

$$N_{\min} = 0.5(3/\varepsilon + 5), \quad (11)$$

where  $N_{\min}$ —the minimum required number of experts;  $\varepsilon$ —parameter setting a minimum level of an error expertize ( $0 < \varepsilon \leq 1$ ).

In case of an admissible error expertize in 5 % ( $\varepsilon = 0.05$ ) the number of experts should be at least 32. According to [26] the necessary number of experts for the assessment must be at least 7–9 people, therefore, the number of experts involved in forecasting, is in limits  $7 \leq N \leq 32$ .

To receive the final list of all experts who passed certification is range on the competence level (value of the generalized indicator  $K_i$ ) and according to the relation (11) the list of the expert members is formed.

### 3.2 *The Initial List Formation of the Subject Directions in Terms of Green IT Engineering*

Within this stage, there is a formation of the initial list of the directions, for its subsequent assessment, and values of criteria of their assessment are calculated.

We will break the task set above into a row of subtasks:

1. to form the initial list of subject directions (SD), for their subsequent assessment;
2. to calculate the values of the quantitative criteria assessment on each of the directions;
3. to get the values of qualitative criteria of an assessment on each of the directions.

It is necessary for the solution of first formulated subtasks to use methods of bibliometrics, scientometrics and patent analysis to form the initial list of SD. For solution of two remaining tasks, it is necessary to calculate values criteria from system criteria assessment for each SD. As a result, more perfect lists of STD SD, each of which has the quantitative assessment based on the received values of criteria of their assessment that further will allow defining a row of the priority is formed.

Formation of the list of SD will made by methods of bibliometrics, scientometrics and patent analysis.

**Bibliometric Analysis.** “*Calculation the number of publications*” method consists in the following: need to made the quantitative assessment of the document flow that organized within one of the accepted classifications i.e. the analysis of amount of abstracting scientific documents number from different knowledge domains is carried out. Thus, it is selected the areas of science and separate sections, which take the leading place in structure of scientific knowledge on the number of scientific publications. After that, it is compared the amount of publications on separate branches to select the “leading” branches of knowledge (as a percentage of total quantity of the abstracting publications for this period).

**Scientometrics Analysis.** The *analysis of citing* is carried out by research of bibliographic links in publications of scientific periodical press databases (Web of Science, SCOPUS, the Russian index of scientific citing, National library of Ukraine of V. I. Vernadsky and etc.) for the quoting of the publications detection that form a certain direction of science (the direction of science, number of links [self-citing is excluded], total quantity of publications in the direction). The leading scientific directions is selected upon results analysis of citing.

**Patent Analysis.** In the patent analysis, for obtaining the quantitative characteristics of the certain directions of science and technique development, statistical techniques of patent information arrays processing are used. These include the trace analysis of the dynamics of inventive activity in each scientific and technical direction, which consists of the cumulative rows patenting construction characterized by increase of summary number of the patents relating to this direction. Intensity of the researched direction development is define by a slope ratio of curve dynamics of patenting to a timebase. On its basis, calculate the coefficient of ponderability for the researched SD, which is accepted as the quantitative index of the researched direction prospects:

$$D_i = \frac{\operatorname{tg}\alpha_i}{\sum_{i=1}^n \operatorname{tg}\alpha_i}, \quad (12)$$

where  $D_i$ —ponderability coefficient of  $i$ th SD, and  $\sum D_i = 1$ ;  $\operatorname{tg}\alpha_i$ —a slope ratio of tangent line to a curves of the dynamics of inventive activity of  $i$ th SD;  $\sum \operatorname{tg}\alpha_i$ —sum of slope ratios tangent lines to curves of the dynamics of inventive activity of all SD.

The ranged list of SD for further calculation of criteria values of their assessment we will receive because of the first delivered subtasks solution.

In the procedure of initial lists SD formation the following step is the solution of the second and third subtasks, namely—calculation the values of the criteria assessment on each SD. The specified criteria, according to their values, divide into the quantitative and qualitative, received by expert estimation.

