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EUROPEAN BORDER AND COAST GUARD AGENCY

Executive Summary

Research Study

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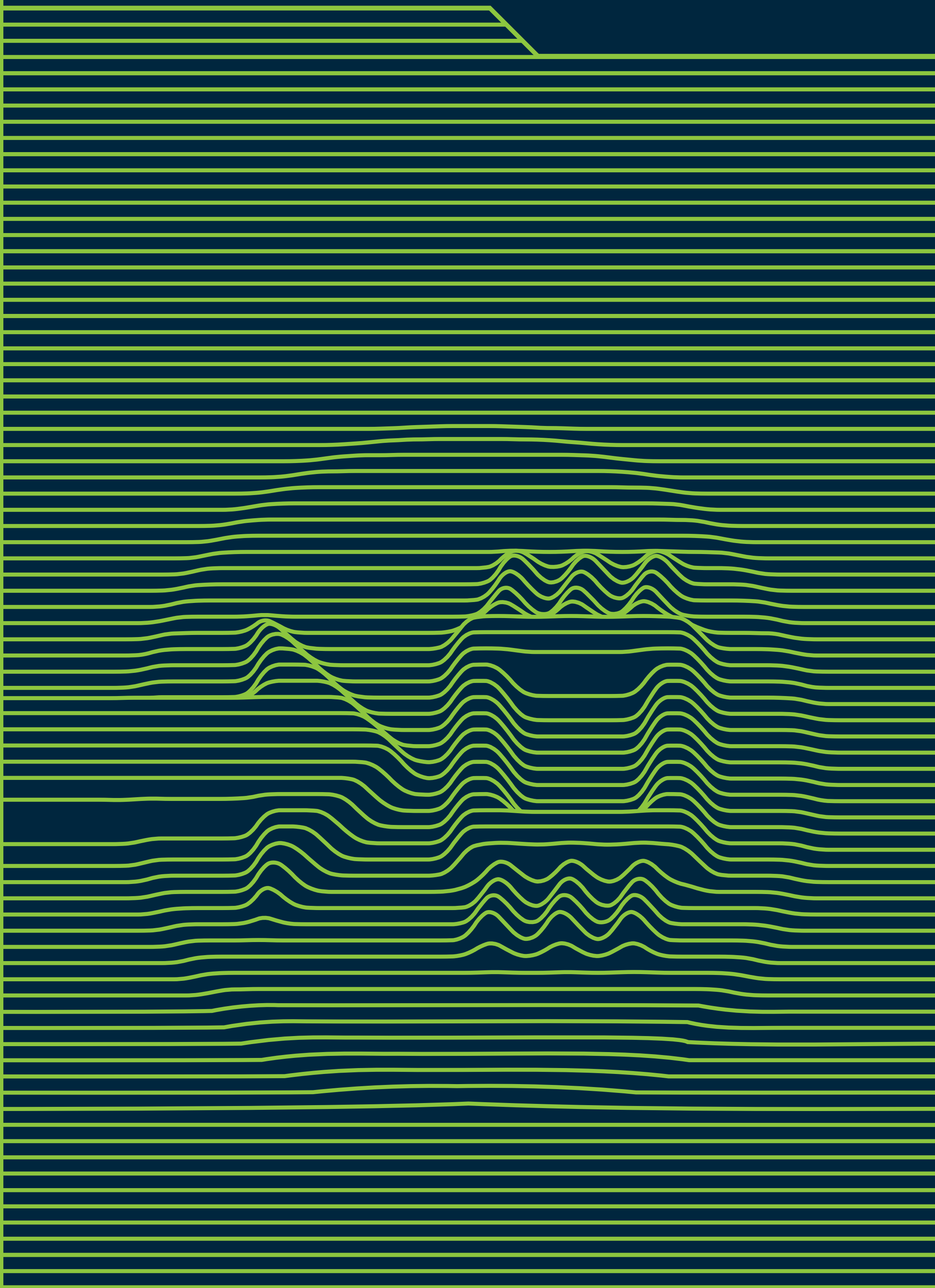
TECHNOLOGY FORESIGHT ON BIOMETRICS FOR THE FUTURE OF TRAVEL

ANNEX I

Technology Foresight Manual



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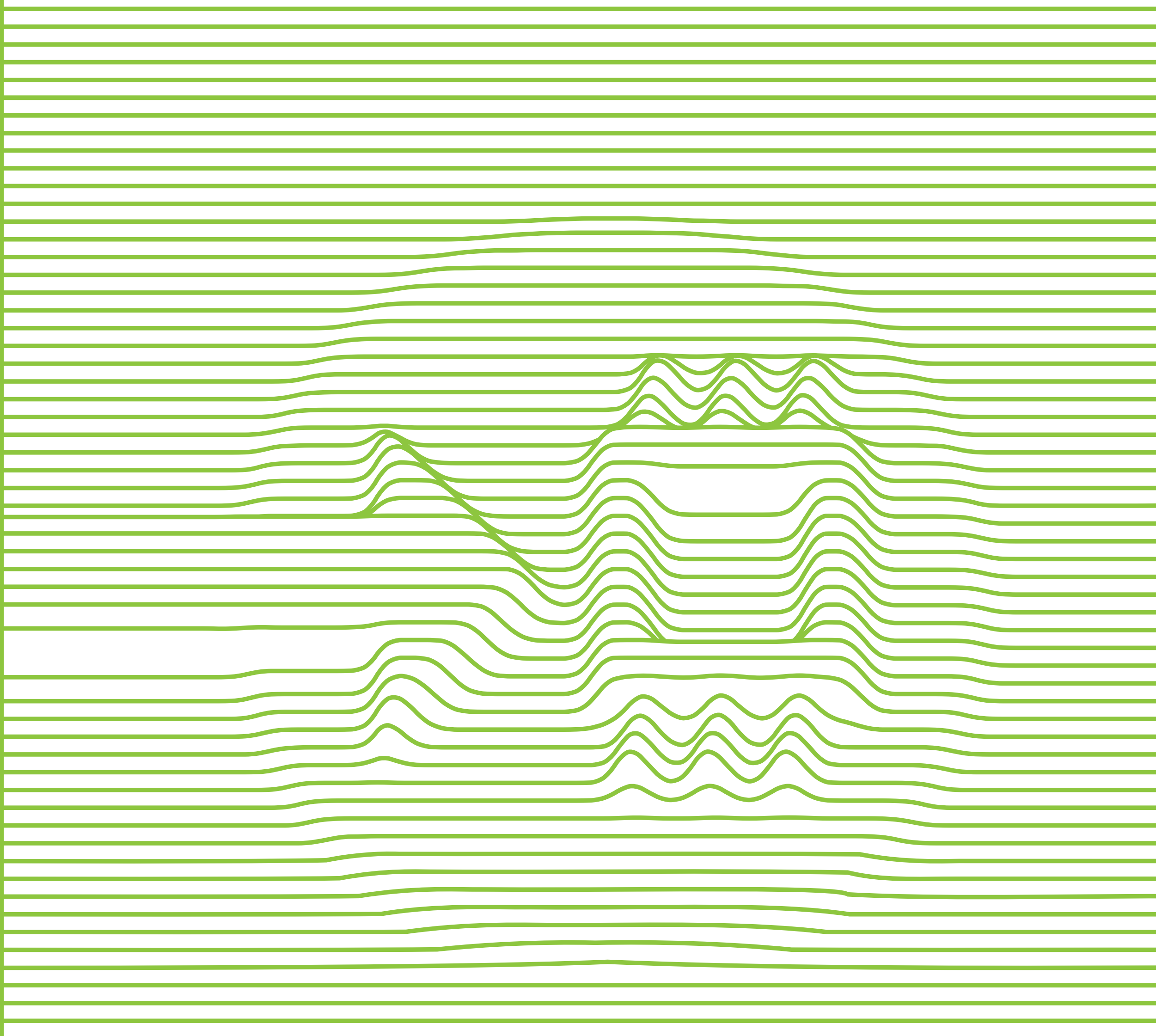
TECHNOLOGY FORESIGHT ON BIOMETRICS
FOR THE FUTURE OF TRAVEL

ANNEX I

Technology Foresight Manual



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Warsaw, September 2021

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Abbreviations and Acronyms

Abbreviation / Acronym	Definition
BAU	Business As Usual
CORDIS	European Commission's Community Research and Development Information Service
DG TAXUD	European Commission's Directorate-General for Taxation and Customs Union
EBCG	European Border and Coast Guard
EBCG community	Frontex; the national authorities of Member States responsible for border management, including coast guards to the extent that they carry out border control tasks; and the national authorities responsible for return, as indicated in Regulation (EU) 2019/1896 of the European Parliament and of the Council of 13 November 2019 on the European Border and Coast Guard – Article 4
EES	Entry-Exit System Currently under development, the EES will electronically register the time and place of the entry and exit from the EU of third country nationals as well as calculate the duration of their authorised stay. It will replace the obligation to stamp the passports of third country nationals Established by Regulation (EU) 2017/2226
ETA	Earliest Time to Arrival
ETM	Earliest Time to Mainstream
EU	European Union
Frontex	The European Border and Coast Guard Agency Governed by Regulation (EU) 2019/1896
Frontex Representatives	Frontex staff who participated in the *Tech Foresight on Biometrics*
FTO	Freedom To Operate
Group of Experts	Subject-matter experts representative of stakeholders selected to participate in the consultation and collective intelligence activities conducted within the framework of the *Tech Foresight on Biometrics*, such as the workshops and the *Delphi Survey*. This also included members of the Research Team and Frontex Representatives
IATA	International Air Transport Association
IEEE	Institute of Electrical and Electronics Engineers
IPC	International Patent Classification
IT	Information Technology
JRC	European Commission’s Directorate-General Joint Research Centre
KTC	Key Technological Cluster
ML	Machine Learning
NEXTT	New Experience Travel Technologies (https://www.nextt.aero/en/)
NIR	Near-infrared; electromagnetic radiation with 0.78-1.0 μm wavelength
NLP	Natural Language Processing
OpenAIRE	Open Access Infrastructure for Research in Europe (https://www.openaire.eu/)

Abbreviation / Acronym	Definition
PESTLE	Political Economical Social Technological Legal Environmental
R&D	Research and Development
R&I	Research and Innovation
RA	Relative Advantage
Research Team	Employees of the of the Contractor selected by Frontex to conduct the *Technology Foresight on Biometrics for the Future of Travel* (Steinbeis 2i GmbH) and its Subcontractors (4CF Sp. z o.o., Erre Quadro S.r.l. and the Instytut Optoelektroniki – Wojskowa Akademia Techniczna), who jointly provided expertise in the following fields: • Project Management • Strategic Technology Foresight • Biometrics for border control systems • Smart and Autonomous Systems • Systems Engineering for border control
Research Team Experts	Members of the Research Team who provided subject-matter expertise in the following disciplines: • Biometrics for border control systems • Smart and Autonomous Systems • Systems Engineering for border control
RTDI	Research, Technology, Development and Innovation
RTO	Research and Technology Organisation
SWOT	Strengths Weaknesses Opportunities Threats
TC	Technological Cluster. TCs represent a level of abstraction of the biometric technologies included in the Taxonomy of biometric technology, which was defined in order to enable *Patentometric and Bibliometric Analyses* and to ensure the usability of the taxonomy in the different phases of the *Tech Foresight on Biometrics*. See Annex III – Patentometric and Bibliometric Analyses of Biometric Technologies
Tech Foresight on Biometrics	Technology Foresight on Biometrics for the Future of Travel
TF	Technology Foresight
TFP	Technology Foresight Process
TM	Text Mining
TRIZ	From Russian *"Teoriya Resheniya Izobretatelskikh Zadatch"*, which may be translated as *"Theory of Inventive Problem Solving"*
TRL	Technology Readiness Level
US	United States of America
WTTC	World Travel and Tourism Council

Introduction

Technology Foresight (TF) is a process that brings together scientists, industrial entities, civil society, government officials and others to identify the areas of strategic research and the emerging technologies likely to yield the greatest economic and social benefits.[1] The concept of *foresight* emerged from the need to improve the strategic planning process and for a broader participation in decision-making.[2] Although the idea of foresight is relatively young, it has won general acclaim. It has been employed on a large scale to assist in the development of policies and strategies related to science, technology and innovation in several countries and at many organisational levels: supra-national, national, sectoral, regional, and corporate[3].

As yet, a uniform definition of TF has not emerged, nor has a commonly adopted methodology. This is primarily because Technology Foresight processes[4] (TFPs) are still not particularly widespread, and each case is specifically tailored to the needs of its recipient. All the processes, however, display common elements, which constitute the basis of a definition proposed for the purposes of the present exercise: **Technology Foresight is a research-driven process specifically designed for the technological assessment and identification of key future technologies for a particular subject**.[5]

Unlike forecasting, TF focuses on assessing the current state of technology and identifying a wide range of plausible future consequences of technological development. Results are often presented as linked to scenarios for the future. *Forecasting*, on the other hand, aims to identify the most probable future path of events; in other words: to state, with a high degree of certainty, what the future will look like.

There are many different methods and tools in the strategic foresight toolbox. Not all are suited to the needs of Technology Foresight. TF processes are usually time-limited rather than continuous (which is not to say that they cannot be performed cyclically); therefore, the methods and tools must deliver the desired outcomes in specific time constraints. This renders continuous foresight methods (like *Technology Watch* or *Horizon Scanning*[6]) inadequate as the sole methods for conducting a TF, although relevant to supporting *State-of-the-Art Review* activities. As previously mentioned, Technology Foresight methodologies are virtually always constructed to fit the needs of their recipi-

1 B. R. Martin, "The origins of the concept of 'foresight' in science and technology: An insider's perspective", Technological Forecasting and Social Change, Volume 77, no. 9, pp. 1438-1447, 2010.

2 E. Hideg, "Theory and practice in the field of foresight", Foresight, Vol. 9, no. 4, pp. 36-46, 2007

3 B. Poteralska and A. Sacio-Szymańska, "Evaluation of technology foresight projects", European Journal of Futures Research Vol. 2, no. 26, 2014.

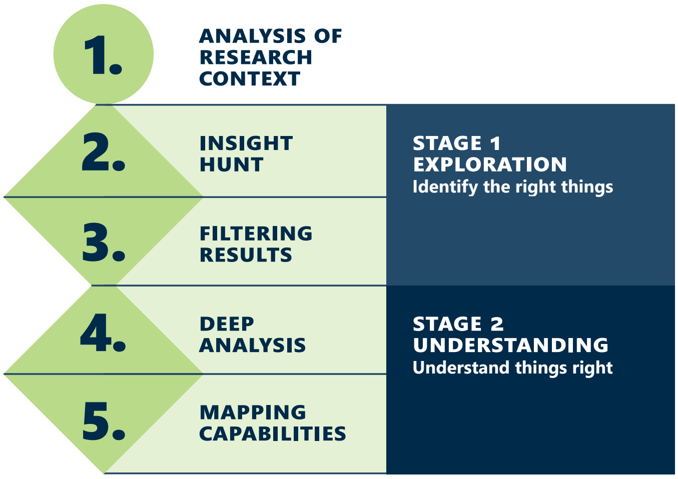
4 In this document, the terms Technology Foresight process and Technology Foresight methodology are used interchangeably.

5 L. Georghiou, I. Miles, and R. Popper, "The Handbook of Technology Foresight: Concepts and Practice", Edward Elgar, Cheltenham, 2009.

6 Typically, **Technology Watch** activities track specific technologies and their developments, while **Horizon Scanning** observes all new knowledge developments, thus allowing for the early analysis of technological developments happening in different fields before their emergence in a specific sector.

ents. Thus, there is no universal blueprint for TF. This also indicates that the spectrum of available methods is limited to a set already chosen by the recipient or stemming directly from the recipient's needs, as in the present case stated in the *Terms of Reference*.[7]

Figure 1: *The Double Diamond approach for the Technology Foresight methodology.*



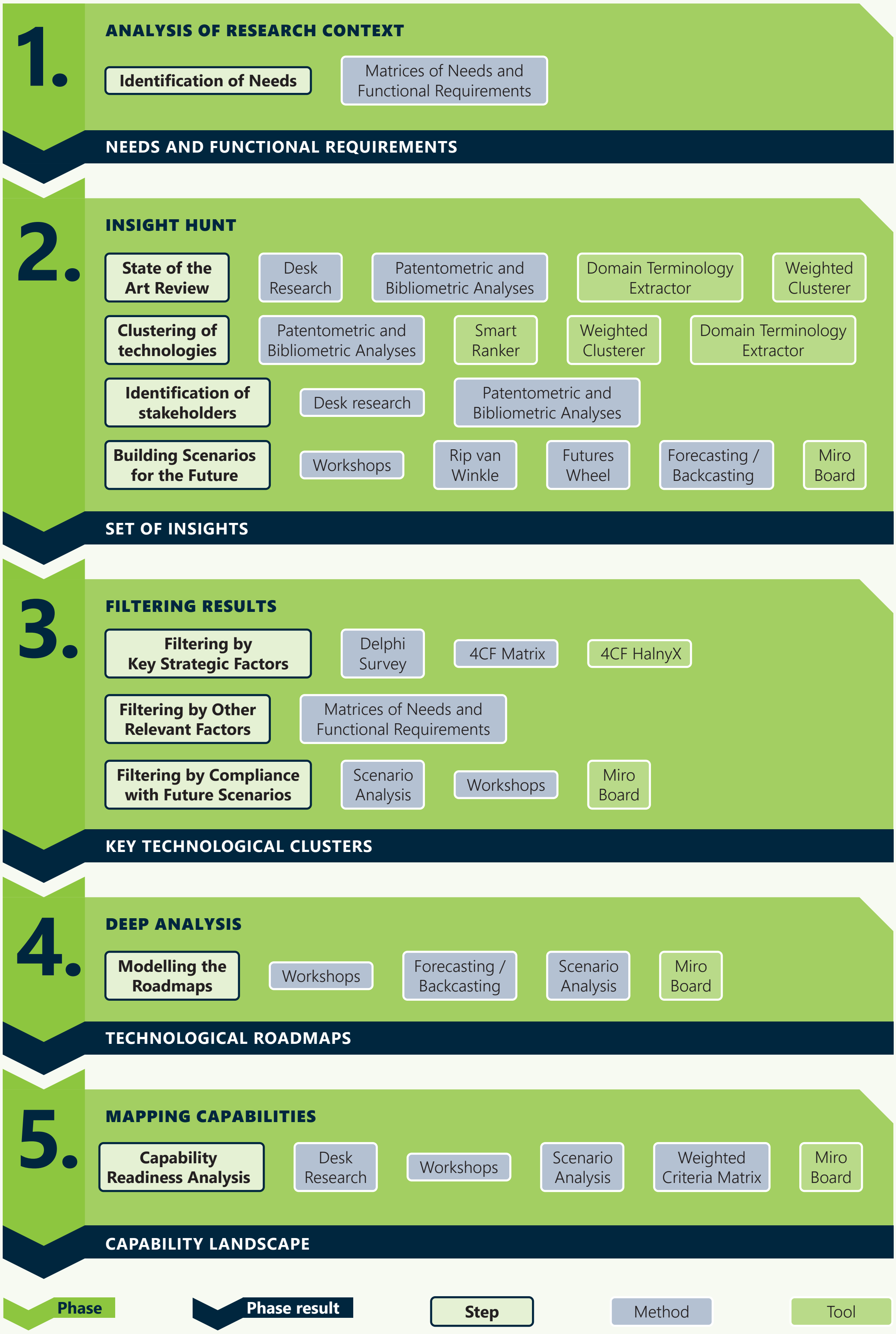
The TFP proposed here is, in summary, a 5-phase *Double Diamond* approach:

- The initial *Analysis of Research Context* phase is followed by an *Exploration* stage (1st diamond), which is in turn followed by an *Understanding* stage, as shown in Figure 1.
- The first diamond can be split into two phases: *Insight Hunt* and *Filtering Results*. The first phase is meant to identify as many insights as possible, while the second defines them precisely to concentrate on the most valuable ones.
- Within the second diamond, the first phase, *Deep Analysis*, focuses on developing and expanding the insights previously identified as most useful. Lastly, the second half of the diamond, the *Mapping Capabilities* phase, delivers actionable insights by mapping specific capabilities to determine the feasibility of pursuing the future key technological solutions.

A more detailed overview of each phase of the proposed Technology Foresight methodology is presented in the following block diagram (Figure 2).

7 The Terms of Reference for this study are published in https://etendering.ted.europa.eu/cft/cft-document.html?docId=75972

Figure 2: *A detailed overview of each of the five phases of the proposed Technology Foresight methodology.*



We refer to *experts* many times throughout this manual. These may be classified as:

- **Research Team Experts**, i.e. those members of the Research Team performing the study who are subject-matter experts in Technology Foresight and/or in the scientific and technological domains covered by the specific Technology Foresight exercise;
- **Experts of the Recipient** of the study (in this case Frontex Representatives) who participate in the project;
- The **Group of Experts**, typically composed of a range of subject-matter experts, representatives of stakeholders selected to participate in the consultation and collective intelligence activities conducted in the frame of the specific TF exercise, such as the workshops and the *Delphi Survey* (see Chapters 9 and 16). Depending on the situation, the Group of Experts might also include members of the Research Team and Experts of the Recipient of the study.

The exact composition of these groups depends strongly on the topic and scope of the study as well as the availability of experts from specific fields within the Research Team and the recipient of the study. It can be adjusted in future implementations of the method.

In the specific case of the *Tech Foresight on Biometrics*, general information on the composition of the Research Team, the Research Team Experts, Frontex Representatives and the Group of Experts is reported in the table of Abbreviations and Acronyms.

The following chapters in the first part of this ***Technology Foresight Manual*** describe in detail all five phases of the proposed TFP. The specific methods utilised in the TFP are then explained in Part 2, while the supporting IT tools are described in Part 3.

All the information reported in this manual refers to the proposed overarching Technology Foresight methodological framework and the application of the relevant methods and tools, except in the "Example of implementation" paragraphs included in the chapters in Part 1 and Part 2 whose content is based on the data acquired from the specific *Technology Foresight on Biometrics for the Future of Travel*.

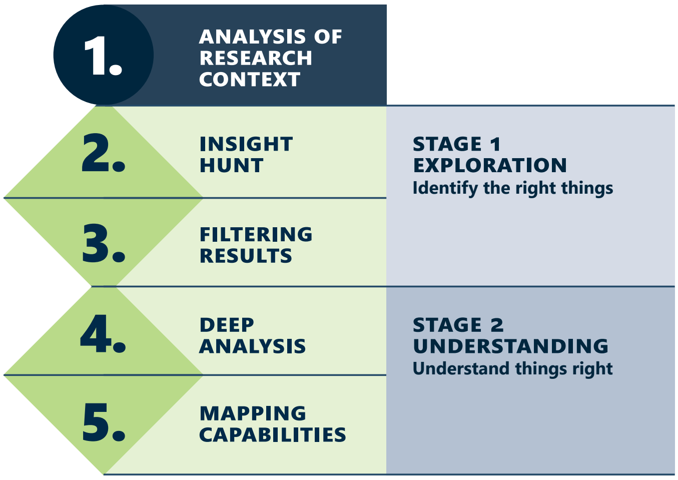
Part 1 – Technology Foresight Process

This first part of the manual provides the reader with key information about the objectives and the methodological approach for the steps foreseen in each of the five phases of the Technology Foresight process. Short instructions on the modalities of implementation are also included.

1. Analysis of Research Context

TF is a research-driven process aimed at indicating key future technologies from the perspective of a specific subject area.[8] The accompanying research is practical and goal-oriented. Therefore, the prerequisite for a foresight study is the precise definition of its context. This serves as the basis for preparing an overarching methodological framework as well as optimising and adapting it to the needs of the specific case.

Figure 3: *Analysis of Research Context within the Double Diamond approach.*



The purpose of this phase is the identification of boundary needs and research questions that the study will address, as well as initial research, which provides a foundation for the subsequent phases. The general objective is to establish a precise definition of the study's scope, to understand *what* to look for and *where* to look for it, which will help to define the final shape of the study and the tools that will be required to conduct it. A synthesis of the findings thus obtained will serve as input for further phases.

8 L. Georghiou, I. Miles, and R. Popper, "The Handbook of Technology Foresight: Concepts and Practice", Edward Elgar, Cheltenham, 2009.

1.1. Identification of Needs

1.1.1. Main objectives

The *Identification of Needs* is the first, indispensable step of the TFP. It aims to specify the exact field and scope of the process and to set goals for the study. The results of this step narrow the area of further analysis to the technologies and technological systems of greatest potential importance to the TF recipient.

1.1.2. Approach

The needs are considered at two levels, with the second level clarifying the needs formulated at the first level:

- *Level 1*: current problems and expected benefits in relation to the assumed objectives, effects, and beneficiaries of the study;
- *Level 2*: key features of technologies in the chosen research area.

The purpose of identifying Level 1 needs is to define the overall framework of the study. These include its timeframe, the precise area of research, the primary beneficiaries of the project and its expected effects. At this level, the needs include answers to the most general questions concerning the purpose of the study. To cover all the crucial issues, it is advised to use a matrix with predefined, generic questions regarding the most important aspects of the TFP. Depending on the specific circumstances of a given project, questions may be tailored to capture all the peculiarities.

The purpose of identifying Level 2 needs is to depict the specific requirements (*must-haves*) for the technologies achievable within the research area and timeframe defined at Level 1. Each potential technology is characterised in detail based on the key features from the perspective of the TF recipient's requirements. The resulting list of must-haves is then used to cross-check the analysed technologies during the *Filtering Results* phase (Chapter 3) in terms of their potential to fulfil the defined needs.

1.1.3. Recommended methods and tools

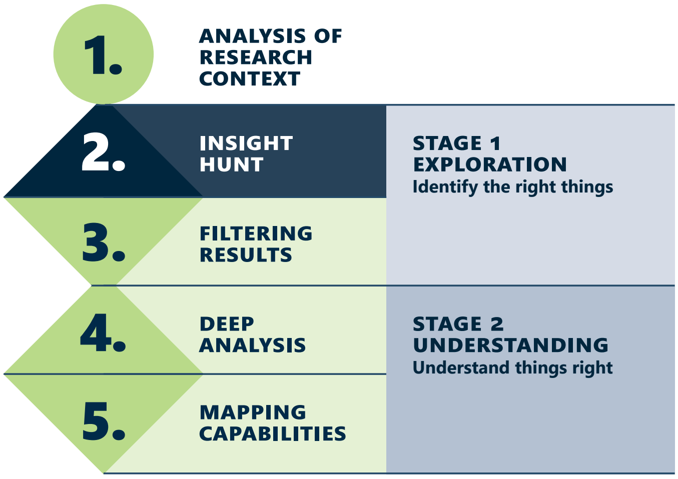
- Methods:
  - *Matrixes of Needs and Functional Requirements* (see Chapter 6)
- Tools:
  - Not specified

1.1.4. Example of implementation

For the example of implementation of this step in the *Tech Foresight on Biometrics*, please refer to the one provided in Section 6.6, as well as to the *Analysis of Frontex needs* reported in the Research Study – Chapter 1.

2. Insight Hunt

Figure 4: *Insight Hunt within the Double Diamond approach.*



The *Insight Hunt* phase focuses on acquiring information specific to the topic of the TF. Its purpose is to gather potentially valuable insights from the selected set of sources, using the basic knowledge generated during the *Analysis of Research Context* phase (see Chapter 1).

The first general objective of the *Insight Hunt* is the creation of a *longlist of technologies* relevant to the TF topic which provides general information on the technological landscape of the domain being analysed and generates useful inputs for the following phase, *Filtering Results* (Chapter 3). This is done by conducting a *State-of-the-Art Review* followed by a clustering process.

The second objective of this phase is to identify a broad range of Stakeholders, primarily to include the indispensable collective intelligence component into the TFP through the involvement of a suitable Group of Experts select from the most relevant Stakeholder.

A third ambition of this phase is to create a set of scenarios for the future, which through the *Scenario Analysis* method (Chapter 14) will be used in all the subsequent phases of the TFP to envision the effects of plausible future conditions on the developments of the investigated technological fields, thus helping to devise strategies to take advantage of the opportunities offered by the use of novel technological solutions under the different hypothetical futures, while at the same time reducing risks and avoiding threats.

This phase is therefore subdivided into four separate steps:

- State-of-the-Art Review,
- Clustering of Technologies,
- Identification of Stakeholders,
- Building Scenarios for the Future.

2.1. State-of-the-Art Review

2.1.1. Main objectives

The *State-of-the-Art Review* is conducted to determine the main research directions, to explore the current state of technological progress in the science and technology areas identified in the previous phase and to assess the possibility of adapting existing technologies to new uses within the same areas. The step results in the development of a **taxonomy** of technologies (at a component level) and technological solutions (at a system level). This constitutes the basis for further stages of the study.

2.1.2. Approach

The *State-of-the-Art Review* is executed in two steps:
- Identification of the main areas of research,
- Development of a technological taxonomy.

A combination of several tools is necessary to complete the first step of the review. First, extensive interviews are conducted with Research Team Experts and Experts of the Recipient. The experts are selected based on their expertise in the scope of the Technology Foresight project. The information they provide is later supplemented by extensive *Desk Research* covering industry literature, internet sources, scientific publications, patents, etc. This comprehensive approach guarantees satisfactory results and a thorough understanding of the research context. Last but not least, the information is gathered rapidly and is general enough to facilitate interpretation by the Research Team (as opposed to experts' lengthy research or surveys based on statistics).

Building a repository of research areas for the subsequent *Development of a Technological Taxonomy* requires a list of key technical characteristics. The list serves as a guide for gathering information related to the specific objectives and subsequent steps of the foresight study. The main areas of research identified in this step are then used as input to perform quantitative analyses and thus to create a taxonomy of technologies.

Once the research areas are defined, a technological taxonomy is iteratively extracted using patents and scientific literature.[9] Today's *Text Mining* (TM) and *Natural Language Processing* (NLP) tools and techniques permit the automatic analysis of these text documents. The list of main areas of research is used to create an initial set of keywords and criteria for automated analysis. Furthermore, an initial list of technologies may already be extracted from the list of research areas.

Patents are a type of text document suited for automatic analysis, and constitute a superior source of technical information for a number of reasons:

9 More information on the characteristics of patents and scientific publications can be found in Annex III – Patentometric and Bibliometric Analyses of Biometric Technologies, Chapter 3.

- 80% of the technical information contained in patents is not available elsewhere.[10, 11]
- Patents precede market launch as well as scientific publications since the latter may compromise the patentability of inventions.
- Patents entail significant costs for companies, and thus are only filed to protect innovations considered crucial to an enterprise, i.e. innovations worthy of investments likely to be put into production. Thus, the correlation between patents and the economic impact of the innovations they describe is much more direct than that of research papers.
- Patents describe innovative and emerging technologies that are often characterised by a higher level of maturity and feasibility than those presented in papers.
- Finally, patent data are publicly available and are easy to find for any sector.

Even though the primary aim of patents is to protect inventions, they constitute a robust and accessible source of information on field-specific technologies, techniques and methodologies. However, patent databases do not contain complete data on all existing technologies. Many inventions and innovations are, in fact, unpatented. This may be because an invention must satisfy strict criteria to receive a patent, and because regulations differ across countries and evolve over time. Furthermore, patents are not the only mechanism that protects innovations. Equally essential and powerful protection mechanisms include trade secrets, rapid product development, complex product design and control of distinguishing capabilities. Hence, not all technologies and innovations can be found within the patent universe. Furthermore, due to the duration and mechanisms of the application process, public patent databases contain incomplete data for the last 18 months. Nevertheless, the ontological characteristics and structure of patents, whose content and structure are standardised in many ways, enable a reliable and scalable NLP approach to the analysis. Even if a particular methodology or technology is not central to an invention and is therefore unpatented, it may still be cited (and thus can be identified with NLP tools) or referred to within the description of another invention. Hence, the risk of missing technologies or techniques is limited.

However, to further limit the risks stemming from the characteristics of the patent system, an analysis of scientific publications is also often conducted to obtain complete and trustworthy results. It should be noted, however, that scientific publications may also describe cutting edge technologies, but:

- Usually, in high-tech sectors, fewer technologies are discussed in papers than in patents.
- Technologies that are reported in papers may be less feasible and advantageous from an industrial manufacturing point of view, or may never enter the market at all.
- Although relevant, some technical information might be considered unsuitable for publication;
- The number of papers on a specific technology does not necessarily correlate with its relevance for the economy.

10 M. W. Kütt, and M. Schmiemann, "Quick Scan: a novelty search service in the framework of Euro-R&D programmes", World Patent Information, vol. 20, no. 2, pp. 146-147, 1998.

11 P.J. Terragno, "Patents as Technical Literature", IEEE Transaction on Professional Communication, vol. 22, no. 2, pp. 101-104, 1979.

- Freely available information in databases of non-open-access scientific journals is normally limited to titles and abstracts of papers, and the cost for access to a comprehensive database can be very high.
- The available search engines often have severe limitations (e.g. in the Scopus[12] database, the search field is limited to 250 characters; no advanced search functions are available and the user cannot download more than 100 articles at a time).

2.1.3. Recommended methods and tools

- Methods:
  - *Desk Research* (see Chapter 7)
  - *Patentometric and Bibliometric Analyses* (see Chapter 8)
- Tools:
  - *Domain Terminology Extractor* (see Chapter 19)
  - *Weighted Clusterer* (see Chapter 21)

2.1.4. Example of implementation

In the framework of the *Tech Foresight on Biometrics*, the Research Team Experts were consulted to develop, through *Desk Research*, a list of *Main Areas of Research* in the field of biometrics for border checks.

The main sources of information at this stage of analysis included:

- Recent forward-looking studies in the field;
- Official research agendas (EU or national government strategies);
- Reports and strategies developed as a result of international research projects;
- Internal documents of the recipient of the foresight study.

A list of 43 *Main Areas of Research* was defined. These areas were preliminarily grouped into three categories: biometric technologies, applications and biometrics-enabling technologies (also referred to as 'cross-cutting technologies'). The complete list of results is included in the Research Study – Chapter 2, while more information on the use of the *Desk Research* method for this step of the TFP can be found in Section 7.6.

Within this step, two taxonomies were also developed, based on two different approaches:

- The *taxonomy of biometric technologies*, developed primarily through an analysis of patents and scientific literature with the use of automatic tools;
- The *taxonomy of biometrics-enabled technological systems*, developed primarily through a process of consultation with the Research Team Experts.

Due to the extensive scope and technological complexity of a TF study devoted to biometrics, the primary focus was on purely biometric technologies. Cross-cutting technologies and related research fields were also addressed within this study but on a reduced scale. This strategy allowed a deepened analysis of the research context and a higher level of detail, especially as regards *Patentometric and Bibliometric Analyses* (see Chapter 8).

12 https://www.scopus.com/

Both taxonomies were developed to provide a uniform framework and create a point of reference which might serve Frontex in future research and innovation activities. The taxonomy of biometric technologies was then used to compile a list of biometric *technological clusters* in the next step of the TFP (Section 2.2), which were the subject of *Patentometric and Bibliometric Analyses*. The taxonomy of biometrics-enabled technological systems also played an essential role, as it guided the development of technological roadmaps during the *Deep Analysis* phase.

The processes that led to the construction of the two taxonomies are briefly outlined below. The reader is referred to Annex II – Taxonomy of Biometric Technologies and Biometrics-Enabled Technological Systems, and to the Research Study – Chapter 3, for more details.

1. Taxonomy of biometric technologies

Figure 5 shows the process of developing the taxonomy of biometric technologies,[13] which was organised into three hierarchical levels:[14]

- The ***first level***, consisting of a set of three macro-areas: biomolecular biometrics, morphological biometrics and behavioural biometrics;
- The ***second level***, including 14 technological fields belonging to the three macro-areas;
- The ***third level***, comprising all 57 specific biometric recognition or acquisition technologies and modalities (five biomolecular, 39 morphological and 13 behavioural), each representing a narrow family of similar applications within a technological field.

The third-level technologies and modalities were subsequently grouped into 20 technological clusters, which formed the primary input for the *Patentometric and Bibliometric Analyses*, and which ensured the applicability of the taxonomy to successive phases of the TF project.

As also indicated in Section 21.3, the *Weighted Clusterer* tool can also be used within the development of taxonomies to support the classification of patent literature in a specific field and the categorisation of technologies they describe. This step may contribute to the taxonomical analysis, following a bottom-up approach.

2. Taxonomy of biometrics-enabled technological systems

The taxonomy of biometrics-enabled technological systems was developed primarily through *Desk Research* by the Research Team Experts, who considered the systemic aspects and potential applications of various biometric technologies. They also assessed how an individual traveller would interact with the technologies.

13 All the steps of the process are described in detail in Annex II – Taxonomy of Biometric Technologies and Biometrics-Enabled Technological Systems – Chapter 1.

14 The complete structure of the taxonomy is shown in Annex II – Taxonomy of Biometric Technologies and Biometrics-Enabled Technological Systems – Chapter 2.

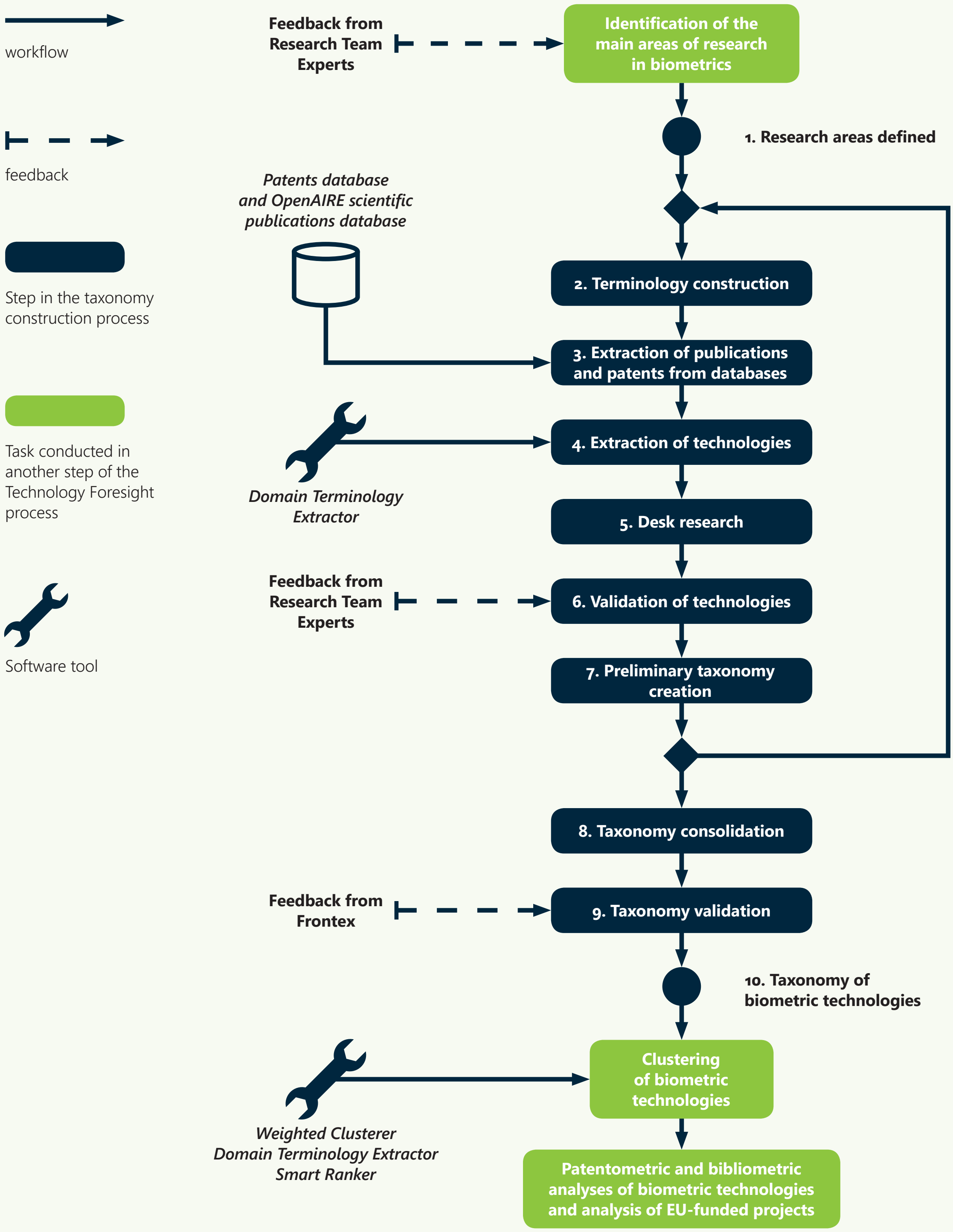


Figure 5: *Workflow for constructing the taxonomy of biometric technologies.*

The end-to-end journey of a traveller as they encounter various technological systems along their way, from bookings to arrival at the final destination, was analysed. Valuable background information was provided by sources such as *IATA NEXTT – Building the* *journey of the future*,[15] the *World Economic Forum*'s[16] project on *Shaping the Future of Security in Travel*[17] and the *World Travel and Tourism Council*'s[18] (WTTC) publicly available information on the future of travel. The proposed taxonomy of biometrics-enabled technological systems used the knowledge of the Research Team Experts regarding existing and projected systems worldwide and was organised into a two-tier structure:[19]

- The ***first level***, consisting of a set of **seven groups**;
- The ***second level***, including **31 categories**.

Such a taxonomy can be interpreted with the aid of the *Technical Guide for Border Checks on EES related equipment*[20] recently issued by Frontex.

2.2. Clustering of Technologies

2.2.1. Main objectives

The goal of this step is to define a level of abstraction suitable for the analysis of the technological areas defined in the taxonomy and for the discovery of insights resulting from global R&D activities.

As it is impossible to manually review the research of the entire international scientific community, computer tools and statistical methods are employed to analyse the patents and scientific literature related to the previously mentioned technological areas, assuming that these documental sources contain all the required information. These types of analyses are called *Patentometric and Bibliometric Analyses*.[21]

Because the list of technologies included in the technological taxonomy is usually too broad for efficient and effective handling by the Research Team, it is essential to group such technologies into technological clusters. Each cluster will represent a level of abstraction suitable to conduct *Patentometric and Bibliometric Analyses* as well as to assure the usability of the taxonomy in the successive phases of the TFP.