The quantitative criteria (expressed by the quantitative values) are—financing ( $K_f$ ); presence of scientific experts ( $K_{sc}$ ); productivity of scientific and technical activities ( $K_{sta}$ ); existence of production capacities ( $K_{pc}$ ) and existence of experimental and production basis ( $K_{epb}$ ).

The qualitative criteria is received by expert estimation include applicability ( $K_a$ ), presence of the potential investor ( $K_{pi}$ ), output perspective to the world market ( $K_{wm}$ ), and presence of the scientific leader belong ( $K_{sl}$ ).

For determination of values on each of qualitative criteria experts need to fill in the polling questionnaire. For processing of group expert estimates it is necessary to check a level of coherence of experts judgments, and then the generalized (aggregated) group assessment for each SD by each of criteria is determined.

As exponents of coherence of experts judgments apply the variation coefficient characterizing the relative dispersion of result:

$$V_j = \frac{\sqrt{\frac{\sum_{i=1}^{m_j} (x_{ij} - \bar{x}_j)^2}{m_j - 1}}}{\bar{x}_j} \cdot 100 \%, \quad (13)$$

where  $V_j$ —variation coefficient of estimates on  $j$ th SD;  $m_j$ —amount of the experts estimating  $j$ th SD;  $x_{ij}$ —an assessment the  $i$ th expert of  $j$ th SD in points;  $\bar{x}_j$ —average value an assessment of SD in points:

$$\bar{x}_j = \frac{\sum_{i=1}^{m_j} x_{ij}}{m_j}. \quad (14)$$

The coherent a consensus of experts when value of coefficient variation is less. If coherence of experts judgments is absent, repeated questioning is carried out. To experts, except polling questionnaires, additional information on a subject of expertize is sending and they, as a rule, adjust the estimates. The corrected information comes to analytical group for coherence check again.

For calculation of the aggregated group assessment, we will use method of average ball estimates. Taking into account the weight coefficients of the experts, group evaluation of  $j$ th SD is calculated as a weighted average:

$$x_j^{CB} = \sum_{i=1}^{m_j} (K_i \cdot x_{ij}), \quad (15)$$

where  $K_i$ —weight factors of experts competence;  $m_j$ —amount of the experts  $j$ th TD estimating;  $x_{ij}$ —an assessment in points by  $i$ th expert of  $j$ th SD.

### 3.3 Selection of Priority Directions in Terms of Green IT Engineering

At this stage, it is necessary to select the STD of priority directions by an assessment among themselves of SD received at the previous stage i.e. to evaluate SD on values of their criteria. The assessment of SD occurs by principle of Pareto optimality and a method of t-ordering (for narrowing of Pareto area). Priority directions are SD, whose vector estimates make the Pareto set. We will consider in detail each of methods.

The mathematical model of the task about a choice most of the priority directions of STD can be presented in the form

$$B_f = \langle X, f_1, f_2, \dots, f_m \rangle,$$

where  $X$ —a set of SD;  $f_j$ —the numerical function defined on a set  $X$ , at that  $f_j(x)$  is assessment a SD  $x \in X$  on  $j$ th criterion assessment ( $j = 1, m$ ).

The purpose of the given problem solution is consisted of getting the directions having as much as possible highest marks by each criterion i.e. in allocation of Pareto set [8, 15]. All criteria functions  $f_j$  reflect usefulness of SD  $x \in X$  from the viewpoint of different criteria assessment and shall be commensurable, i.e. values of each criteria function change in the same limits  $[a, b]$ :

$$\forall x \in X : 0 \leq a \leq f_j(x) \leq b, j = \overline{1, m}. \tag{16}$$

At that the least preferable SD on any of private criteria  $f_j(x)$  will receive a mark **a** and the most preferable—a mark **b** ( $a = 0, b = 1$ ).

The numerical functions  $f_j(x)$  ( $j = 1, m$ ), stated above, is formed the vector criterion  $f = (f_1(x), f_2(x), \dots, f_m(x)) \in R^m$ , where  $R_m$ —field of  $m$ -dimensional vectors. For any of SD  $x \in X$  a set of its marks by all criteria, i.e. the set  $(f_1(x), f_2(x), \dots, f_m(x))$  is a vector mark of SD  $x$ . All possible vector marks will formed a set of possible marks  $Y = f(X) = \{y \in R^m | y = f(x) \text{ in case of some } x \in X\}$ .