These clusters are then subjected to a multi-level assessment by the Group of Experts in a series of consultations conducted as part of the *Filtering Results* phase, with the aim to identify a shortlist of technologies of primary interest within the subject area of the study.

15 https://www.nextt.aero/en/

16 https://www.weforum.org/

17 https://www.weforum.org/videos/shaping-the-future-of-security-in-travel

18 https://wttc.org/

19 The complete structure of the taxonomy is shown in Annex II – Taxonomy of Biometric Technologies and Biometrics-Enabled Technological Systems – Chapter 6.

20 European Border and Coast Guard Agency, "Technical Guide for Border Checks on Entry/Exit Systems (EES) related equipment," Publications Office of the European Union, Luxembourg, 2021.

21 An extensive explanation of these can be found in Annex III – Patentometric and Bibliometric Analyses of Biometric Technologies.

2.2.2. Approach

Clustering of Technologies is partly executed with the application of NLP tools. In accordance with the taxonomy construction process introduced in Paragraph 2.1.2, each element of the taxonomy is associated with a specific set of patents and scientific papers. NLP algorithms are then used to interpret the content of such document sets and to suggest possible grouping alternatives based on their semantic similarities.

Such a procedure identifies the preliminary series of clusters, which must be validated by the Research Team. The identification of the final series of clusters is then typically based on parameters such as the size of document sets (patents and scientific publications), the affinity between technologies and the relevance to the subject area of the study.

This approach in *Clustering of Technologies* produces two main results:
- The identification of a set of technological clusters;
- The creation, for each of the identified clusters, of a homogeneous dataset of patents and scientific publications on which to conduct *Patentometric and Bibliometric Analyses*.

Special attention must be devoted to the creation of the datasets of patents and scientific publications, whose quality critically depends on the data gathering process (based on textual document analysis) from relevant databases, which must be queried using appropriate tools, terminology and syntax. In fact, poor quality in the datasets can negatively impact the results of the analysis conducted on them, because:
- an erroneously defined search focus can provide misleading or incomplete results;
- inadequate *recall*[22] can result in the loss of vital elements; while
- low *precision*[23] and *noise* can produce poor results.

When datasets are created based on textual document analysis, not all documents within the resulting dataset discuss the topics of interest, and not all the existing relevant documents are initially collected. This might be due to:
- ambiguity in the employed terminology;
- limited sectoral knowledge of the analyst;
- incomplete lists of keywords.

For this reason, generally, the initially extracted datasets must be "cleaned" through iterative refinement steps. The cleaning of datasets, which is performed by adding constraints to the retrieval process or through iterative query refinements, is the process of detecting corrupted, inaccurate, incomplete, incorrect or irrelevant records from the datasets, and replacing, correcting or deleting them. As quality indicators, the two parameters defined above are typically used to control the cleaning process: *precision* and *recall*.

22 In the field of information retrieval, "recall" is the fraction of the relevant documents that are successfully retrieved. A more precise definition is given in Paragraph 2.2.4.

23 In the field of information retrieval, "precision" is the fraction of retrieved documents that are relevant to the query. A more precise definition is given in Paragraph 2.2.4.

Multiple iterations are generally needed to increase the number of intercepted true positives (achieving the so-called *recall parameter increase*) and reduce the risk of including false positives within the dataset (achieving the so-called *precision parameter increase*).

Once the datasets of patents and scientific publications are cleaned, multiple NLP tools are used to further extract information from the textual data contained in the dataset records and perform *Patentometric and Bibliometric Analyses* according to the theoretical framework and the criteria summarised in Chapter 8.

2.2.3. Recommended methods and tools

- Methods:
  - *Patentometric and Bibliometric Analyses* (see Chapter 8)
- Tools:
  - *Domain Terminology Extractor* (see Chapter 19)
  - *Smart Ranker* (see Chapter 20)
  - *Weighted Clusterer* (see Chapter 21)

2.2.4. Example of implementation

Within the framework of the *Tech Foresight on Biometrics*, *Patentometric and Bibliometric Analyses* were conducted to identify a set of 20 biometric technological clusters[24] on the basis of the list of 57 technologies included within the taxonomy of biometric technologies.

Patent documentation was acquired using a proprietary database (hereinafter referred to as the Patents Database), which contains over 120 million patents. Concurrently, the OpenAIRE open-access database was used by the Research Team to collect scientific publications, on which a bibliometric analysis was also conducted to complement the patent analysis.

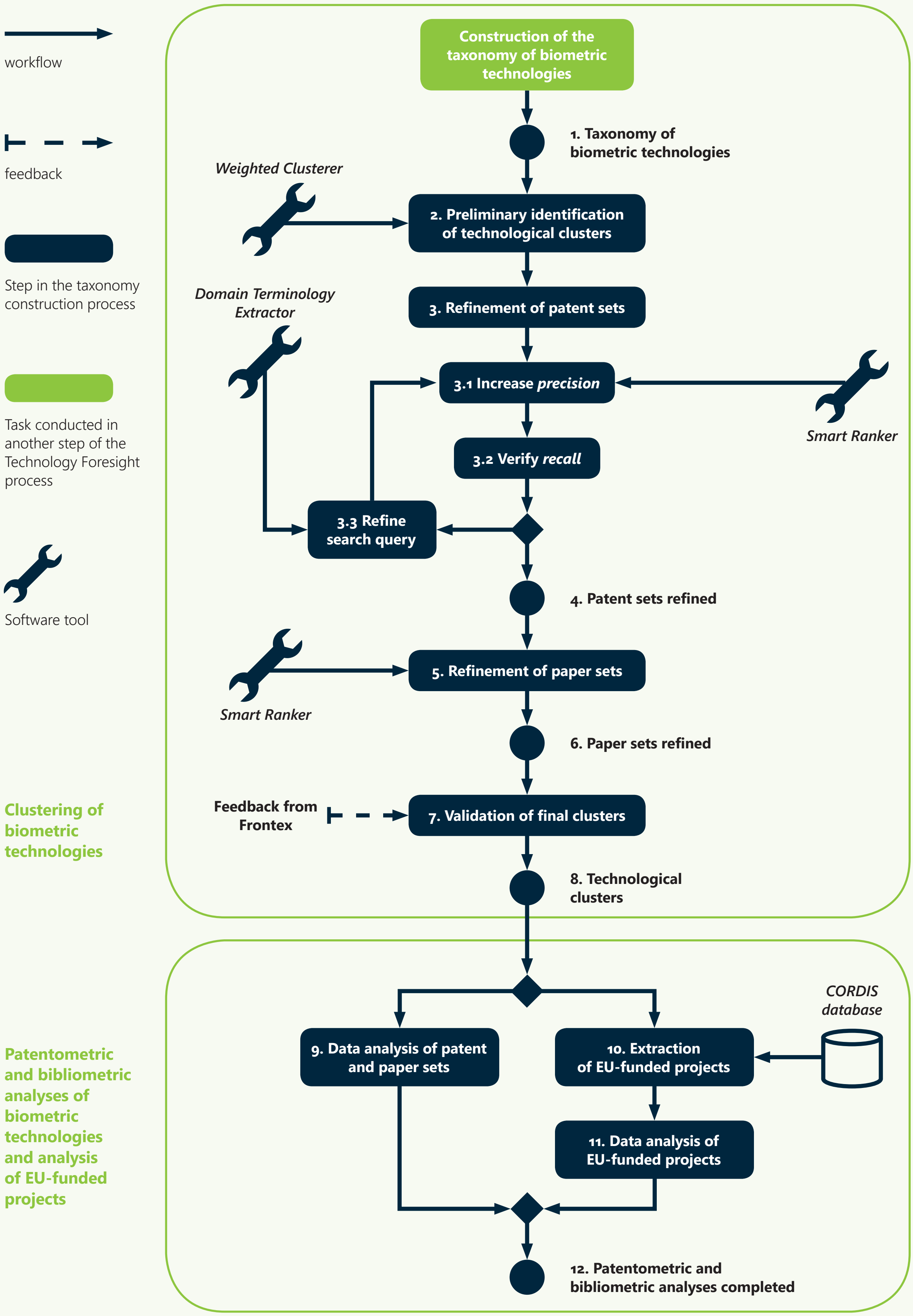
Figure 6 shows the workflow followed in creating the set of technological clusters (Steps 1 to 8) and conducting *Patentometric and Bibliometric Analyses* of the same clusters (Steps 9 to 12, discussed in Chapter 8). The reader is referred to Annex III – Patentometric and Bibliometric Analyses of Biometric Technologies – Section 4.1 for a detailed description of each of the steps of the workflow.

The resulting technological clusters of biometric technologies are described in detail in Annex II – Taxonomy of Biometric Technologies and Biometrics-Enabled Technological Systems – Chapter 3.

Once technological clusters were defined, *Patentometric and Bibliometric Analyses* were performed as explained in Chapter 8.

24 More information can be found in Annex II – Taxonomy of Biometric Technologies and Biometrics-Enabled Technological Systems – Chapter 3; Annex III – Patentometric and Bibliometric Analyses of Biometric Technologies; and in the Research Study – Chapters 3 and 4.

Figure 6: *Workflow followed to create the clusters of biometric technologies and conduct the Patentometric and Bibliometric Analyses of them, as well as the analysis of EU-funded projects.*



2.3. Identification of Stakeholders

2.3.1. Main objectives

Technology Foresight projects depend heavily on the evaluative skills of those who indicate the paths of future development, as well as on their vision and in-depth analyses. It is also important to note that the vision and subjective judgement on complex problems required from foresight experts, who often need to cross disciplinary boundaries, cannot rely on any precise techniques, as no such methods exist. In addition, foresight does not simply depend on previously acquired expertise but instead creates expertise during the process itself.[25] To create this expertise within each Technology Foresight project, it is crucial to obtain a good overview of relevant players in the target technological areas and to engage key stakeholders early on. Feedback from stakeholders is a crucial part of the TF process, which allows the requirements and needs stated by stakeholders to be met. As a result, the project can achieve the desirable medium- and long-term impact. Additionally, stakeholders often possess unique knowledge of the subject and thus are valuable potential members of the Group of Experts.

Therefore, the objective of this step is to identify a wide range of relevant stakeholders within the area of the Research Study. The subset of stakeholders selected as members of the Group of Experts will then become an integral part of the TF methodological process and will provide valuable feedback from the very beginning of the project. This results in the enhanced development and broader uptake of the results of the TF exercise later on.

2.3.2. Approach

Ideally, the Research Team Experts in a specific research field, who are familiar with the community of researchers and practitioners, should be involved in selecting stakeholders. They may use existing business-partner databases and *Desk Research*; in addition, they possess extensive knowledge about state-of-the-art scientific and technological developments in a given field. An early categorisation of stakeholders is highly recommended, as it aids in selecting a broad range of experts to be included in the Group of Experts that will be involved in the TF study. A three-step approach is preferred:

- *Step 1: Creation of an initial list of stakeholders and categories:* this is done by browsing of sources to establish contact information, e.g. own databases and lists of conference participants;
- *Step 2: Acquisition of contact details:* typically done through *Desk Research* aimed at determining e-mail addresses and affiliations, whilst refining the stakeholder category when necessary;
- *Step 3: Identification of research areas:* done by establishing the research areas of interest to each stakeholder through an online search conducted on the website of the institution, university or company to which the stakeholder is affiliated.

Furthermore, *Patentometric and Bibliometric Analyses* can be used to both check/validate and expand the list of stakeholders (people and organizations) coming from the

25 S. Mauksch, H. A. von der Gracht, T. J. Gordon, "Who is an expert for foresight? A review of identification methods", Technological Forecasting and Social Change, vol. 154, 2020.

interactions with the experts. Indeed, patents indicate the assignees that filed them, and the inventors that produced the innovative idea; papers indicate the authors and their affiliations.

2.3.3. Recommended methods and tools

- Methods:
  - *Desk Research* (see Chapter 7)
  - *Patentometric and Bibliometric Analyses* (see Chapter 8)
- Tools:
  - Not specified

2.3.4. Example of implementation

In the *Technology Foresight on Biometrics for the Future of Travel*, stakeholders were not limited to technology providers (industrial entities). They also included public institutions, international organisations, EU-funded projects, possible end-users of the systems, research and technology organisations (RTOs) and universities. The active participation of selected stakeholders in the project as part of the Group of Experts centred around consultative processes such as *Workshops* (see Chapter 16) and a *Delphi Survey* (see Chapter 9).

In the first step, an initial list with a wide range of stakeholders was created, considering multiple categories:

- The EBCG community (Frontex and Member States' Border and Coast Guard Authorities),[26]
- EU institutions, bodies or agencies,
- International organisations,
- Extra-EU border management authorities,
- EU-funded R&I projects,
- Industrial producers of systems and components,
- Academic institutions,
- Research and technology organisations,
- Civil society and trade associations,
- Consultants,
- Experts and keynote speakers who participated in conferences in the field of biometrics.[27]

The second and third steps were conducted by an online search for further details regarding stakeholders' contact information and research areas. The following information was used to categorise the stakeholders: name, country (if multiple locations were listed, the headquarters or a coordinator's location of origin was chosen), category

26 As indicated in Regulation (EU) 2019/1896 of the European Parliament and of the Council of 13 November 2019 on the European Border and Coast Guard – Article 4, The national authorities of Member States responsible for border management, including coast guards to the extent that they carry out border control tasks, the national authorities responsible for return and the European Border and Coast Guard Agency shall constitute the European Border and Coast Guard.

27 For example: https://eab.org/events/program/208, https://eab.org/events/program/195, https://eab.org/events/program/202.

(selected from the list above), research areas of interest (up to five fields most relevant to the study's subject fields), contact information and relevant sources of information (URLs). In the case of EU-funded R&I projects, the name of the coordinating organisation as well as information regarding the project were added.

An Excel template with drop-down lists of the research areas was a useful tool at this stage. An example is shown in Figure 7.

Figure 7: *Excel template for stakeholder identification.*

Furthermore, with the employment of automatic operations on available datasets (patents and scientific publications) performed within the framework of the *Patentometric and Bibliometric Analyses* (see Chapter 8), 15 key stakeholders were determined for each of the 20 biometric technological clusters identified during the *Clustering of Technologies* step. The major geographic areas where inventive and innovative activities occurred were also established, and a list of the 15 most prolific authors and publishers of scientific publications in each of the clusters was also obtained. This set of information supplemented the initial list of stakeholders.

The overall outcome of the *Identification of Key Stakeholders* step within the *Tech Foresight on Biometrics* can be found in the Research Study – Section 2.2.

2.4. Building Scenarios for the Future

2.4.1. Main objectives

To broaden the strategic analysis arising from a Technology Foresight exercise, it is necessary to verify how individual technological solutions would perform under various long-term scenarios in terms of associated risks and opportunities. It is also important to compare how the conditions of the alternative scenarios might influence the technological developments envisaged in technology roadmaps, as well as the evolution of the capability-related needs associated with technological clusters.

Therefore, a set of hypothetical scenarios for the future must be constructed, which is the objective of this step of the TFP, with the purpose of using them not to forecast the future, but rather to stress-test strategies, insights, technologies and technological solutions in the context of a broad spectrum of possible futures in all the subsequent phases of the TFP. In addition, the use of scenarios in a foresight study facilitates the popularisation of results among the stakeholders and the wider public.

As all the other steps of the *Insight Hunt* phase, this is a preparatory step: once a set of scenarios is created, it will be used throughout the TFP by applying the *Scenario Analysis* method in the:

- *Filtering Results* phase, for filtering the technological clusters by compliance with future scenarios;
- *Deep Analysis* phase, to confront the technology roadmaps with the alternative scenarios;
- *Mapping Capability* phase, to analyse how well capability-related needs associated with the different technological clusters are expected to be met within the context of the different scenarios.

2.4.2. Approach

Scenario development is usually a lengthy process that may take several months. Two different approaches are typically considered when subject-specific scenarios have to be created:

a) A first approach consists in searching for already-made suitable general scenarios and customising them to obtain the desired subject-specific scenarios. This process is conducted in two consecutive steps:
   - Step 1. **Search** for the most suitable set of general scenarios (i.e. scenarios not directly connected to the topic of the study) for the timeframe which the TFP refers to;
   - Step 2. **Adaptation** of the selected general scenarios to the TF study's subject. The scenarios are customised to fit the needs of the TFP by adding depth and breadth adequate to the topic.

b) A second alternative approach consists in replacing the aforementioned steps with the development of future scenarios from scratch. This strategy is chosen when highly unspecific technologies are to be included in a foresight project. In other words, whenever it would be difficult to find ready-to-use or customisable, relevant scenarios.

In the following part of this chapter, attention has been focused on the first approach, being in general the most agile one and the one most suitable for the purpose of this Manual.

First, the general scenarios are chosen in accordance with the *postulates of similar levels of probability and desirability*. This does not mean that the level of probability and desirability of the scenarios must be very high; what is important is that they are at a similar level in each of the scenarios and, in aggregate, that they cover a wide spectrum of possible futures. This is partly to avoid a cognitive bias whereby technologies that are the most likely candidates and the most desirable scenarios receive higher ratings.

Once the general scenarios are selected, since varying circumstances may affect the process of adopting a technology differently, it is crucial to customise them in such a way as to render them relevant to the subject of the study. The specific procedure and the scope of adaptation depend on the degree to which the general scenarios already cover specific future aspects which could influence the technologies. In general, it is recommended the *First Technology Foresight Workshop* (see Paragraph 16.6.1) be designed for scenario building, where preparation steps conducted by means of methods such as *Rip Van Winkle* (see Chapter 11) and the *Futures Wheel* (see Chapter 12) might precede the actual scenario customisation, in turn often followed by a *Forecasting/Backcasting* exercise (see Chapter 13).

To perform the adaptation of all the general scenarios to the TFP's subject and time-frame, the following alternative modus operandi are suggested:

- **Modus Operandi A**: If the research is focused on a specific topic, then the relevant aspects of reality should be the focal point of the developed scenarios. Thus, the research questions to be considered for scenario adaptation are like "*What does this specific aspect of reality look like in the future described by the general scenarios*?"
- **Modus Operandi B:** An alternative approach is to treat the technologies as a point of departure. In this case, because no specific aspects of reality are initially provided, the first step is to identify the aspects of reality relevant to the analysed technologies. Once such aspects are identified, the research process resumes its usual path.

It should be noted that the second approach requires significantly more future-oriented researchers because it is much more difficult to envision all the possible functionalities of a given technology and aspects of reality that a given technology could influence in the future.

An effective tool for finding answers to these research questions is the *Futures Wheel* method,[28] described in Chapter 12. Then, for each of the characteristics of the general scenarios divided into PESTLE (Political Economic Social Technological Legal Environmental) categories, possible answers to the selected research question are determined. The step is repeated until all relevant aspects of reality are described.

It is also worth noting that general scenarios may be intended for a different time scope than the one used in TFP. If so, the issue should also be addressed in the process of adaptation to maximise the usefulness of strategic insights for further decision-making processes. The *Forecasting*[29] or *Backcasting* methods[30, 31] (see also Chapter 13) are usually employed for this purpose.

2.4.3. Recommended methods and tools

- Methods:
  - *Workshops* (see Chapter 16)
  - *Rip Van Winkle* (see Chapter 11)
  - *Futures Wheel* (see Chapter 12)
  - *Forecasting/Backcasting* (see Chapter 13)
- Tools:
  - *Miro Board* with prepared templates (see Chapter 18)

28 D.N. Bengston, "The Futures Wheel: A Method for Exploring the Implications of Social–Ecological Change", Society & Natural Resources, vol. 29, pp. 374–379, 2015.

29 In the field of future studies the word "forecasting" may be used in two different ways: as a general approach to analysing the future (which was explained in the Introduction) and as a specific method of creating the continuous scenarios of the future.

30 A. Hines, J. Schutte, M. Romero, "Transition Scenarios via Backcasting", Journal of Futures Studies, vol. 24, no. 1, pp. 1–14, 2019.

31 United Nations Development Programme (UNDP) Global Centre for Public Service Excellence, "Foresight Manual. Empowered Futures for the 2030 Agenda", Singapore, 2018.

2.4.4. Example of implementation

During the *Technology Foresight on Biometrics for the Future of Travel*, scenarios were not developed from scratch. Instead, the Research Team used scenarios that had already been developed within a different project. They were customised for the needs and the topic of this particular study.

Presented below are highlights from the search for appropriate scenarios, accompanied by arguments in favour/against specific choices.

Option 1 (chosen):
Set of scenarios from *The Future of Customs in the EU 2040: A foresight project for EU policy*.[32]

Project summary: The research study on *The Future of Customs in the EU 2040* results from a year-long foresight process. Its aim is to support strategic reflections on the future of the European Union's Customs Union, its relevance and its effectiveness in the long term. The European Commission's Joint Research Centre (JRC) undertook the project in collaboration with the Directorate-General for Taxation and Customs Union (DG TAXUD). A participatory and multidisciplinary nature is inherent to any foresight process, and thus it involved all relevant stakeholder groups, including representatives of Member States, key trading partners, trade associations, businesses, consumer organisations, international organisations, academia, and various services and Directorates-General of the European Commission.

Advantages

- Four scenarios were considered, each relatively extensive and detailed so relevant parts could be chosen for this study.
- The scenarios covered a wide range of factors that seemed relevant to this study (e.g. geopolitics, economy, technology and society).
- They also encompassed a vision of the EU in 2040 (a timeline similar to that of the present project).
- They were created from an EU perspective; thus they include factors and developments relevant to the EU.
- The project was completed in 2020; hence it is up to date.
- The *probability* level of the scenarios is not identical, but none can be disregarded as highly improbable.

Disadvantages

- The *desirability* of the four scenarios is varied: two out of four fall into the *bittersweet* category; one may be described as primarily positive, whilst another as mostly negative. Nevertheless, considering the prominent advantages of this set of scenarios, the decision was made to use them.

32 A. Ghiran, A. Hakami, L. Bontoux and F. Scapolo, "The Future of Customs in the EU 2040: A foresight project for EU policy", Publications Office of the European Union, Luxembourg, 2020.

Option 2:

Set of scenarios from _Work/Technology 2050 (The Millennium Project)_[33]

Advantages
• Three scenarios (negative, positive, mixed) described in relatively high detail.   • The scenarios include developments up to 2050.
Disadvantages
• Too much focus on the future of work, with a limited spectrum of factors directly relevant to employment.   • Two of the scenarios are polarised (negative to positive), therefore the only one that could be used is the mixed scenario.

Option 3:

Set of scenarios from the research study _Global Trends to 2030: Challenges and choices for Europe (ESPAS, 2019)_[34]

Advantages
• The project is written from the perspective of the European Union and includes factors relevant to the EU.
Disadvantages
• The project includes only two scenarios that are polarised (negative and positive) and not extensively described.   • The project focuses on analysing megatrends rather than on developing scenarios.   • Only a short-term vision (up to 2030) is considered.

Option 4:

Set of scenarios from the project _Beyond the Horizon: foresight in support of future EU research and innovation policy – BOHEMIA (European Commission, 2017)_[35]

Advantages
• The project is written from the perspective of the European Union and includes factors relevant to the EU.
Disadvantages
• The project includes 19 scenarios, each devoted to a different aspect.   • The project focuses on analysing megatrends rather than on developing complex scenarios.   • Only a short-term vision (up to 2030) is considered.

33 J. C. Glenn and Millennium Project Team, "Work/Technology 2050: Scenarios and Actions", The Millennium Project 2019, retrieved from: http://www.millennium-project.org/projects/workshops-on-future-of-worktechnology-2050-scenarios/.

34 European Strategy and Policy Analysis System, "Global Trends to 2030: Challenges and Choices for Europe", 2019.

35 European Commission, Directorate-General for Research and Innovation, "Transitions on the Horizon: Perspectives for the European Union's future research and innovation policies", Publications Office of the European Union, Luxembourg, 2018. ISBN 978-92-79-81266-8.

Option 5:

Set of scenarios from other thematic projects

- Other thematic projects were considered (e.g. the future of transport, the future of cities), but the proposed scenarios tended to focus on a specific area of interest without simultaneous consideration of sufficient social, technological, economic or political contexts.

The four general scenarios[36] selected for the *Technology Foresight on Biometrics for the Future of Travel* did not describe the reality of biometrics and travel in 2040. Thus, the scenarios needed to be customised in order to provide the required information about travel and the use of biometric technologies during border-check processes. The adaptation of scenarios, which were needed for the subsequent *Filtering Results*, *Modelling the Roadmaps* and *Mapping Capabilities* phases, was conducted using the first of the two proposed alternative Modus Operandi (Modus operandi A – see Paragraph 2.4.2) and involved the following three phases implemented in the course of the *First Technology Foresight Workshop on Scenario Building* (see Paragraph 16.6.1) with the support of the Group of Experts:

- ***Customisation of scenarios – Phase 1:*** *Collecting insights regarding the 2040 travelling experience.*
  The specific questions answered, for each scenario, by the Group of Experts participating in the workshop at this stage are shown in Table 1. Examples of raw insights collected via the online *Miro Board* (see Chapter 18) are also presented in Figure 8.
- ***Customisation of scenarios – Phase 2:*** *Collecting insights on how the events described in the scenarios and their impact on travel would affect border check processes from the perspective of travellers, the EBCG community, carriers and other entities.* Examples of the raw insights collected via the online *Miro Board* are presented in Figure 9.
- ***Customisation of scenarios – Phase 3:*** *Collecting insights on the key changes that would need to occur (or trends that would have to be sustained) in 2022-2040 for a specific scenario to become reality.*
  Since the general scenarios were set in 2040, they needed additional timeframe adjustments to the TFP timeframes of 2022-2027 (short-term), 2028-2033 (medium-term), 2034-2040 (long-term). The *Backcasting* method was used to perform this step. The Group of Experts proposed specific PESTLE trends and events, which could lead to the fulfilment of a particular 2040 scenario. The analysis was performed for the three timeframes: 2022-2027, 2028-2033 and 2034-2040. Examples of the raw insights collected via the *Miro Board* are shown in Figure 10.

Additional information on the four s*cenarios for the future of travel, border checks and biometric technologies in 2040* created within the frame of the *Tech Foresight on Biometrics* can be found in the Research Study – Chapter 5.

36 A. Ghiran, A. Hakami, L. Bontoux and F. Scapolo, "The Future of Customs in the EU 2040: A foresight project for EU policy", Publications Office of the European Union, Luxembourg, 2020.

Table 1: *Customisation of scenarios – Phase 1: Collecting insights regarding the travelling experience in 2040.*

How has international travelling changed since 2021 regarding...						
purposes of travel?	**prevalent modes of transport?**	**people travelling?**	**popularity of travelling?**	**frequency and duration of travel?**	**destinations of travel?**	**other aspects of travel?**
Why are people travelling?	*What means of transport do they use?*	*Who is travelling? What are the demographics, economic status, etc., of travellers? Where do they come from? Do they travel in groups or alone?*	*What percentage of people travel yearly?*	*How often do people travel abroad? How long do they stay abroad?*	*What destinations in and outside the EU are most popular? What is the ratio of inter- to intracontinental travels? What is the average travelling distance?*	*What else has changed?*

Figure 8: *Customisation of scenarios - Phase 1: sample insights regarding the travelling experience in 2040.*

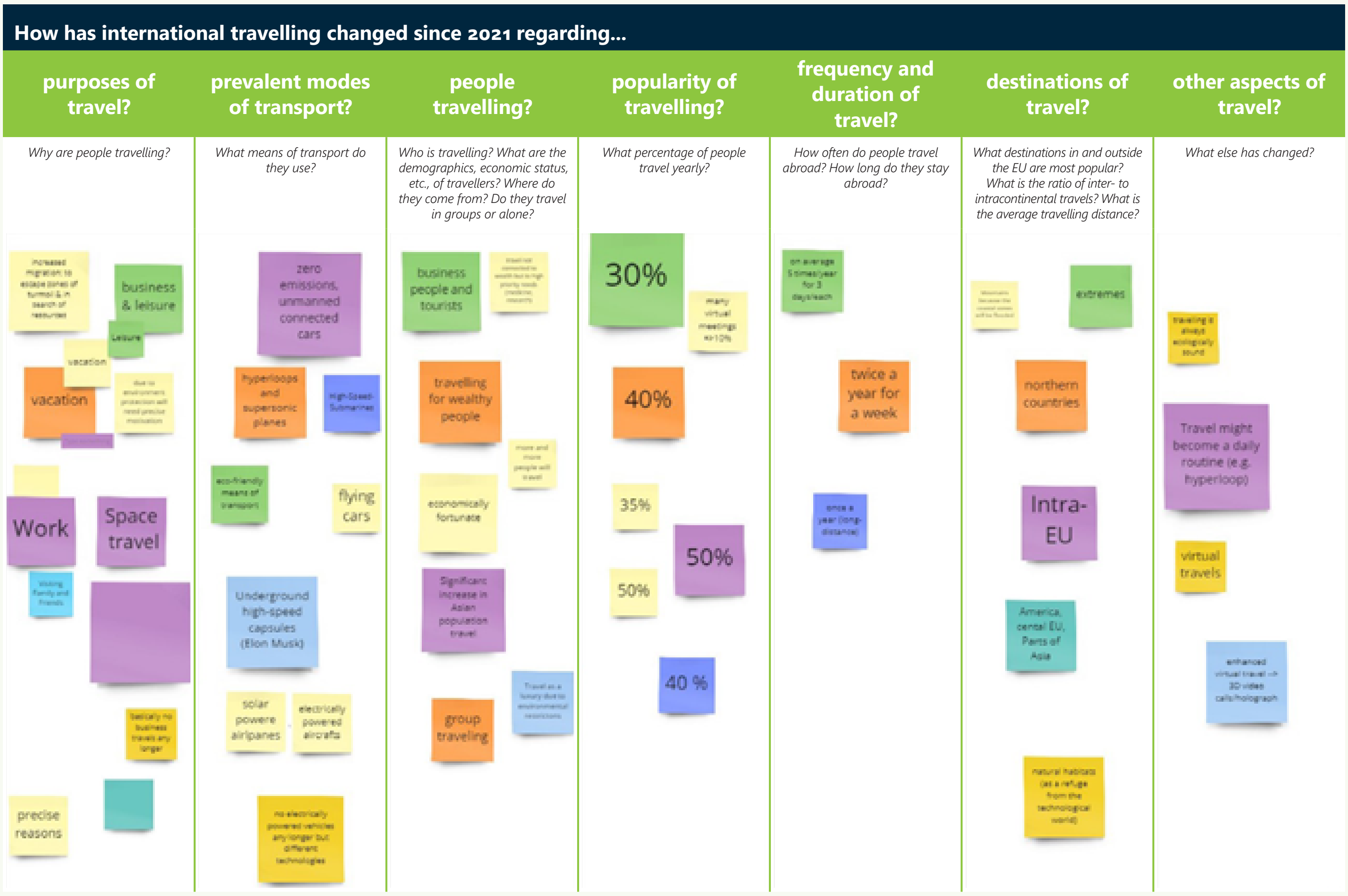


Figure 9: *Customisation of scenarios – Phase 2: sample insights regarding border checks in 2040.*

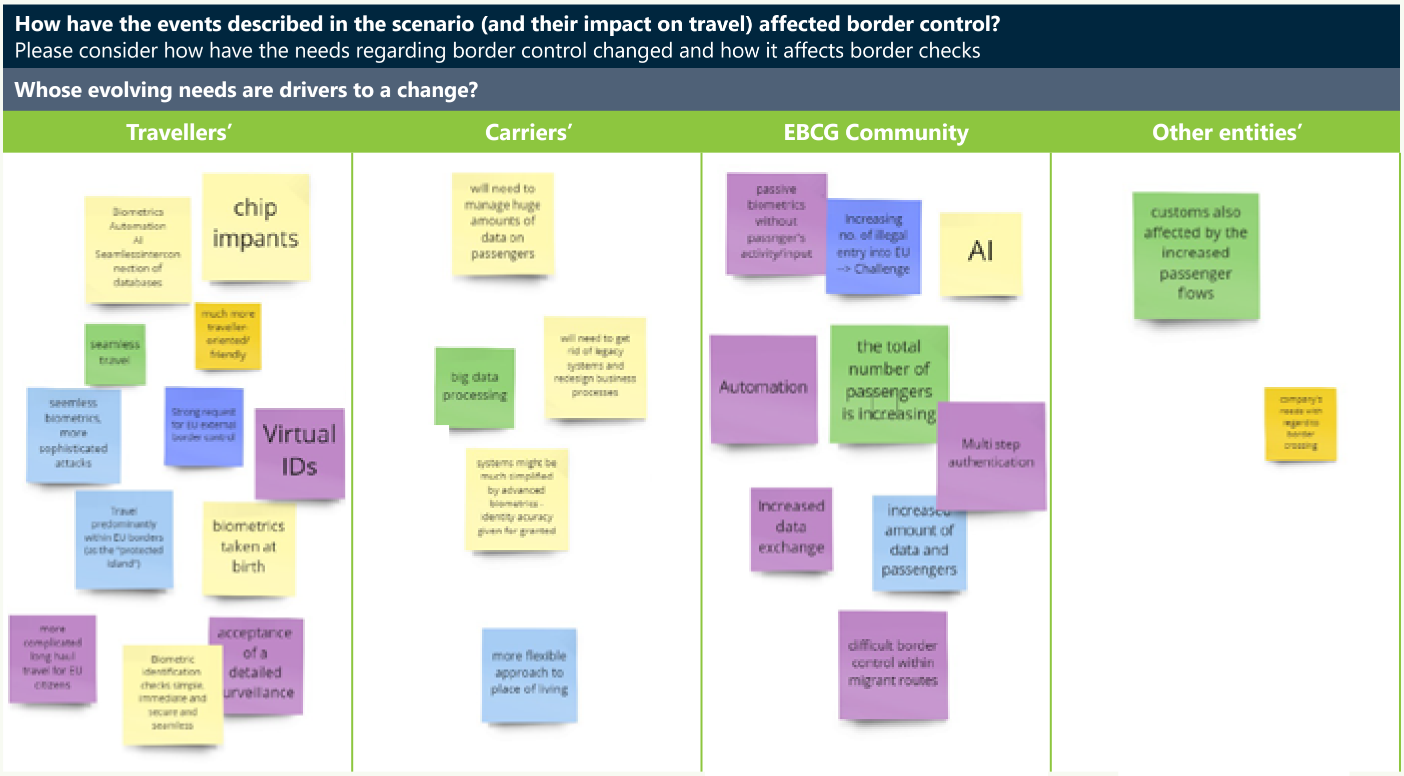
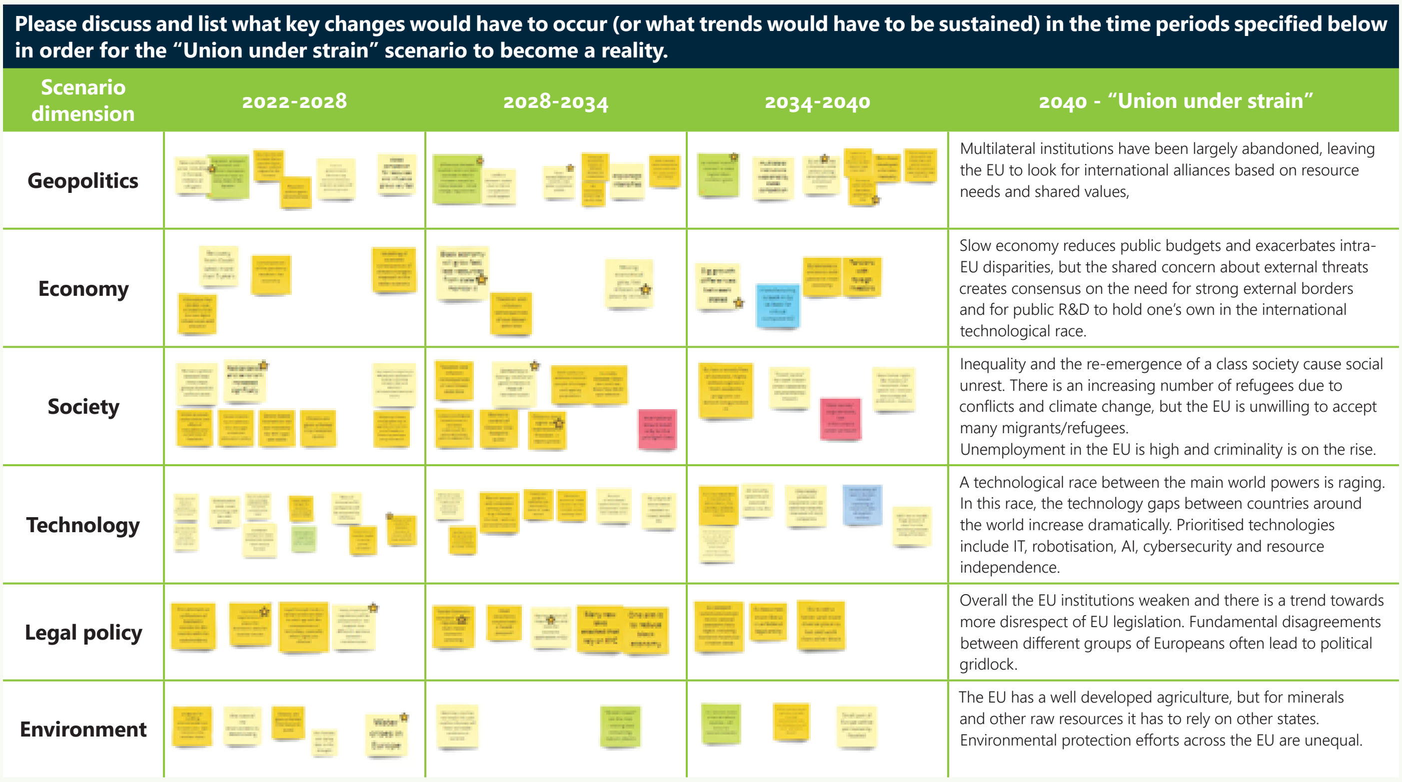
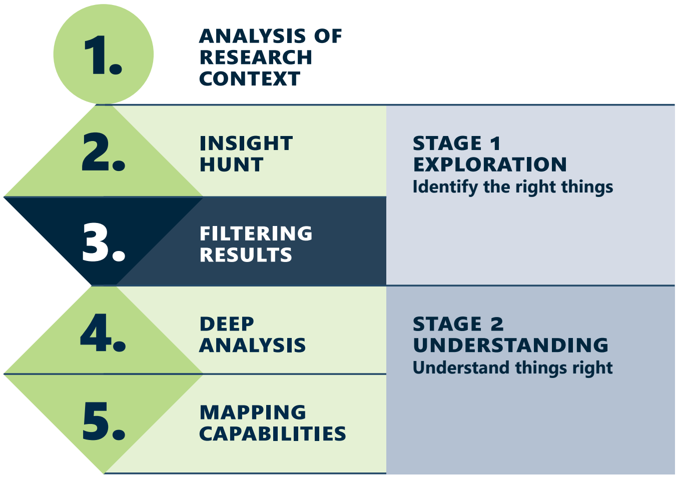


Figure 10: *Customisation of scenarios - Phase 3: sample insights regarding PESTLE trends and events occurring in 2022-2040.*



3. Filtering Results

Figure 11: *Filtering Results within the Double Diamond approach.*



The final results of the *Insight Hunt* stage include a *longlist* of technological clusters (typically about 20) in the predefined research area. However, not all the identified clusters are of equal potential importance to the recipient of the study. The purpose of the *Filtering Results* phase is to refine the selection and compile a *shortlist* of **key technological clusters** (about 5 is generally considered a suitable number) to be analysed in detail. Therefore, the clusters are subjected to a multi-level assessment also performed with the support of the Group of Experts through a series of consultations.

This phase is divided into three steps: *Filtering by Key Strategic factors, Filtering by Other Relevant Factors, Filtering by Compliance with Future Scenarios.*

3.1. Filtering by Key Strategic Factors

3.1.1. Main objectives

The aim of this step is to identify technological clusters that present the highest strategic value for the recipient of the TF. To achieve this goal, the previously identified technological clusters are quantitatively assessed using *key strategic factors.* The assessments are subsequently used to create a hierarchy of technological clusters based on their potential to provide strategic value for the recipient of the TF.

3.1.2. Approach

The most important criteria employed in the strategic analysis are the availability of specific clusters and potential strategic advantage that specific clusters provide for the recipient of the TF. A typical set of key strategic factors include:

- From an availability standpoint:
  - *Technology Readiness Level (TRL);*[37]
  - *Earliest Time to Arrival (ETA)* – the shortest time needed for a technology to achieve TRL 9;
  - *Earliest Time to Mainstream (ETM)* – the shortest time needed for a technology to enter the mainstream of technologies in its field.
- From a strategic advantage standpoint:
  - *Relative Advantage (RA)* – quantified degree (usually on a scale from 0 to 10) by which the technology surpasses present mainstream technologies in a given strategic advantage used in the subject field of the TFP. Also referred to in literature as the *Disruptiveness potential.*[38] The 0-10 spectrum is defined as follows:
    - 0 indicates that the proposed technology would not have the potential to provide any significant advantage over currently available best-in-class technological solutions or would be impossible to achieve;
    - 10 indicates a so-called *game-changer* that would rapidly render the current best-in-class technology obsolete and uncompetitive due to factors such as cost, reliability, eco-friendliness, etc.
  - *Impact* – an alternative to RA, this factor describes the potential of the identified technologies to influence the real world. Sometimes also referred to as *radicalness.*[38] Usually assessed on a scale from 0 to 10, where:
    - 0 indicates that the technology would not change the current state of affairs;
    - 10 indicates a game-changer, which would not only force a change in the sector but would also cause significant changes in the political, economic, social, environmental or even philosophical spheres.

The main difference between TRL, ETA and ETM lies in the portion of the technology implementation process covered by each of these metrics:

- **TRL** describes the development phase of a technology, from the initial observations of basic physical phenomena (TRL 1) to the operational readiness phase (TRL 9);
- **ETA** is an indicator that broadens the TRL spectrum by adding the product launch on the market;
- **ETM** broadens it further still by adding the product launch and the time necessary for a technology to enter the mainstream.

This difference is illustrated in Figure 12.