The domination relation by Pareto is determined as follows: SD  $x_i$  dominates according to Pareto of TD  $x_j$ , if the vector mark  $f(x_i) = (f_1(x_i), \dots, f_m(x_i))$  of SD  $x_i$  dominates according to Pareto a vector mark  $f(x_j) = (f_1(x_j), \dots, f_m(x_j))$  of SD  $x_j$ , i.e. if the inequality  $f(x_i) \geq f(x_j)$  is executed, consequently  $x_i \geq x_j$ . The domination condition on Pareto in informative means, that SD  $x_i$  isn't worse, than SD  $x_j$  on any of the considered criteria, and at least, on one of these criteria  $x_i$  is better than  $x_j$ .

So, according to values criteria functions of SD we will receive their vector marks. For searching of a set of Pareto-optimal vectors  $P(Y)$  we compare them among themselves by the rule described above. If the received couples are incomparable on Pareto relation, then setting up the task of narrowing of the initial set by means of a t-ordering method, for choice of several SD as final output.

Setting up the task for choice of several SD as final output by means of narrowing of Pareto set. One of such methods is the method of t-ordering [8, 15] using ordinal information of the person making decision (PDM) on the relative significance of criteria.

As the initial information for a method of t-ordering the set S of expressions PDM about the relative importance of criteria assessment of a look is accepted:

$$S = \{f_k = f_j; \dots; f_q > f_p\}, \quad (17)$$

which needs to be expanded due to adding of the new transitive expressions which are consequences of the already available.

Taking into account the received set (17) when comparing two vector marks of SD the preference relation on a t-ordering method is built:

$$\begin{aligned} f(x_z)^t \succ f(x_w) &\leftrightarrow \left[ \exists f''(x_w) \in f(x_w)I : f(x_z) \underset{\sim}{\overset{p}{\succ}} f''(x_w) \right], \\ f(x_z)^t \underset{\sim}{\overset{p}{\succ}} f(x_w) &\leftrightarrow \forall j \in f[1 : m] : f_j(x_z) \geq f_j(x_w) \end{aligned} \quad (18)$$

where  $f(x_z)$ ,  $f(x_w)$ —SD vector estimates ( $f(x_z) = (f_1(x_z), \dots, f_m(x_z))$ );

$f(x_w) = (f_1(x_w), \dots, f_m(x_w))$ );

$f(x_w)I$ —set  $f(x_w)$ —the improved vectors ( $f_k = f_j; f_q > f_p$ ).

Thus, basic data of the task are a set (16) of ordinal informations on the relative importance of criteria and a set of vectors, incomparable on Pareto. Selecting a couple of vectors  $f(x_i)$  and  $f(x_j)$  for comparing of their vector estimates. The vector  $f(x_i)$  is fixed, and on a vector  $f(x_j)$  we receive sets of the improved vectors  $f(x_j)I$  according to (18). After conversions we receive the vectors, comparable according to Pareto. As a result we receive a set of Pareto-optimal vectors, and so—the priority directions of STD.