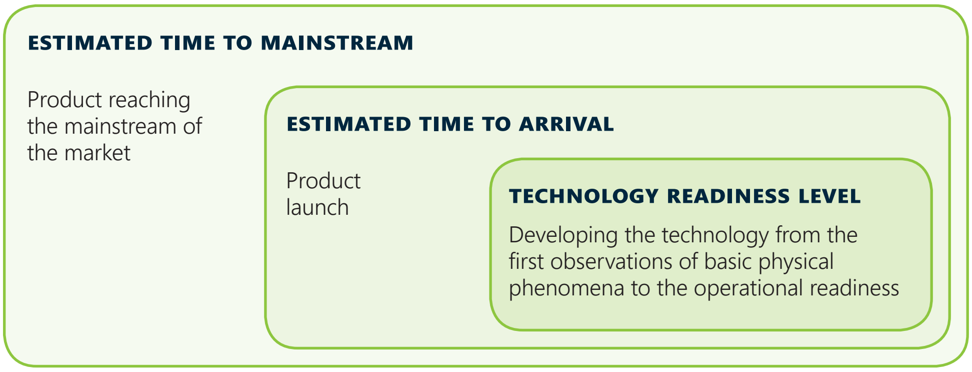
37 Detailed definitions of TRLs are contained in: h2020-wp1617-annex-ga_en.pdf.

38 V. Govindarajan and P. K. Kopalle, "Disruptiveness of innovations: measurement and an assessment of reliability and validity", Strategic Management Journal, vol. 27, pp. 189–199, 2006.

Much as the availability metrics differ as to the stages of technology implementation, strategic advantage metrics differ in the scope of influence on reality:

- **RA** is a measure of the benefits that implementing a technology would entail, in comparison to the current state-of-the-art technological solutions. It is assumed that gaining access to a beneficial technology faster than market competitors provides a strategic advantage.
- **Impact**, on the other hand, is a measure which describes not just the market reality or the industry but the *big picture* (benefits in comparison to the competition, plus the influence on politics, society, economy, environment etc.). While RA is always positive, Impact may be either positive or negative. It is therefore important to state clearly how the Impact metric is to be employed.

Figure 12: *Relation between TRL, ETA and ETM.*



The selection of key strategic factors used in TFP for filtering depends on the *Identification of Needs* step (see Section 1.1).

In this step, technological clusters are evaluated through the chosen key strategic factors, assuming that the future will develop along its current path (i.e. existing trends will not change and the picture of the future will be that of an extrapolated present).

The most appropriate approach to this step is a *Delphi Survey* (see Chapter 9). The advantage of the *Delphi Survey* over alternative methods of quantitative and semi-quantitative evaluation is its anonymity (which eliminates the cognitive bias resulting from the recognition of authority) and its iterative nature. This means the results of the survey reflect the arguments of the participants but also provide a group consensus. Thus, the *Delphi Survey* offers the benefits of collective intelligence, as opposed to a conventional quantitative survey which would merely provide a statistical distribution of experts' answers.

3.1.3. Recommended methods and tools

- Methods:
  - *Delphi Survey* (see Chapter 9)
  - *4CF Matrix* (see Chapter 10)
- Tools:
  - *4CF HalnyX* (see Chapter 17)

3.1.4. Example of implementation

The process of *Filtering by Key Strategic Factors* during the *Technology Foresight on Biometrics for the Future of Travel* was carried out in accordance with the methodology of a *real-time Delphi Survey* (see Chapter 9) and with the use of the so-called *Smart Delphi system – 4CF HalnyX* (see Chapter 17), available to the Research Team.

Relative Advantage and Earliest Time to Mainstream were selected as the key strategic factors.

RA was rated on a scale of 0-10, where:

- 0 indicated that the proposed solution would not have the potential to provide any significant advantage over currently available best-in-class solutions or would be impossible to achieve;
- 10 indicated a *game-changer*, i.e. a solution which would drastically improve travellers' border check experience.

The ETM was assessed on a scale of 0-20 years:

- 0 indicated that the envisaged technological solution is already available on the market and is widely adopted;
- 20 indicated periods of 20 years and longer, including cases of technological solutions which can never be realised.

The online platform hosting the *Delphi Survey* was open for two weeks, during which the experts were encouraged to revisit the survey as many times as they wished. However, to ensure maximised benefits and the achievement of expected goals, the experts were asked to access the platform and provide their input at least three times – once during each of the three predefined time slots of 4-5 days.

The results of the *Delphi Survey* were then assessed through the *4CF Matrix* method (see Chapter 10) and a composite metric combining RA and ETM to obtain a ranking list of technological clusters, representing the final output of this *filtering* step. The overall outcome of this *filtering* step within the *Tech Foresight on Biometrics* can be found in the Research Study – Chapter 7.

3.2. Filtering by Other Relevant Factors

3.2.1. Main objectives

This step narrows down the list of identified technological clusters by means of an assessment that includes additional factors. This is potentially relevant due to the nature of the research area or the specific needs of the recipient of the foresight study. The factors reflect the needs identified during the *Identification of Needs* step (see Section 1.1).

3.2.2. Approach

The selection of additional factors can be conducted by the Research Team, the Group of Experts, the ordering party and/or the recipient of the foresight study. It is important not to select too many additional factors, to avoid prolonging the research process unnecessarily, as this would reduce the quality of results.

The assessment of the identified technological clusters by the additional factors is carried out through consultations that consider the previously identified needs. If technological expertise is necessary for the evaluation, subject-matter experts with in-depth knowledge about the factors are chosen.

3.2.3. Recommended methods and tools

- Methods:
    - *Matrixes of Needs and Functional Requirements* (see Chapter 6)

3.2.4. Example of implementation

The process of *Filtering by Other Relevant Factors* during the *Technology Foresight on Biometrics for the Future of Travel* was conducted once Frontex's needs were identified. The additional factors selected to address specific needs included:

- Security of technological clusters, encompassing:
    - Vulnerability to adversary attacks
    - Main associated risks
    - Main associated opportunities
- Compatibility with policies and measures typically taken in the event of pandemics
- Compliance with EU regulations and values
- Potential to enable seamless biometrics acquisition in border checks

The ability to provide a seamless border check experience as well as compliance with EU values and regulations were both added as requisites for the ETM metrics used in the *Delphi Survey* (see Section 9.6).

The security analysis was performed by the Research Team Experts using a *Matrix of Needs and Functional Requirements* (see Chapter 6). The outcomes of this filtering step are described in detail in the Research Study – Chapter 7.

3.3. Filtering by Compliance with Future Scenarios

3.3.1. Main objectives

Scenario Analysis (see Chapter 14) applied to filtering technological clusters is an additional step that narrows the initial list of relevant clusters. The two previously mentioned filtering steps are conducted within the framework of the *Business as Usual* (BAU) scenario. To broaden the strategic analysis, it is necessary to verify how individual solutions would perform in various future scenarios in terms of associated risks and opportunities. Therefore, the purpose of this further filtering exercise, which is based on the use of long-term scenarios, is to stress-test technological clusters in the context of a broad spectrum of possible futures.

3.3.2. Approach

Each technological cluster remaining after filtering in the previous steps of this phase is assessed for compatibility with the set of customised scenarios built within the *Insight Hunt* phase (see Section 2.4). This can be done by the Research Team or by the Group of Experts in a workshop. Clusters that display opportunities in most scenarios are ranked higher than those with more risks connected to their implementation in the different scenarios.

In conclusion, the expected overall outcome of the *Filtering Results* phase is a short-list of key technological clusters which is used during the *Second Technology Foresight Workshop* (see Paragraph 16.6.2) where, after this three-stage screening and assess-ment process, the highest-rated clusters are subjected to *roadmapping* (see Section 4.1).

3.3.3. Recommended methods and tools

- Methods:
    - *Scenario Analysis* (see Chapter 14)
    - *Workshops* (see Chapter 16)
- Tools:
    - *Miro Board* (see Chapter 18)

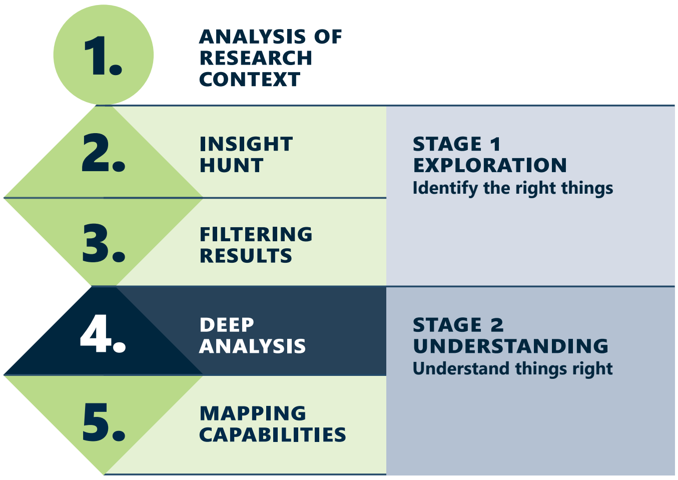
3.3.4. Example of implementation

During the execution of the *Tech Foresight on Biometrics*, since the two filtering steps described above already resulted in a shortlist of five key technological clusters, no additional filtering was required. However, to provide a more comprehensive picture of technological clusters' compatibility with the specific conditions described in the four customised scenarios, a *Scenario Analysis* was also performed, whose results are reported in the Research Study – Chapter 6.

4. Deep Analysis

The most promising technological clusters are selected during the *Filtering Results* phase. This set provides the input for the second stage of the TFP: the *Understanding* stage. Its first phase, *Deep Analysis*, is intended to deepen and broaden the knowledge about the future of each key technological cluster. The analysis aims to answer what their development will look like in diverse future scenarios and what risks and opportunities they may bring. The main objective of this phase is the development of technology roadmaps for each of the selected key clusters.

Figure 13: *Deep Analysis within the Double Diamond approach.*



4.1. Modelling the Roadmaps

4.1.1. Main objectives

The primary purpose of this step is to generate knowledge and strategic insights which serve as the input for development strategies for the key technological clusters selected in Phase 3 of the TFP. This step is performed via technology roadmapping, and the final output takes the form of roadmaps for each of the key clusters. Roadmaps show detailed development paths of technologies over a particular time horizon. To go beyond a mere technology extrapolation, the objective of this step is to create a set of roadmaps: one for each technological cluster within a specific scenario (delineated in Section 5.1 above); if there are five key technological clusters and four scenarios, the end results would include:

- Five baseline roadmaps in a BAU condition;
- 5x4=20 additional roadmaps obtained, adapting each of the five baseline roadmaps to each of the four customised scenarios.

4.1.2. Approach

Modelling a roadmap requires the following input:

- The subject of each roadmap: the key technological clusters. These may be obtained from the final result of the *Filtering Results* phase (see Chapter 3);
- The context in which the modelling will take place: the subject-specific scenarios of the future. These are obtained in the 4th step of the *Insight Hunt* phase (see Section 2.4), typically through a *scenario building* workshop (see Chapter 16);
- The general structure of the roadmap, which usually consists of layers related to *technology-push* and *market–pull* realities of the targeted technological clusters.

The general methodological approach to the modelling of a technology roadmap is composed of three phases:

- Phase 1: Defining the time frame and general structure of the technology roadmap;
- Phase 2: Envisioning technological developments in the specified time frames and in the context of alternative scenarios during a roadmapping workshop (see Paragraph 16.6.2);
- Phase 3: Processing the insights and preparing a synthesis of the roadmapping workshop results (visual roadmaps and structured information about key turning points regarding envisioned developments).

The architecture of the roadmap, which includes the time frames and the roadmap layers (as well as potential sublayers), needs to be consulted with the recipient of the study before the workshop. Generic roadmaps typically include the following layers:[39]

- **Market**: Business environment, Applications, Industry, Business, Customers, Competitors;
- **Product**: Services, Processes, Systems, Platforms;
- **Features**: Components, Capabilities, Performance;
- **Technology**: Functions, Families;
- **Resources**: Knowledge, Competences, Finance, R&D projects, Infrastructure, Partnerships, Suppliers, Organisation, Standards.

These generic layers can be merged or modified according to the recipient's requirements regarding the expected output of roadmapping. In general, they should provide a vision of the development of a specific technological cluster in terms of market and technology trends and drivers. In addition, a roadmap may detail the resources which underpin specific market or technological developments.

A roadmap example is described in the *Example of Implementation* Section (Paragraph 4.1.4).

39 R. Phaal, C. J. P. Farrukh and D. R. Probert, "Strategic roadmapping: a workshop based approach for identifying and exploring innovation issues and opportunities", Engineering Management Journal, vol. 19, 2007.

4.1.3. Recommended methods and tools

- Methods
    - *Forecasting/Backcasting* (see Chapter 13)
    - *Scenario Analysis* (see Chapter 14)
    - *Workshops* (see Chapter 16)
- Tools:
    - *Miro Board* (see Chapter 18)

4.1.4. Example of implementation

The role of roadmapping in the *Technology Foresight on Biometrics for the Future of Travel* was threefold:

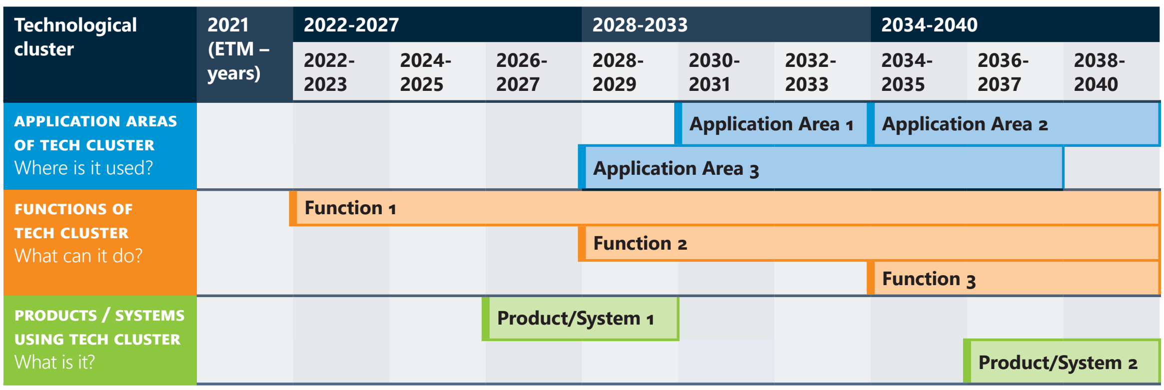
- to identify the development paths of the key biometric technological clusters in the 2021-2040 timeframe;
- to identify key turning points in technological development (factors delaying or accelerating the envisioned development);
- to confront technology roadmaps with alternative scenarios regarding border-check processes and the future of travel in the 2021-2040 timeframe, in order to compare how the conditions of the alternative scenarios might influence the developments envisaged in the roadmaps.

The roadmapping exercise was conducted during the *Second Technology Foresight Workshop* (see Paragraph 16.6.2)

In Phase 1 of the roadmapping, the overall time frame was defined (2040), as well as the general structure of the technology roadmap to be used for each of the five selected key technological clusters, as shown in Figure 14. It consisted of three layers:

- **Application areas:** lists the potential applications of the key cluster;
- **Functions:** refers to the evolving technical capabilities of the cluster;
- **Products or systems:** provides examples of devices and solutions that use the specific technologies from the cluster.

Figure 14: *Technology roadmap structure applied in the context of the Tech Foresight on Biometrics.*



The four main focal points of Phase 2 during the roadmapping workshop, when envisioning technological developments by 2040 in the context of alternative scenarios, were:

1. The construction of baseline roadmaps to identify the development paths of the five key clusters in 2021-2040;
2. The confrontation of the envisioned developments with the four alternative scenarios regarding the future of travel and border checks by adjusting the baseline roadmaps to the conditions of each scenario in 2021-2040;
3. The identification of key factors delaying or accelerating the envisioned developments;
4. The identification of the capability-related needs and requirements for successful implementation of each cluster. This activity was preparatory for the capability mapping conducted in Phase 5 of the TFP (see Chapter 5).

The third and last phase of the roadmapping process aimed at processing the insights and preparing a synthesis of the roadmapping workshop results.

Figure 15 below illustrates processed technology roadmapping data within a baseline roadmap developed for a specific technological cluster (*Contactless Friction Ridge Recognition*) after the roadmapping workshop.

The overall results of the roadmapping exercise for the key biometric technological clusters in the 2040 timeframe are reported with all the relevant details in the Research Study – Chapter 8.

Figure 15: *Technology roadmap for the Contactless friction ridge recognition technological cluster.*

Contactless friction ridge recognition	**2021 (ETM: 7.7 years)**	**2022-2027**			**2028-2033**			**2034-2040**		
		2022-2023	**2024-2025**	**2026-2027**	**2028-2029**	**2030-2031**	**2032-2033**	**2034-2035**	**2036-2037**	**2038-2040**
APPLICATION AREAS OF TECH CLUSTER Where is it used?	It is not used in border checks. Pilot tests took place within the "Biometrics on the move" Frontex project at Lisbon Airport in 2019	**Growing number of pilot applications in seamless border check processes**				**Mainstream applications in the area of seamless border checks**				
					Military and security applications					
	Self-driving cars				**Public (i.e. e-government) and private sector services (i.e. physical access control and information security)**					
	Entertainment sector (e.g. digitising paintings and sculptures via 3D scanning)				**Financial services (authentication process in banking and digital transactions)**					
FUNCTIONS OF TECH CLUSTER What can it do?	Person recognition at a very short distance	**Recognition of persons from a very short distance**								
					Recognition of persons from a short distance					
								Stand-off person recognition (a few meters' distance)		
PRODUCTS / SYSTEMS USING TECH CLUSTER What is it?	Stationary scanners (and sub-systems)	**Stationary scanners**								
					Mobile scanners (e.g. portable/handheld devices; portable/handheld mobile phone-based scanners; portable/hand-held tablet-based scanners)					
					Self-service systems					
								Stand-off scanners (a few meters' distance)		

5. Mapping Capabilities

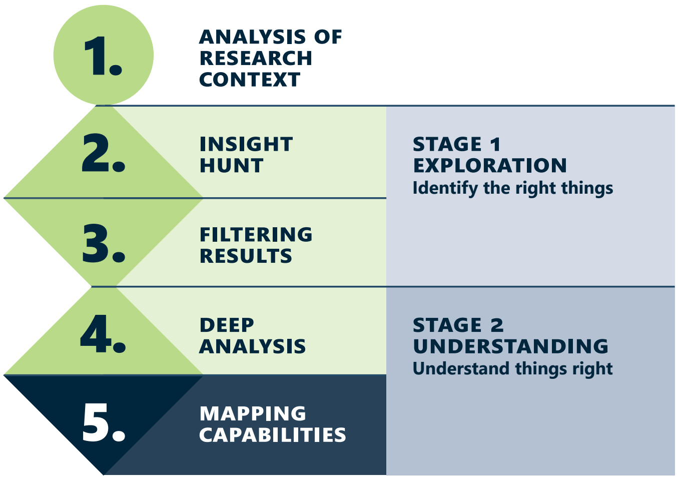
In general, the aim of capability mapping[40] is to provide a solid base for strategic planning for the achievement of self-defined objectives. It provides an assessment of the available capabilities in terms of their sufficiency and shows potential gaps, where further action is needed. Further, it points out opportunities that can be exploited when developing capabilities.

5.1. Capability Readiness Analysis

5.1.1. Main objectives

The main objective of this phase is to analyse the existing capability landscape within the EU, particularly in the domains of research, industry and institutions, and to identify opportunities and gaps (in the short, medium and long term) associated with capability-related needs for each of the selected key clusters in the context of the customised scenarios. The resulting insights on the capability landscape can then serve as a base for the strategic development of the KTCs, exploiting capability opportunities while closing capability gaps.

Figure 16: *Mapping Capabilities within the Double Diamond approach.*



40 It is worth noting that the capability mapping process mentioned within the framework of the Research Study this manual refers to is clearly distinguished from the institutional capability development planning process of Frontex, referred to in Article 9 (Integrated planning) of the Regulation (EU) 2019/1896 of the European Parliament and of the Council of 13 November 2019 on the European Border and Coast Guard.

5.1.2. Approach

Heatmaps of capability readiness for technological cluster are the ultimate result of this phase, in which the following research questions are addressed:

- What are the objectives in terms of the target state for a given cluster, and when will this state be reached?
- What capabilities are needed within the EU to reach the objectives for each cluster?
- How far developed are these capabilities in comparison to the cluster-specific, capability-related needs?

At a glance, the heatmaps visualise:

- The existing and expected capability readiness with regard to cluster-specific needs in the context of the selected scenarios;
- Capability opportunities and gaps within each cluster.

For the purposes of the kind of TF studies this manual refers to, the research, industrial and institutional feasibility of selected technological clusters within the EU are of main interest. Hence, these aspects must be reflected in the heatmaps developed as a result of this step. The outcomes of the capability mapping can be regarded as a starting point for capability-based planning. To commence this step, further prioritisation of capability gaps and opportunities is recommended, using e.g. the *Weighted Criteria Matrix* method (see Chapter 15). Capability planning shall ultimately aim at the exploitation of the identified capability opportunities and closure of critical gaps, to achieve a future-proof strategic development of the respective technological clusters.

5.1.3. Recommended methods and tools

- Methods:
  - *Desk Research* (see Chapter 7)
  - *Scenario Analysis* (see Chapter 14)
  - *Weighted Criteria Matrix* (see Chapter 15)
  - *Workshops* (see Chapter 16)
- Tools:
  - *Miro Board* (see Chapter 18)

5.1.4. Example of implementation

Capability mapping inputs were mainly gathered from the Group of Experts during the *Second Technology Foresight Workshop on Roadmapping* (see Paragraph 16.6.2). By way of a step-by-step approach (see Figure 17), a set of objectives was defined by Frontex *a priori* for the KTCs along with the main capabilities within the three relevant domains (research, industrial and institutional), which were given to the Group of Experts during the workshop as a guideline. Based on this input, cluster-specific capability-related needs were then postulated by the Group of Experts.

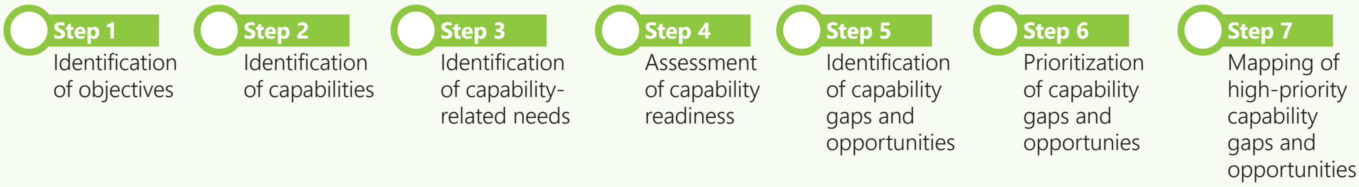
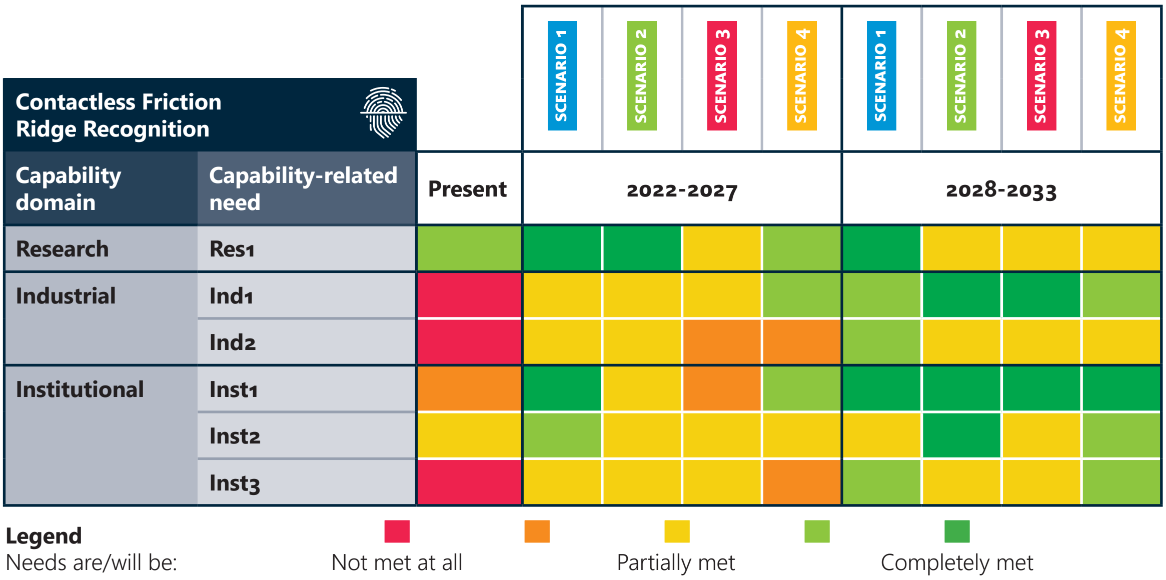


Figure 17: *Example of a step-by-step approach in objective-driven capability mapping conducted for the Technology Foresight on Biometrics for the Future of Travel. In Step 1, Frontex's input was used to tailor the exercise to the Agency's specific needs.*

Capability readiness, intended as a measure of how well capability-related needs are expected to be met, was subsequently assessed in the short- and medium-term,[41] within the context of the four customised scenarios. The outcomes of the *Capability Readiness Analysis* were condensed into heatmaps (an example is shown in Table 2 for one on the KTCs), revealing opportunities and gaps regarding capability-related needs within the EU, in the different timeframes and within the bounds of the customised scenarios, which consider the relevant socio-economic effects. Such an approach will enable Frontex to apply the information obtained to assess the capabilities available in Europe and to direct additional efforts, for example into enhancing European scientific and industrial research capabilities (e.g. via EU-funded RTDI framework programmes), especially to strengthen EU strategic autonomy in the field of biometrics.

The approach to the *Capability Readiness Analysis* adopted within the framework of the *Technology Foresight on Biometrics* and the entire set of associated results are all detailed in the Research Study – Chapter 9.

Table 2: *Heatmap of capability readiness for the Contactless friction ridge recognition technological cluster. The abbreviations used for the capability-related needs (e.g. Res1) relate to specific capability-related needs in the domains of research (Res), industry (Ind) and institutions (Inst).*



41 Under the assumption that once a biometric TC has entered the mainstream it will be available for implementation in border-check systems, and therefore will not require any further capability development, the long-term timeframe (2034-2040) was eliminated from the capability mapping exercise, as all 5 KTCs demonstrate an ETM before 2033.

Part 2 – Technology Foresight Methods

This part of the manual provides the reader with key information about the foresight methods used in the TFP. The primary focus is on their uses in Technology Foresight processes as well as their objectives and outcomes. Short instructions on their implementation are also included.

6. Matrixes of Needs and Functional Requirements

6.1. The method, its purpose and objectives

The *Matrixes of Needs and Functional Requirements* are a graphic representation of the needs stated by the recipient of the TF study and are directly connected to the study's topic and the functional requirements of the corresponding technologies. They serve as a crucial point of reference at various stages of the project and help to focus the *Deep Analysis* phase on adequate groups of solutions. The method aims to select the crucial analytical parameters from the point of view of the recipient of the study. The objective is to identify a set of requirements that will be applicable to the analysed insights and which will simultaneously describe the most important needs of the recipient.

In TFP, *Matrixes of Needs and Functional Requirements* are used in:

- Phase 1, Step 1 – *Identification of Needs*
- Phase 3, Step 2 – *Filtering by Other Relevant Factors*

6.2. Required input data

A list or description of the recipient's basic expectations regarding the TF study.

6.3. Expected results

The method produces lists of high-level requirements that need to be met for the solutions to be employed in specific types of operations. The results can be used as a benchmark for the later assessment of a group of future solutions in terms of their potential to fulfil the recipient's needs.

6.4. User of the method

Experts of the Recipient with the support of the Research Team Experts or Group of Experts (if needed).

6.5. Modality of implementation

The first step is to obtain an overview of the study recipient's needs. The study can then be narrowed accordingly, and misunderstandings as to the scope of analysis can be avoided. The requirements identified at this stage are called general needs or Level 1 needs (see also Section 1.1). Their identification can be structured and facilitated by means of a matrix, focused e.g. on pinpointing the current limitations and expected benefits (value added by the Technology Foresight study) for the field of interest. The assumed objectives, results, beneficiaries and time horizon of the study should be specified in the description of the TFP. A generic matrix with predefined questions and answer examples is provided in Table 3.

Table 3: *Identification of the general (Level 1) needs with regard to a Technology Foresight study.*

Topic	Why?		How? (Frontex tips & tricks)	
	"Pains" Current limitations to address	"Gains" Expected added value	Key success factors	Constraints / risks to be taken into account
Topic 1				
Topic 2				
Topic n				

A matrix similar to the one presented above is generally completed in the course of a meeting with the recipient of the study to determine Level 1 needs. Once the matrix is complete, more detailed functional requirements – Level 2 needs (see also Section 1.1) – can be identified. There are many approaches to this step, but a simple list of must-haves may be the most practical solution in the case of the long-term Technology Foresight. If the subject of analysis is suited to the assignment of quantitative parameters to specific functional requirements, such an additional step may be considered, but is not indispensable in Technology Foresight.

If the level of detail that a specific topic would require from quantitative assessment criteria is impractical, an alternative can be used in the matrix: a list of qualitative must-haves that address particular functions or the topic of the study in general. Such a list should be prepared by the Experts of the Recipient of the study and should only include uncontroversial requirements that are highly probable within the time horizon of the study. Once such a list is provided, the suitability of specific parameters for assessing technological clusters should also be evaluated by the Experts of the Recipient of the study. A simple table, such as Table 4 presented here, is well suited for this task.

Table 4: *Identification of the specific (Level 2) needs through a list of qualitative parameters (must-haves) with suitability for the assessment of technological clusters.*

Qualitative parameters ("must-haves")	Suitable for assessment of Technological Clusters?
Parameter 1	Y/N
Parameter 2	Y/N
Parameter n	Y/N

The suitability assessment should consider the requirements of the subsequent stages of the TF project and is therefore highly dependent on the specifics of the project.

6.6. Example of implementation

In the case of the *Technology Foresight on Biometrics for the Future of Travel*, Level 1 needs were identified during the kick-off meeting. This online event, facilitated by representatives of Frontex, provided an opportunity to discuss the current limitations that the project should address, the expected added value, key success factors as well as the constraints/risks to be considered within the project. Table 5 was prepared to aid the discussion. It identified specific aspects of the projects' Work Packages. An example of the results is presented below.

Table 5: *Example of identification of general (Level 1) needs with regard to the Technology Foresight on Biometrics for the Future of Travel (partial results of the projects' kick-off meeting).*

Topic	Why?		How? (Frontex tips & tricks)	
	"Pains" Current limitations to address	"Gains" Expected added value	Key success factors	Constraints / risks to be taken into account
1) Why biometric technologies? Relevance to border control as perceived by Frontex	Use of biometrics so far mainly limited to face and fingerprint recognition. Other biometric technologies are emerging for applications in border checks	Maximise the opportunities provided by future technological developments in Biometrics for supporting the management of the EU's external borders Biometrics is a key technology for border control, high relevance for seamless travel, also enforced by COVID-19 (touchless). The EBCG community needs to understand the changes in related technologies and in the operational environment	Focus on Seamless Travel Consider the impact of pandemics on the usability of future Biometric technologies (e.g. need for contactless processes and impact of face masks) Tackle both hardware and software	Biometrics is highly regulated within the EU. This might significantly decrease flexibility in the adoption of certain biometric technologies. Traveller experience, border crossing experience Human-Machine Interaction Interoperability (many others as specified in the ToR) Interoperability as a cross-cutting issue

As for Level 2 needs, a detailed semi-quantitative approach initially seemed a good fit for the project. Requirements for the specific functions of technological solutions were to be defined quantitatively through various criteria. However, this approach soon proved impractical, for several reasons. First, there were difficulties in stating specific values for many of the criteria. Second, the goal of the study was to identify the most promising future technological solutions, with the fundamental prerequisite that they could not be worse than current ones; the minimum requirement was "*not worse than currently available*." Finally, many of the functions and criteria could only be evaluated from the perspective of specific implementations of the technologies within integrated systems.

Therefore, a decision was reached to use the simplified approach described in Section 6.5. A list of qualitative must-haves was compiled through the collaboration between Frontex and the Research Team. The earlier attempts to formulate quantitative parameters were recorded in an additional column of the must-haves table, thus facilitating possible references if they should prove useful in later stages.

Once the qualitative parameters had been established, the last step was to identify those suitable for assessing technological clusters. An important factor was related to the evaluation of the clusters in Phase 3, Step 1 (*Filtering by Key Strategic Factors*). One of the employed key strategic factors was the *Earliest Time to Mainstream* (ETM), which inherently assumes that a given technology will enter the mainstream at some point. This rendered many of the identified must-haves redundant (e.g. it is difficult to imagine a biometric technology that would be widely used despite inaccuracy in identification and verification). Another critical factor was the applicability of the qualitative parameters to the assessment of technological clusters rather than to the evaluation of specific implementations (products or systems) of the analysed technologies. The results are presented in Table 6. As a result, four parameters were selected for use in later stages of the project. The other factors remained a useful point of reference for assessing and cross-checking how the technologies meet the specified needs.

Table 6: *Example of identification of the specific (Level 2) needs, through qualitative parameters (must-haves) used in the Tech Foresight on Biometrics.*

Qualitative parameters ("must-haves")	**Quantitative equivalent available?**	**Suitable for assessment of Technological Clusters?** (as a reference in the Delphi Survey and for ranking cross-check; taking into account the "mainstream" requirement in the ETM assessment)
Technology demonstrated in operational environment (TRL≥7)		
High quality of biometric data achievable		
High accuracy in identification and verification	Y	
Low vulnerability to adversary attacks	Y	Y
Highly reliable		
Highly durable		
Significantly reduced traveller crossing time at BCPs		
Capable of contactless operation (short distance)	Y	
Capable of stand-off operation (medium-long distances)	Y	
Suitable for seamless border checks	Y	Y
Smooth human-machine interaction		

Qualitative parameters ("must-haves")	**Quantitative equivalent available?**	**Suitable for assessment of Technological Clusters?** (as a reference in the Delphi Survey and for ranking cross-check; taking into account the "mainstream" requirement in the ETM assessment)
Potential for improved border crossing experience for travellers		
Innovative (potential for carrying out border check functions through a novel approach)		
Highly scalable		
Simple operational implementation at BCPs		
Compatible with European Smart Borders requirements[42]		
Compatible with Entry/Exit System requirements[42]		
Potential to support virtual identity schemes (e.g. Digital Travel Credentials)		
Compatible with policies and measures taken in case of pandemics (e.g. use of personal protection devices such as face masks, social distancing, measures to reduce the risks of biological contamination, disinfection)		**Y**
Compliant with EU general legal requirements		**Y** **Compliant with EU regulations and values**
Compliant with EU requirements for fundamental rights protection		
Compliant with EU data protection regulations		
Compliant with EU ethical requirements		
Potential for political and public acceptance		
Cost-effective (competitive cost to acquire, operate and maintain the system)		
Limited additional infrastructure required		
Technological components available in the EU supply chain (e.g. no export restrictions, European suppliers available)		

6.7. Recommended supporting tools

Any spreadsheet (e.g. Microsoft Excel, Google Sheets, Apple Tables).

42 European Union, Regulation (EU) 2017/2226 of the European Parliament and of the Council of 30 November 2017 establishing an Entry/Exit System (EES), 2017.

7. Desk Research

7.1. The method, its purpose and objectives

Desk Research (or secondary research) is one of the primary methods of conducting a study and involves the use of existing data. The data is summarised and collated to increase the overall effectiveness of the research.

The method includes analyses of published research reports and similar documents. These materials can be found in public libraries, on websites, obtained from surveys, etc. Some government and non-government agencies also store data that can be used for research purposes.

One of the goals of *Desk Research* in TFP is to screen existing research areas and identify the main topics and technologies. The results serve as input for the *State-of-the-Art Review* step (see Section 2.1) and are especially important in the construction of the taxonomy: they help create a synoptic map of the potential of particular research areas and topics to find applications within the study's field of interest.

The *Desk Research* method is also used to identify stakeholders (see Section 2.3), consisting of groups and organisations with a potential interest in the outcome of the foresight study, and to select those who will be invited to participate in various stages of the TFP (the Group of Experts).

Desk Research also indirectly supports the *Capability Readiness Analysis* (see Section 5.1), where the list of stakeholders is used to study the existing capability landscape within the EU for each key technological cluster.

In the TFP the *Desk Research* method is used in:

- Phase 2, Step 1 – *State-of-the-Art Review*,
- Phase 2, Step 3 – *Identification of Stakeholders*,
- Phase 5, Step 1 – *Capability Readiness Analysis*.

7.2. Required input data

In general, except for the subject of the *Desk Research* and adequate searchable sources of information, no additional data is needed.

When used for the *Identification of Stakeholders*, *Desk Research* could also be supported by quantitative data based on the results of the *Patentometric and Bibliometric Analyses* (Chapter 8) when available.

7.3. Expected results

The expected output consists of:

- a list of the main research topics which encompass the relevant technologies. The research topics are grouped into categories which provide a framework for the categorisation and assessment of technologies throughout the foresight study;
- a list of stakeholders.

7.4. User of the method

The Research Team.

7.5. Modality of implementation

The Research Team populates the list of research areas and topics based on their knowledge and expertise, as well as by using keywords in automated searches.

7.6. Example of implementation

During the *Technology Foresight on Biometrics for the Future of Travel, Desk Research* was mainly conducted:

a) as part of the *State-of-the-Art Review* step (see Section 2.1);
b) for the *Identification of Stakeholders* (see Section 2.3).

In the *State-of-the-Art Review*, the aim of the *Desk Research* was to map key research areas and topics in the field of biometrics and to explore the potential applications of existing and emerging technologies in border security. The main sources of information at this stage of analysis included recent forward-looking studies in the field, official research agendas (EU or national government strategies), reports and strategies developed as a result of international research projects and documents provided by Frontex. The Research Team Experts used the template shown in Table 7 to map a wide range of research areas within the scope of the project.

Table 7: *Template for the identification of areas of research within the field of biometric technologies.*

Research Area or topic	Short description	Category	Estimated TRL (Technology Readiness Level)	Status	Potential applications in the context of border checks
[Name]		[Biometric technology] [Biometrics-enabling technology] [Application]	[TRL 1-2] [TRL 3-4] [TRL 5-7] [TRL 8-9]	[Emerging] [Existing]	

The proposed basic assessment aspects used by the experts to map key research areas and topics were:

- *Research Area or Topic:* the name of the research area or topic;
- *Short description:* brief description of the research area or topic;
- *Category*: biometric technologies, biometric-enabling technologies and applications were distinguished;
- *Estimated TRL:* TRL was estimated based on the definitions given by the European Commission;[43]
- *Status*: biometric technologies were classified based on the estimated TRL as "emerging" if TRL < 5 and "existing" if TRL ≥ 5;
- *Potential applications in the context of border checks*: for research areas in the category of biometric technologies and biometrics-enabling technologies, potential applications were listed, where possible. The scope of application and market segments was further divided into:[44] *Public Security*, *Other Public or Business Services* and *Consumer*.

Regarding the *Identification of Stakeholders,* a detailed description of the implementation of *Desk Research* within this step of the *Tech Foresight on Biometrics* can be found in Paragraph 2.3.4.

7.7. Recommended supporting tools

- *Domain Terminology Extractor* (see Chapter 19)
- Internet search engines

43 Detailed definitions of TRLs are contained in: h2020-wp1617-annex-ga_en.pdf.

44 G. Költzsch, "Biometrics - market segments and applications", Journal of Business Economics and Management, vol. 8, pp. 119-122, 2007.

8. Patentometric and Bibliometric Analyses

8.1. The method, its purpose and objectives

Patentometric and Bibliometric Analyses[45] refer to the application of:

- NLP methods and techniques to gather textual data from technical literature (patents and scientific publications);
- Statistical analyses of the data to extract useful information.

In general, *Patentometric and Bibliometric Analyses* may be used for several purposes, e.g. to:

- Obtain an overview of the technological landscape within a specific field;
- Perform priority searches to assess whether an invention might be patented;
- Perform *freedom to operate* (FTO) searches to assess whether a product may be commercialised or manufactured within a specific geographic region;
- Conduct a stakeholder analysis within a technological field;
- Conduct an analysis of competitors' R&D activities and strategies;
- Assess the possibility of applying *fencing*[46] strategies to competitors' intellectual property as well as to determine the risk of being fenced by competitors;
- Conduct a needs analysis for marketing or product development;
- Perform technical studies to support product design processes and enhance creativity.

In the case of the Technology Foresight, the main goal of using this method is to obtain an overview of the technological landscape within a specific field as part of the *Insight Hunt* phase. Particular emphasis is placed on studying the lifecycle of technological clusters and identifying early-stage technologies which may shape the future of the field.

The use of *Patentometric and Bibliometric Analyses* for studying the lifecycle of technological clusters is motivated by the fact that patents and scientific articles may be used and analysed to obtain an overview of how technological fields evolve over time. The evolution of a technology is a complex phenomenon, but as discovered over a century ago by G. Tarde,[47] the *logistic function*,[48] usually referred to as the *S-curve* (due to its shape), can be used to illustrate an innovation's lifecycle. The parameter usually studied by traditional economic models to describe technology evolution is the innovation's

45 The interested reader can find all relevant details about the Patentometric and Bibliometric Analyses in Annex III – Patentometric and Bibliometric Analyses of Biometric Technologies.

46 A patent fence is a series of patents issued with a view to block any innovators linked to an initial patent (usually a competitor) from further developing any innovation or applying for further follow-on patents around the initial one.