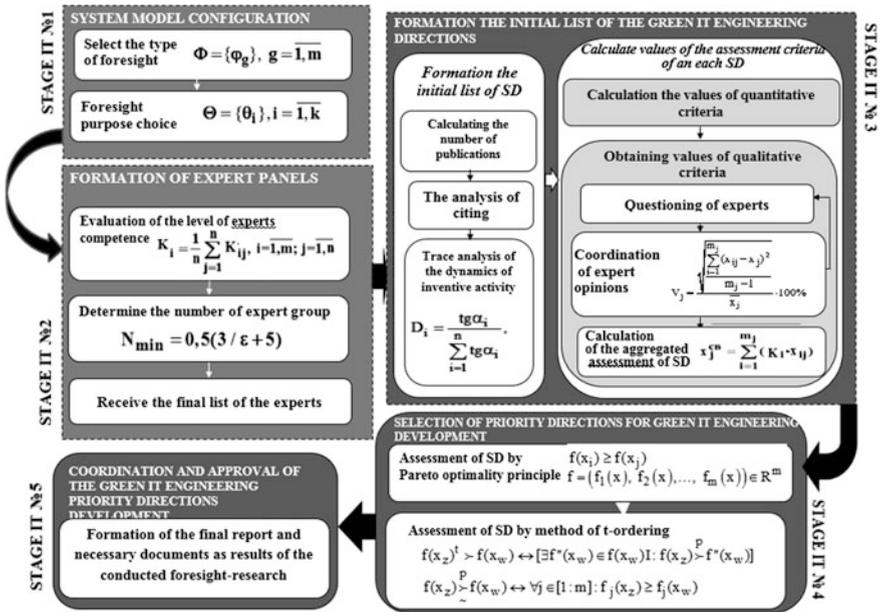
## 4 Results and Analysis

As initial data in the foresight-research for the selection of priority directions of STD Green IT Engineering in Ukraine are used statistical data for 2010–2015 years.

For an objective analysis of each direction of Green IT Engineering in the beginning of foresight-research the following assumptions of sufficiency were entered: information from the selected sources; specified time intervals; values of the basic criteria calculation for their assessment.

The result of the foresight-research implementation has become a number of Green IT Engineering priorities in Ukraine.

Course of foresight-research according to the developed applied IT [15], based on the foresight-research system model implementation and decision-making



**Fig. 3** The structure of applied information technology for foresight-researches of priority directions selection of STD Green IT Engineering

support methods for STD priorities selection that are proposed in the previous sections, consists of five main parts (stages) (Fig. 3): SM configuration; formation of expert panels; formation of the initial list of Green IT Engineering directions; selection the priority directions of Green IT Engineering; coordination and approval of the Green IT Engineering priority directions.

The first stage provides the configuration of foresight-researches and consists of the procedures of selection the type and objectives of foresight-research. At the second stage it is carried out operations such as calculations of required number of experts for research and generalized indicator in level of competence for each expert based on the coefficients reflecting both training and personal qualities of the expert. Further experts are ranged on value of the generalized indicator level of their competence and it is formed the final list of experts taking into account the number of expert group.

Thus, in the context of foresight-research there were attested 12 candidates in experts, 7 of them were selected for further involvement in expertize that enters the calculated earlier allowable range.

Within the third stage there is a formation of the initial list of the SD and calculating the values of criteria for their assessment. The initial data of this stage, in view of the assumptions about sufficiency made at the beginning of the research, are the following directions of Green IT Engineering development [23–25]:

1. Energy-saving green software.
2. Green software engineering.
3. Software ecosystem.
4. Development of green telecommunications.

To form the initial list of SD it is used the methods of counting the number of publications to analyze of the Ukrainian documentary flow in the Green IT Engineering directions. The results of this analysis for the 5-year time period (2010–2015 years) are shown in Table 1.

Thus, according to the results of the bibliometric analyze in the initial list for identifying the priorities of the Green IT Engineering included those that received the highest marks—namely, energy-saving green software, green software engineering and development of green telecommunications.

The next step is calculation of criteria values provided by the developed IT [15], for each initial direction, taking into account the assumptions made by us (Table 2).

At the fourth stage there is processing of the results obtained at the previous stage taking into account ordinal information from decision-making person (DMP) on the relative importance of assessment criteria of the SD. Comparison of the approved SD by means of the principle of Pareto-optimality is carried out. If comparison of the SDs across Pareto is impossible, we apply the t-ordering method considering ordinal information of the DMP on the relative importance of assessment criteria for the SDs. As a result we obtain the ranged list of priority directions of STD Green IT Engineering.