47 G. Tarde, "The laws of imitations", Henry Holt and Company, New York, 1903.

48 https://en.wikipedia.org/wiki/Logistic_function

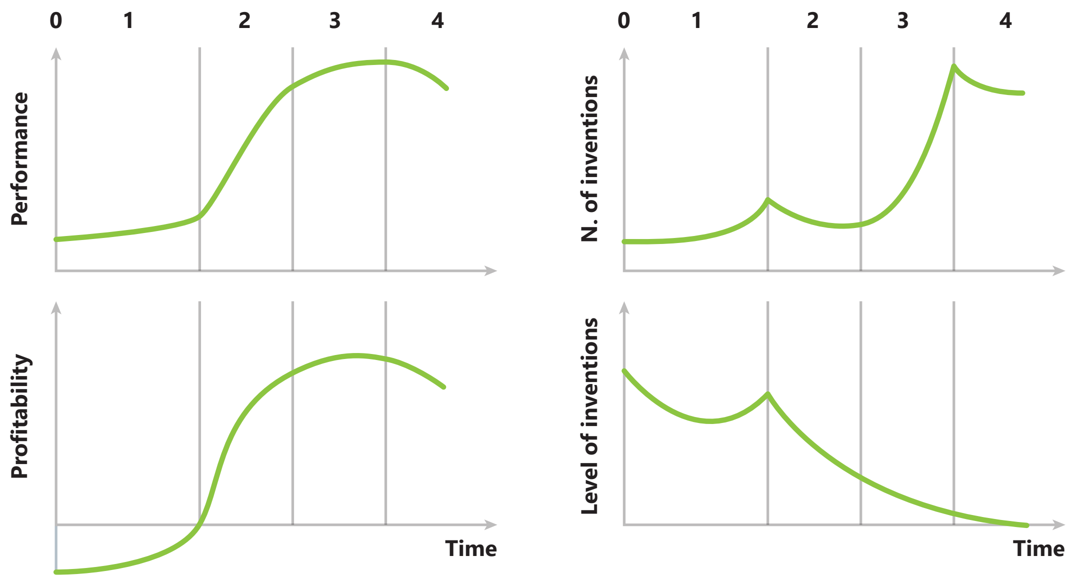
adoption (or diffusion) rate, defined by Rogers[49] as "*the relative speed with which an innovation is adopted by members of a social system*". The theory pioneered by Altshuller[50] focuses instead on performance as a technical counterpart to the economic variables. Following Altshuller's *Theory of Inventive Problem Solving* (TRIZ), Mann[51] coined four metrics that can be used to assess a product or technology lifecycle (Figure 18):

- **Performance** (upper left chart): the technical measure of how well a technology or product works;
- **Number of inventions** (upper right chart): probably the easiest metric to obtain data for, particularly thanks to the availability of online patent databases and effective search engines;
- **Level of inventions** (bottom right chart): the degree of changes compared to existing solutions produced by the inventions;
- **Profitability** (bottom left chart).

Mann also defined five stages in the typical lifecycle of a technology:

0. ***Birth***: when the new product is created via radical innovation;
1. ***Childhood***: the first cycle of incremental innovation, characterised by slow development due to a lack of profits;
2. ***Growth***: the stage when the benefits of the product are recognised, characterised by an increase of performance, profits, and R&D investments;
3. ***Maturity***: the stage denoted by high profitability but saturation in terms of opportunities for innovation and improvement;
4. ***Decline***: the stage when the limits of product evolution are achieved, profitability decreases and the technology is no longer necessary.

Figure 18: *Altshuller's 'lifelines' of technological systems, as formalised by Mann. The upper right graph shows how the temporal distribution of inventions (patents) may be used to describe a technology's lifecycle.*



49 E. M. Rogers, "Diffusion of Innovations", Free Press of Glencoe, New York, 1962.

50 G. S. Altshuller and A. Williams, "Creativity as an Exact Science", Gordon and Breach Science Publishers, New York, 1984.

51 D. Mann, "Using S-Curves and Trends of Evolution in R&D Strategy Planning", TRIZ Journal, 1999.

In accordance with this theory, the evolution of the number of yearly filed patent families over time may be a good indicator for assessing a technology's lifecycle (Figure 18, upper right graph).

Generally, the temporal distribution of the number of publications in scientific literature follows the same theoretical pattern and may be used for validation or integration purposes. It must be highlighted that scientific publications are far more difficult to retrieve than patents, and consequently it is typically challenging to obtain precise paper sets from the available search engines.

Other useful information may be retrieved from patents and papers to supplement the analysis of the technological landscape in a specific field, such as:

- Geographic distribution of inventive activity;
- Major assignees and inventors ranked based on the number of owned patents;
- Temporal distribution of inventive activity, per assignee;
- Major problems tackled within the technological field;
- Major authors ranked based on the number of published papers;
- Major publishers.

In TFP, the *Patentometric and Bibliometric Analyses* method is used in:

- Phase 2, Step 1 – *State-of-the-Art Review*
- Phase 2, Step 2 – *Clustering of Technologies*
- Phase 2, Step 3 – *Identification of Stakeholders*

8.2. Required input data

Patentometric and Bibliometric Analyses are performed on datasets composed of textual documentation (patents and scientific publications), which are the only required input. The results strongly depend on the quality of the datasets. Therefore, the databases from which the datasets are retrieved need to be evaluated with regard to accessibility as well as the quantity, quality and manageability of the obtainable datasets.

8.3. Expected results

The following results of *Patentometric and Bibliometric Analyses* may be expected for technological landscape analyses performed within Technology Foresight projects:[52]

- From patents:
  - Temporal distribution of inventive activity displayed by the production of patent literature, which is analysed to evaluate a technological field's lifecycle evolution;
  - A list of the most prolific patent assignees, which provides an overview of the most prominent inventors as regards the clusters and shows what share of inventive activity they account for;

52 The reader is referred to Annex III – Patentometric and Bibliometric Analyses of Biometric Technologies – Chapter 5 for more details.

    - Geographic distribution of inventive activity, which provides an overview of the primary locations of R&D activity and where patents are filed for commercial or manufacturing purposes.
- From scientific papers:
    - Temporal distribution of scientific publications, useful to supplement the information retrieved from patents to refine the assessment of technological lifecycles;
    - The most prolific authors are identified to obtain an overview of the researchers and affiliations most engaged in studies devoted to the clusters being analysed; their distribution in terms of the percentage of publication activity is also provided;
    - Geographic distribution of research and experimental activity, which provides an overview of where these activities are performed on the largest scale.

8.4. User of the method

Patentometric and Bibliometric Analyses must be executed by trained analysts, who are able to address all the potential issues that might arise in the process. At present, there is no fully automated tool or methodology capable of performing any of the necessary steps automatically.

8.5. Modality of implementation

The following is a sequence of steps generally applied to conduct *Patentometric and Bibliometric Analyses*. The described steps apply specifically to technological landscape analyses conducted within Technology Foresight studies:

1. *Obtaining preliminary knowledge and terminology within the field of interest*. This step strongly depends on the purpose of the study and the ontological features of the technical field. The lists of possible terms, synonyms, and ambiguities vary significantly from one sector to another.
2. *Designing an appropriate set of database search queries using the acquired knowledge and terminology*. Query syntax depends on the database to be used.
3. *Data gathering*. This is performed by querying the databases. Patent and scientific literature databases usually allow the extraction of metadata such as:
    - Year of filing/publication
    - Assignee/Affiliation
    - Inventor/Author
    - Technical classes (in the case of patents)
    - Country of filing/publication

   Usually databases also allow the extraction of textual data from the Title, Abstract, Description, and also Claims in the case of patents. These can be analysed with NLP tools to retrieve information. Data are usually provided in a tabular format, enabling easy management.
4. *Cleaning the dataset*. The first query, and therefore the first resulting dataset, is usually unsuitable. Not all documents within the obtained dataset discuss the topics of interest, and not all the relevant documents are initially collected. This is due to ontological ambiguities and the limitedness of the chosen terminology. Thus, multiple iterations must be conducted to obtain a “clean” result. Two

quality indicators are used for this purpose: *Precision* and *Recall* (see definitions in Paragraph 2.2.4).

5. *Performing statistical analyses*. Once a dataset is cleaned, statistical analyses of the results may be executed. Any statistical or data analysis tool can be used at this stage. The type of analysis depends on the objectives. For example:
   - The temporal distribution of inventive activity (number of filed patents) can be analysed to evaluate a technological field's evolution status (see Section 8.1).
   - The inventive activity of the major assignees can be extracted and analysed to get an overview of how their R&D activities evolved over time. The analysis helps to identify organisations that have ceased patenting within a specific technological field, as well as emerging, stable or fast-growing organisations.
   - The inventive activity of the most prolific inventors may be extracted and analysed, to get an overview of the collaboration networks between inventors and assignees. Collaboration networks between patent assignees may also be extracted.
   - The geographic distribution of inventive activity in a specific technological field may be analysed to get an overview of where R&D activities are primarily performed and where the greatest number of patents is filed for commercial or manufacturing purposes.
6. *Document classification*. This additional step may be required for technological landscape purposes. The obtained documents are clustered into multiple classes. A typical classification in technological landscape analyses is based on the International Patent Classification (IPC).[53] Patents are assigned to a set of IPC classes during the filing process to identify their technical areas and thus limit their range of applications. IPC classes may therefore be used to group documents into homogeneous classes, without the need to apply any advanced NLP or TM tools. Other types of classification, which rely on the documents' textual content, are also possible. In this case, NLP tools must be used to determine the semantic content of every document and to group similar documents. The number and types of classes depend on the subject of analysis.

8.6. Example of implementation

Patentometric and Bibliometric Analyses were performed in the *Insight Hunt* phase of the *Tech Foresight on Biometrics* once technological clusters were identified, as previously described in Section 2.2 of this document.

Figure 19 shows the workflow followed in conducting such analyses (Steps 9 to 12), which is the same as shown in Paragraph 2.2.4, where the first 8 steps were those relevant for the *Clustering of Technologies*. The reader is referred to Annex III – Patentometric and Bibliometric Analyses of Biometric Technologies – Section 4.1 and Chapter 5 respectively for a detailed description of each of the steps of the workflow, and for the outcomes of the analyses conducted on each of the 20 clusters.

53 The International Patent Classification (IPC), established by the Strasbourg Agreement 1971, provides a hierarchical classification of patents according to the areas of technology which they represent. The IPC contains about 70,000 groups. (https://www.wipo.int/classifications/ipc/en/)

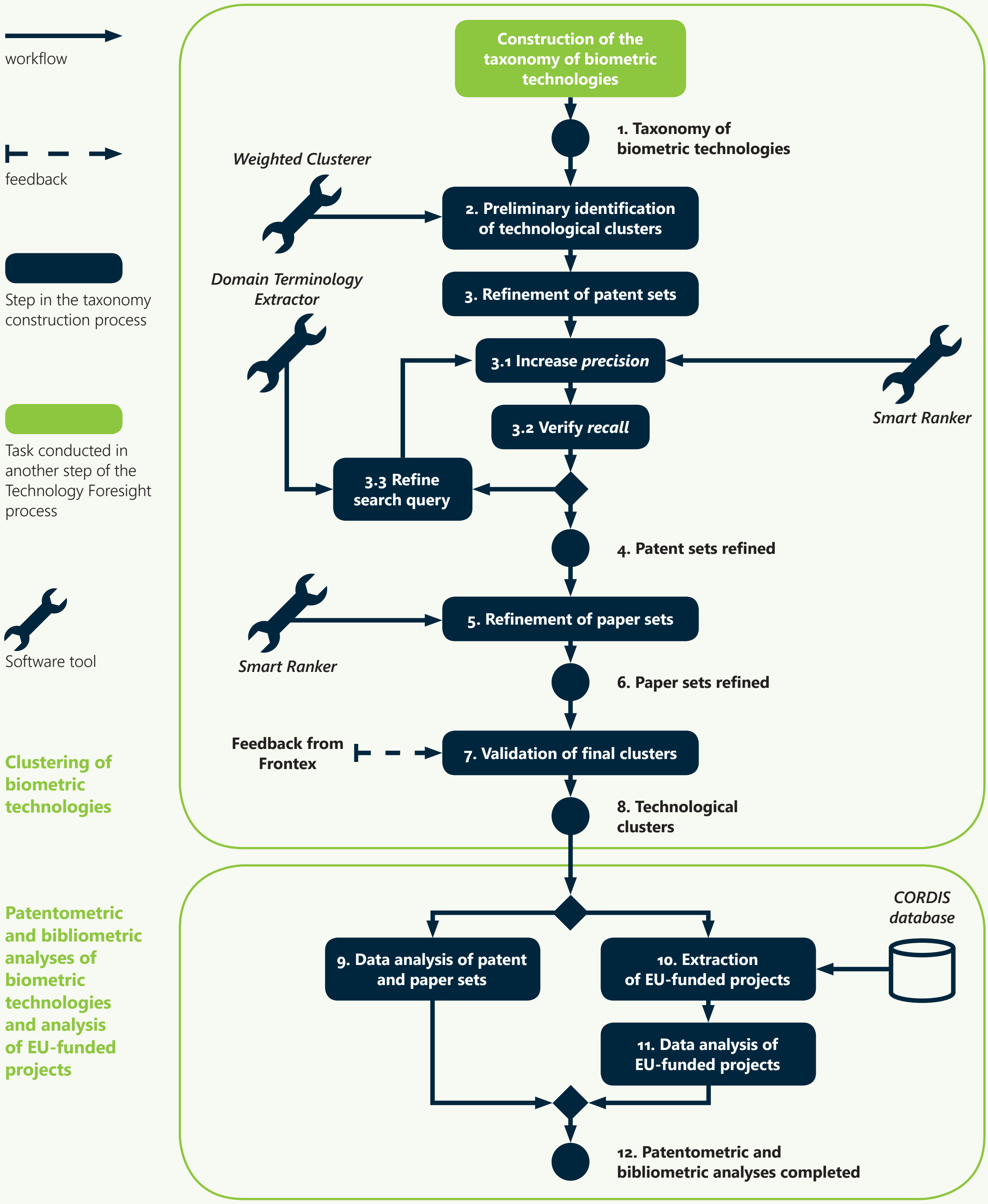


Figure 19: *Clustering and Patentometric and Bibliometric Analyses workflow.*

8.7. Recommended supporting tools

- *Domain Terminology Extractor* (see Chapter 19)
- *Smart Ranker* (see Chapter 20)
- *Weighted Clusterer* (see Chapter 21)

9. Delphi Survey

9.1. The method, its purpose and objectives

The *Delphi* method was originally developed in the 1950s and 1960s in the United States by the RAND Corporation to assess the impact of contemporary technologies on the military domain and to support decision-making.

It is now an essential tool widely used in strategic foresight and modern strategic management. It allows a group of participants to find a consensus quickly. The results of a *Delphi Survey* are relatively unaffected by psychological, rhetorical or sociological factors, which usually have a negative impact on group discussions.

Thus, it is hardly surprising that the *Delphi* method was initially used in classified US Air Force projects to reach a consensus among senior officers, academics, civil experts and decision-makers. Since then, it has proven its worth in thousands of civilian projects in areas such as education, technological development, spatial planning, conservation of natural resources or regional development planning.

For the purposes of the *Technology Foresight on Biometrics for the Future of Travel*, an enhanced version of the *Delphi* method was used to identify the most promising technological clusters: a *real-time Delphi Survey*. This is a significant time-saver, as it replaces traditional surveys where responses are collected and revised in a round-based system until a consensus is reached. The discussion in the online tool is uninterrupted, allowing a more in-depth analysis of the topic and resulting in an expert consensus on precise answers to the research questions (also known as the *Delphi Theses*). Participants in the *Delphi Survey* can access the survey as often as they wish to obtain information on the status of the discussion and current ratings. They can add new arguments and change previously stated opinions based on the indication of how much their opinion differs from the average answer of the group, which makes reaching a consensus easier. Real-time *Delphi Surveys* were well tested over the past decade in prestigious projects on hundreds of topics around the world.

In TFP *Delphi Survey* method is used in:
- Phase 3, Step 1 – *Filtering by Key Strategic Factors*

9.2. Required input data

A *Delphi Survey* requires the formulation of a set of Delphi Theses, which are to be assessed and discussed by the Group of Experts. The time horizon must also be established, along with indicators that will be used to assess the theses. In a classic *Delphi Survey*, theses usually begin with a statement such as "In the year X ….", and the indicators to be numerically assessed by the experts usually include *Probability* (that a thesis will come to fruition by the specified time horizon) and *Impact* (on reality or an analysed sector).

9.3. Expected results

Two types of output can be expected from a *Delphi Survey*:

- The first is a set of data formed by the ratings of the Delphi Theses. These assessments benefit from the design and the characteristics of this type of survey: they are the outcome of a collective intelligence decision-making process and are free from authority-based bias due to the anonymity of the survey.
- The second type of outcome is obtained if the respondents are given the chance to comment and justify their ratings during the discussion, which is typically possible in real-time *Delphi Survey*s. Such data provide a reasoning behind the results while also providing valuable input for an *Insight Hunt*.

9.4. User of the method

Although the overall design of the *Delphi Survey* is not overly complicated, it has a number of critical components that may have a crucial impact on the results of the entire exercise. Thus, *Delphi Survey*s should be carried out by experienced researchers. These critical elements include:

- Assembling a team of expert respondents (or "participants"), which should be as diverse as possible, although their familiarity with the topic is the main selecting factor. There is no restriction on the composition of the group, though it normally corresponds with the Group of Experts, which might in turn include Research Team Experts and Experts of the Recipient of the study.
- Preparing Delphi Theses and assessment indicators.

9.5. Modality of implementation

There are many approaches to conducting a *Delphi Survey*. It might only take a couple of days if it is executed "live", with participants sitting in different rooms of a conference facility, or it might take an entire year if answers are written down on paper and sent back by traditional mail. It all depends on the available resources and the scale of the project within which it is conducted. Therefore, there are a few factors to consider in the design of such a survey:

- *Time available for the entire project.* This will strongly influence any methodological choice. A real-time Delphi simplifies the setup and shortens the time needed in comparison with the round-based approach. However, a well organised offline study with in-person attendance can theoretically be completed within the space of a single day, though this would require extensive preparation and a concentrated effort by multiple people.
- *Ability to use an online Delphi platform.* An online platform tends to simplify *Delphi Surveys*. A traditional (round-based) Delphi can in theory be set up using any online survey tool, but such an approach is far more time-consuming than using dedicated platform. There are several traditional and real-time Delphi platforms to choose from, offered by various providers. They differ significantly in terms of quality, functionality, and pricing, so careful consideration of options is advised.

The process of designing a *Delphi Survey* should follow the guidelines presented below in consecutive steps:

1. *Designing the survey's structure*. There are three main parameters in the design of a *Delphi Survey*:
   - number of theses;
   - type and number of metrics used for assessing each thesis;
   - number of assessments for each thesis.

   A typical *Delphi Survey* involves 10-20 respondents who discuss 10-20 theses. It is often tempting to increase the number of theses, but it should be noted that the number of theses and the number of metrics used directly affects the number of assessments[54] that the respondents face. Ten theses with two metrics (e.g. Relative Advantage and Earliest Time to Mainstream) equates to 20 theses with only one metric. The more assessments the respondents will need to make, the greater the time and effort required to complete a survey. A large number of required assessments makes it challenging to gather in-depth answers from participants. They might find it challenging to stay motivated enough to carefully consider each of their own assessments, reflect on the assessments of other experts and write comments.

   The number and type of assessments required for each thesis may differ, and this is directly connected to the research questions that a *Delphi Survey* aims to answer. In the case of TFs, the most common research questions are: "How much potential does a specific technology have?" and "How fast can it be implemented in the given operational conditions?" The typical metrics used to answer these questions are Relative Advantage, Impact, Earliest Time to Arrival and Earliest Time to Mainstream.
2. *Formulation of the Delphi Theses.* Once the structure of the *Delphi Survey* is determined, the theses need to be formulated. This is one of the most challenging tasks in the survey design process. A good set of Delphi theses should encompass the entire topic of the study and include the most vulnerable assumptions and the most significant uncertainties. In the case of Technology Foresight, however, this step is fairly simple: respondents are asked to assess technologies or technological clusters identified during the *Insight Hunt* phase of the TFP.
3. *Assembling a participants team.* Respondents should represent varied backgrounds and stakeholder groups and constitute a diverse group. They should all possess at least a moderate degree of familiarity with the subject of the study. Another factor that should be considered when assembling respondent teams is that people who like to engage in a discussion will provide more material for further analysis than those who state their opinions categorically.
4. *Survey Set-up.* Depending on the time and resources available, it must be decided whether to adopt a *turn-based* or a *continuous (real-time)* strategy. In the first case, it is necessary to determine how many rounds the survey will consist of. Usually no more than three are conducted. In the case of a continuous survey, it is essential to choose an appropriate online tool.

54 The proposed name for a single assessment in a Delphi Survey is quandel (from delphic quantum).

5. *Survey Execution.* During the survey itself, special attention should be paid to participant feedback. The experts should know if and to what extent their ratings differ from the group average. In the case of a turn-based survey, new, extended forms need to be prepared for participants after each round. They should include the mean ratings, standard deviations and potential comments of other experts, preferably in a synthesised form. Respondents whose ratings differ significantly from the average should be notified and asked to reconsider their rating and/or to justify their opinion. In the case of a real-time survey, these functionalities must be integrated into the online tool. The organiser should continuously monitor the activity of respondents and animate the discussion if necessary.
6. *Collection of results and summary of the survey.* After the survey's completion, the average ratings obtained in the last round, information on dissenting opinions, and comments should be presented, preferably in a synthesised form.

9.6. Example of implementation

The process of designing the *Delphi Survey* for the *Technology Foresight on Biometrics for the Future of Travel* followed the six steps described above. The project outline specified that the survey would be conducted using an online tool during a continuous two-week period.