**Table 1** Distribution of scientific publications in the Green IT Engineering directions for 2010–2015 years

№	Direction	Number of scientific papers (articles, abstracts and books) (pcs)	Specific weight in the total number of publications (%)
1.	Energy-saving green software	87	28
2.	Green software engineering	112	36
3.	Software ecosystem	51	16
4.	Development of green telecommunications	64	20
Total		314	100

**Table 2** Values of main coefficients for Green IT Engineering directions

№	Direction	$K_{se}$	$K_a$	$K_{wm}$	$K_{sl}$
1.	Energy-saving green software	0.31	25.34	9.78	10.89
2.	Green software engineering	0.44	29.36	8.56	11.3
3.	Development of green telecommunications	0.17	20.11	5.09	7.23

To find the set of Pareto-optimal vectors  $P(Y)$  obtaining the vector estimates SDs, the method described in Sect. 3.3:

$$\begin{aligned} y_1 &= (0.01; 0.86; 0.33; 0.38) \\ y_2 &= (0.01; 1.00; 0.29; 0.38), \\ y_3 &= (0.00; 0.68; 0.17; 0.24) \end{aligned}$$

where  $y_1$ —vector estimate of “Energy-saving green software” direction;  $y_2$ —vector estimate of “Green software engineering” direction;  $y_3$ —vector estimate of “Development of green telecommunications” direction.

As a result, we obtain the following set of Pareto-optimal vectors  $P(Y) = \{y_1, y_2\}$ .

Based on the received result it is possible to draw a conclusion that priority directions of development Green IT Engineering, from selected by us, are—energy-saving green software and green software engineering.

## 5 Conclusion

According to the analysis of domestic and foreign publications on results of the carried-out foresight-research in most countries of the world (Japan, USA, France, Germany, etc.)—one of the development priority directions of the country is the sustainable growth through green innovation, which treats also Green IT Engineering, which has a set of the main purpose of reducing the negative impact on the environment through science and technology.

In order to harmonize economic, social and environmental factors affecting the sustainable current state of society and the satisfaction of its potential needs it is appropriate to carrying out the foresight-research on selection the priorities of the STD Green IT Engineering in Ukraine.

The problem description and formal statement of synthesis model problem of foresight-technology computer implementing are produced in the paper. The foresight-research implementation system model based on event-driven approach to decision-making, which, unlike the existing ones, allows to display the complex nature of foresight and provides a transition from heuristic procedures for their formal description for further information of foresight technology is created.

The complex automation approach of foresight-projects in Ukraine is expounded. Within the solution of the problem of the “Formation of Expert Panels” stage automation, it is proposed to perform selection of experts involved in the assessment on the basis of evaluation of their competence level by means of the generalized indicator of the competence level of each expert. For the conducted research on determination of the priority directions of Green IT Engineering development 7 experts are selected that enters the calculated allowable range.

In order to form the initial list of Green IT Engineering areas, technologies of bibliometrics, scientometrics and patent analysis are proposed to be used, which ensures objectivity of initial data of the foresight-research. In the current foresight-research the formation of the initial list of SD produced by using bibliometric analysis for the 5-year time period (2010–2015 years). As a result of this analysis, the initial list, for the subsequent determination of priority directions of Green IT Engineering development, includes SD's with the highest number of scientific publications in the analyzed period—namely, energy-saving green software (87 pcs.), green software engineering (112 pcs.) and development of green telecommunications (64 pcs.).

At the stage of priority directions selection for Green IT Engineering development it is offered to use the t-ordering method and the Pareto-optimality principle that give the chance to increase adequacy of an expert assessment in directions selecting of Green IT Engineering development. According to results of the foresight-research priority directions of Green IT Engineering development in Ukraine are the energy-saving green software and the green software engineering since their vector estimates make Pareto set and have values  $y_1 = (0.01; 0.86; 0.33; 0.38)$  and  $y_2 = (0.01; 1.00; 0.29; 0.38)$  respectively.

Proceeding from the received results of the foresight-research which is carried out by authors it is possible to claim that the specified sector in Ukraine is growing rapidly, however has no sufficient state support. In this connection, it is appropriate to carry out a national Green Foresight-Research which will allow to reveal the leading Green IT Engineering directions for further public financing of scientific researches in the selected priority directions, thereby having increased competitiveness of the state.

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