1. *Designing the survey's structure.* The number of technological clusters identified during the *Insight Hunt* phase was a decisive factor in determining the number of theses. All 20 clusters were to be assessed as to their benefits for the border check processes. It was therefore decided that all would be rated using typical TF metrics: Relative Advantage and Earliest Time to Mainstream. Thus, the survey started with 40 assessments.
2. *Formulation of the Delphi theses.* During the *Identification of Needs* step, it was decided that factors such as seamlessness, accuracy, security and compliance with EU policies and values should play an essential role in the analytical process. Thus, the wording of the theses had to highlight these factors so that the respondents would include them in their assessments. Each thesis was therefore formulated according to the following template:
   "*[Short description of the analysed technological cluster]. Please imagine a technological solution for border checks that utilises biometric technologies belonging to this Technological Cluster and would enable a seamless biometrics acquisition at border checks while also being highly accurate and secure, compatible with policies and measures typically taken in case of pandemics, and fully compliant with EU regulations and values*".
3. *Assembling a participants team.* A Group of Experts composed of 33 participants was selected. They represented various backgrounds and diverse areas of knowledge and experience within the field of biometric technologies and included representatives of external stakeholders, Frontex Representatives and Research Team Experts.

4. *Survey set-up*, **5.** *Survey execution*, **6.** *Collection of results and summary of the survey*. These steps were performed through the *4CF HalnyX* tool[55] (the online real-time *Delphi Survey* tool used for this exercise – see Figure 20).

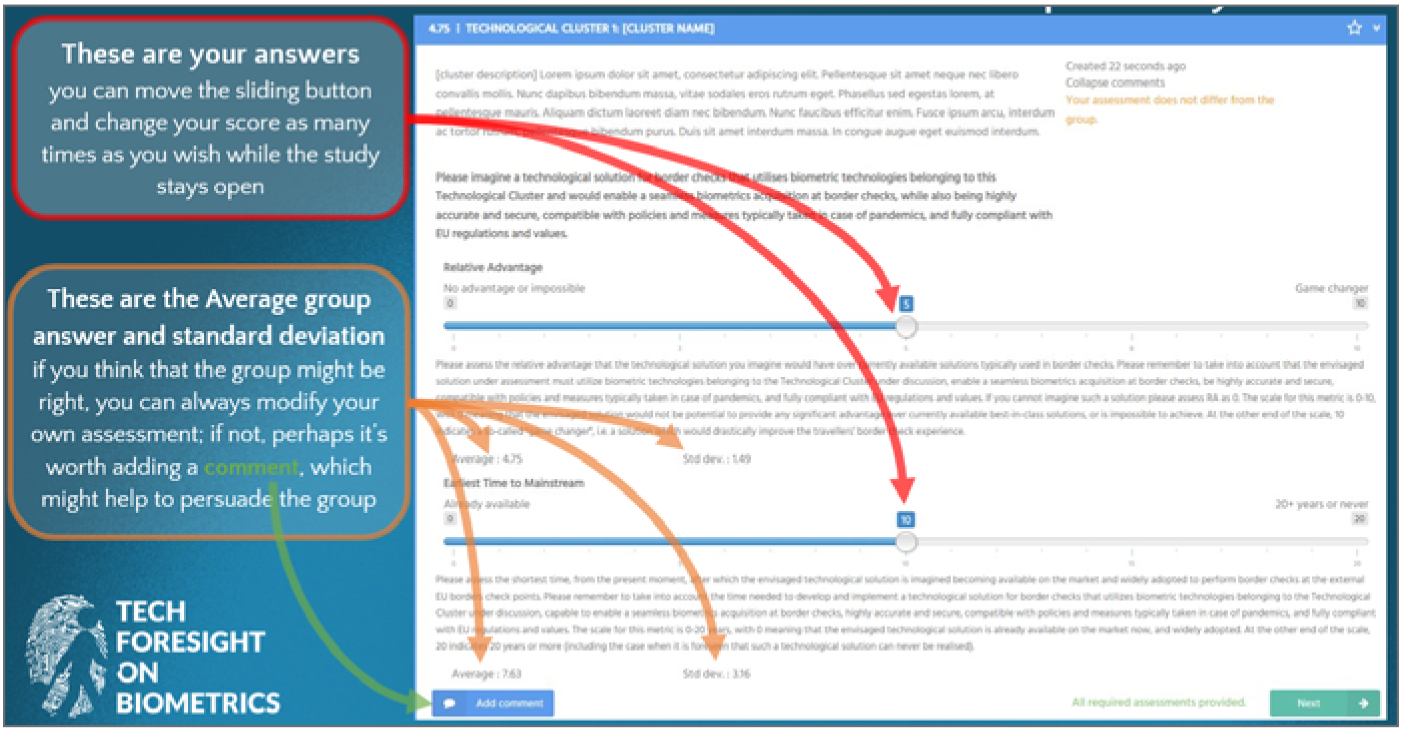
Further details about the tool used (*4CF HalnyX*) are provided in Chapter 17.

9.7. Recommended supporting tools

- *4CF HalnyX* (see Chapter 17)

55 The 4CF HalnyX is a proprietary tool of 4CF and can be accessed and used to set up a Delphi Survey only by the 4CF team. Access to surveys administered by the 4CF team is granted by 4CF.

Figure 20: *Screenshot from the Delphi Survey read-ahead materials, explaining the basics of using the 4CF HalnyX Delphi Platform.*



10. 4CF Matrix

10.1. The method, its purpose and objectives

The primary purpose of the *4CF Matrix* is result interpretation in any analysis where a number of solutions (e.g. technological clusters) are being assessed in terms of two different metrics. Once each solution has been rated, an XY graph is prepared, with the metrics presented on the two axes. The solutions are naturally grouped on the matrix, providing a clear visualisation of the results, which is a substantial aid for decision-making. The matrix serves as a filtering tool for choosing the most promising solutions and selecting proposals that should be analysed on a deeper level. The main objective of using the *4CF Matrix* in a TF is the selection of the most valuable technological solutions.

In TFP, the *4CF Matrix* method is used in:

- Phase 3, Step 1 – *Filtering by Key Strategic Factors*

10.2. Required input data

The *4CF Matrix* in its classic form is an XY graph, where the X-axis describes the *Earliest Time to Mainstream*, while the Y-axis shows the *Relative Advantage (*see Section 3.1). The matrix typically requires a set of 10 to 20 solutions that have already been assessed in terms of the two metrics: ETM and RA.

10.3. Expected results

The output of the *4CF Matrix* is the graph itself as well as further interpretations of the visual representation.

10.4. User of the method

In general, the development of the matrix itself is relatively simple. If RA and ETM values are assigned to the solutions, the matrix can be completed in a simple spreadsheet.

Assigning RA and ETM values requires expert knowledge of the topic under analysis, and thus it is usually performed by consulting the Group of Experts. Depending on the time available, different tools may also be utilised to collect the opinion of the experts, such as an expert survey, expert interview or a *Delphi Survey* (see Chapter 9).

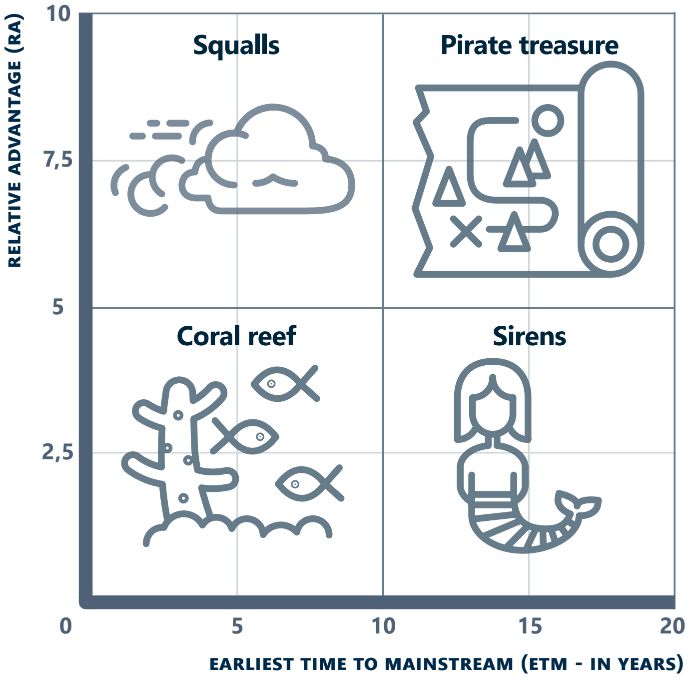
The basic interpretation of a *4CF Matrix* is also relatively simple. However, experienced foresight practitioners may propose deeper, surprising insights rather than a superficial understanding. Again, the time factor is crucial here. If time allows, the interpretation may take the form of a workshop, where a group of foresight practitioners and subject-matter experts try to envision how future events may change the placement of specific technological solutions on the matrix.

10.5. Modality of implementation

The following steps are required to produce a *4CF Matrix*:

1. Obtaining all insights identified in earlier phases of the TF process (e.g. technological clusters).
2. Assigning RA and ETM values to each of the insights. This step may be completed using a separate exercise (for example a *Delphi Survey*).
3. Plotting the matrix once all the insights have been assessed. This step can be performed on a simple sheet of paper or in a spreadsheet.
4. Examining the matrix and its quadrants, which indicate a classification of solutions (Figure 21):
    - *Squalls*: insights with a high relative advantage that may enter the mainstream in a relatively short time.
    - *Pirate treasure*: solutions with a high relative advantage whose implementation requires a significant time period.
    - *Coral reef*: highly attractive insights due to a low ETM, but with weak relative advantage.
    - *Sirens*: insights with a very high ETM which are highly risky and possibly require significant investments. This translates into a limited relative advantage that does not justify execution/implementation.

Figure 21: *Quadrants of the 4CF Matrix.*



The analysis of the matrix typically focuses on identifying surprising patterns in the placement of insights on the matrix and attempting to verify the assessments. The typical questions which arise during the analysis include:

- Are there groups of insights with similar RA and ETM?
- Why is this the case?
- Is there anything that could be done to shorten the ETM or improve the RA rating of a particular insight?

- Should the solutions in the "Coral reef" quadrant of the matrix be avoided, considering that more promising (i.e. higher-RA) alternatives were identified on the matrix?

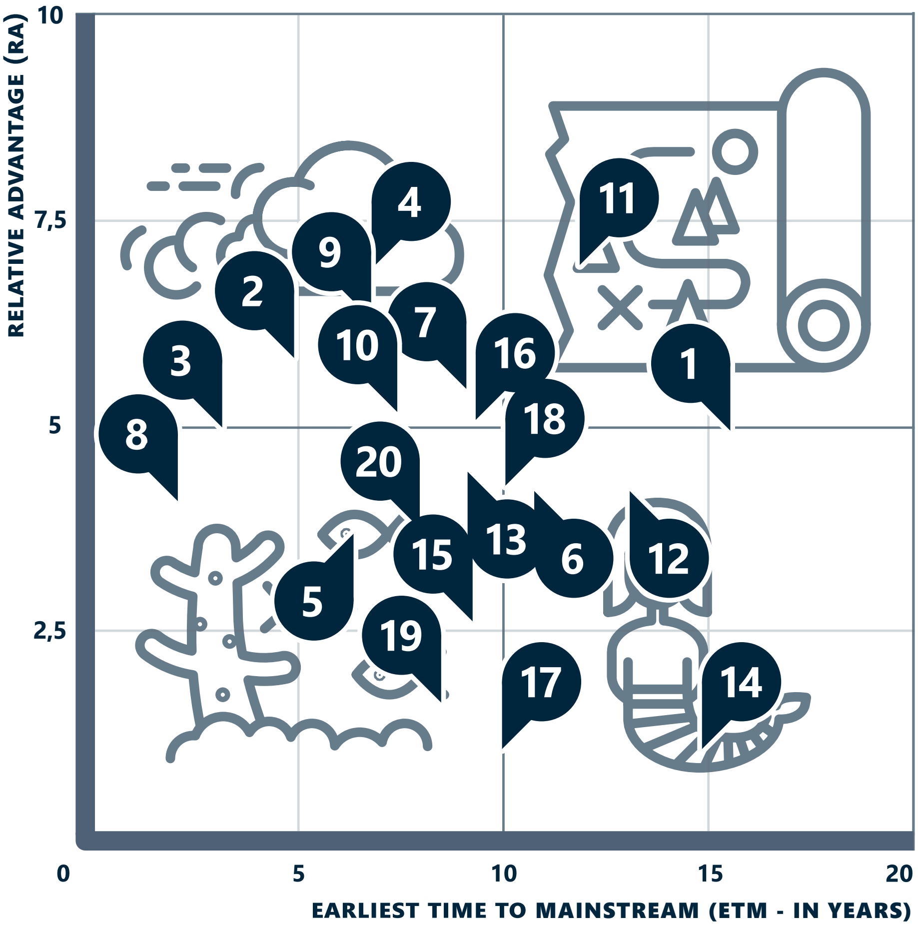
10.6. Example of implementation

In the *Technology Foresight on Biometrics for the Future of Travel*, the *4CF Matrix* was used during the *Filtering Results* phase (see Paragraph 3.1.4). The final matrix is presented in Figure 22.

An extensive discussion on the theory behind the *4CF Matrix* method and its use in the *Tech Foresight on Biometrics* can be found in the Research Study – Chapter 7.

Figure 22: *4CF Matrix presenting the outcomes of the Delphi Survey. Assessment of the 20 biometric technological clusters in terms of their Relative Advantage and Earliest Time to Mainstream.*

TC 1: DNA biometrics
TC 2: Infrared face recognition
TC 3: 2D face recognition in the visible spectrum
TC 4: 3D face recognition
TC 5: Infrared friction ridge recognition
TC 6: 3D friction ridge recognition
TC 7: Contactless friction ridge recognition
TC 8: Contact-based friction ridge recognition
TC 9: Iris recognition in the NIR spectrum
TC 10: Iris recognition in the visible spectrum
TC 11: Iris recognition at a distance
TC 12: Eye vein recognition
TC 13: Hand vein recognition
TC 14: Heart signal recognition
TC 15: Hand geometry recognition
TC 16: Periocular recognition
TC 17: Keystroke recognition
TC 18: Gait recognition
TC 19: Handwriting recognition
TC 20: Speaker recognition



10.7. Recommended supporting tools

- *4CF HalnyX* (see Chapter 17)

11. Rip Van Winkle Method

11.1. The method, its purpose and objectives

The *Rip Van Winkle* technique is a method developed at RAND to easily identify crucial and at the same time "vulnerable" assumptions about the future. The method is described by James A. Dewar[56] as a useful tool for planning and identifying the assumptions that underlie a plan. The main objective of this method is to generate a list of uncertainties presented in the form of "yes/no" questions.

In TFP, the *Rip Van Winkle* method is used in:

- Phase 2, Step 4 – *Building Scenarios for the Future*

11.2. Required input data

This method does not require much preparation or input data, but rather, as will be seen in the following sections of this chapter, a contribution by the Group of Experts who are knowledgeable about the topic. They should represent diverse areas of expertise and backgrounds so that a variety of insights can be gathered.

11.3. Expected results

The use of the method has twofold benefits. First, it identifies the vulnerable assumptions underlying a strategic plan or a vision of the future. Second, it makes the experts more aware of their own implicit and explicit assumptions about the future, which may be the same as their vulnerabilities.

11.4. User of the method

A *Rip Van Winkle* exercise should be prepared and coordinated by experienced facilitators who participate in the Technology Foresight project. They may represent Frontex or an external contractor.

11.5. Modality of implementation

A typical setup, as described by Dewar, uses a story and a task to be executed by the Group of Experts involved in the TF study, described in a way similar to the following:

56 J. A. Dewar, "Assumption-Based Planning: A Tool for Reducing Avoidable Surprises", Cambridge University Press, 2002.

"You have been asleep for the last 20 years. You know nothing about the world in which you awaken. Somewhat unfairly, you have been asked to guess your organisation's current operations. To be somewhat fairer, before answering, you can ask 10 questions about today's world. You are told that these questions must have "yes" or "no" answers and should not be contingent on the answers to other questions. What are your 10 yes/no questions?".

This task can be assigned to the Group of Experts either online or in a traditional workshop setting and can be executed either with the support of a facilitator or via an online survey. The questions that the experts formulate reveal certain aspects of the future which they are uncertain about. The number of questions the experts may ask is limited, forcing them to focus on the most important uncertainties that might influence the topic under discussion. The requirement for the questions to have yes/no answers encourages them to be specific.

11.6. Example of implementation

In the *Technology Foresight on Biometrics for the Future of Travel*, the *Rip Van Winkle* technique was used in the first part of the *First Technology Foresight Workshop on Scenario Building*, conducted online using the *Miro Board*. The main goal of the exercise was to make the participants aware of their implicit and explicit assumptions that could influence their answers during the remainder of the workshop. The Group of Experts participating in the workshop were divided into subgroups and moved to virtual breakout rooms. A facilitator was assigned to each group to explain the tasks at hand.

During the *Rip Van Winkle* exercise, each subgroup member was given five minutes to propose 3 to 5 "yes/no" questions about biometric technologies employed in border security in 2040. The description of the task provided to each subgroup of experts was: *"You have been asleep for almost 20 years. You wake up in 2040 and you ask 3-5 YES/NO questions about the transformation of the EU border check processes and the usage of biometric technologies. Please write down your questions. 1 sticky note = 1 question"*.

Participants wrote their questions, one by one, on separate virtual sticky notes, which were then placed on the virtual board (see Figure 23). Most of the questions were directly related to the future of biometric technologies in border security. There was also a handful of broader questions such as "Does EU still exist in a form known from 2021?" or "Do people still drive cars?"

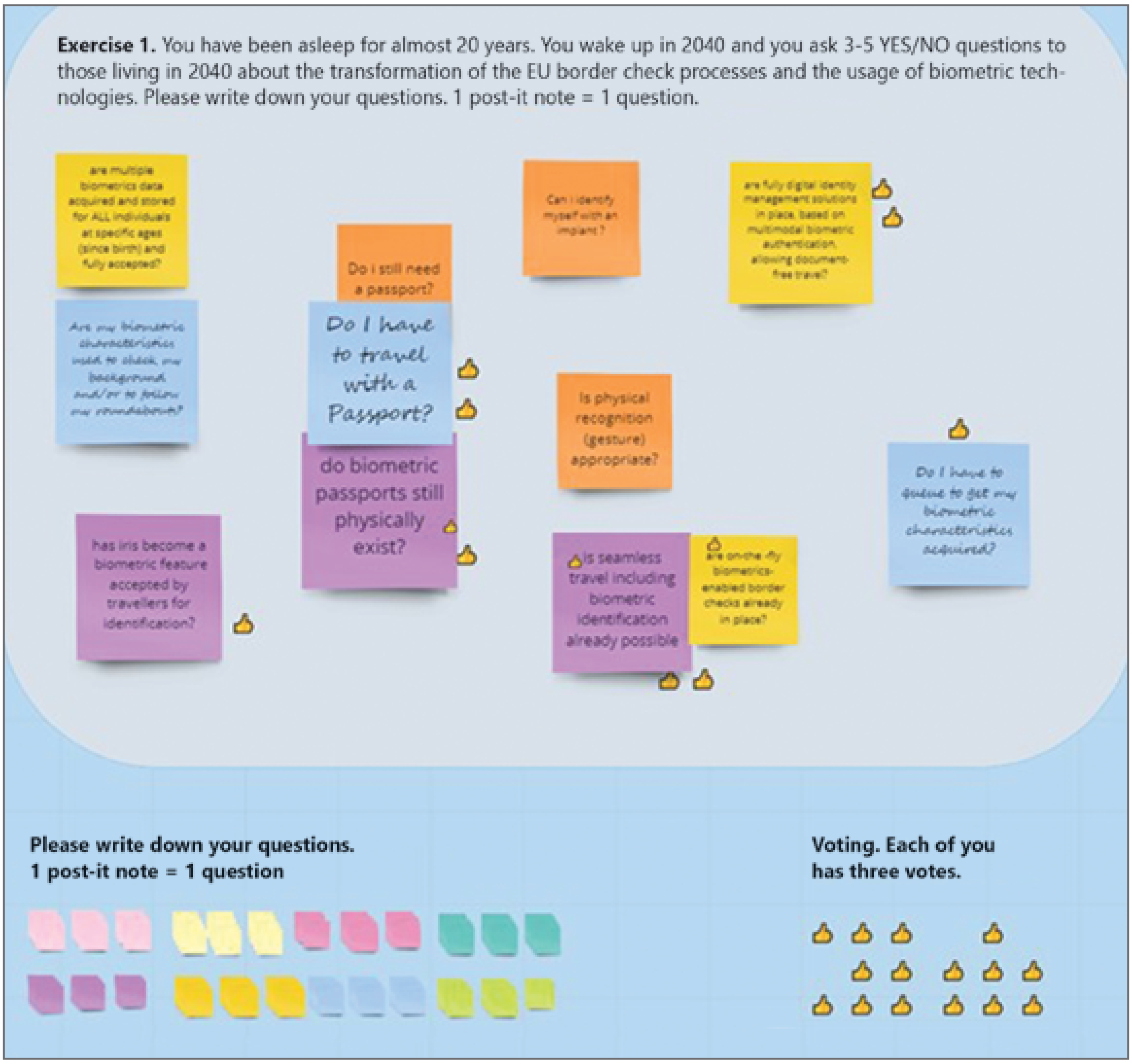
When all questions were written down, the participants were asked to pick the top three questions they would consider of key importance if they had to make a long-term strategic decision concerning border checks. Each person had three votes (virtual thumb-up icons). The vote led to the selection of the top three uncertainties in each subgroup, which were then used as a point of departure for the *Futures Wheel* exercise (see Chapter 12).

For a schematic sequence of the methods used during the *First Technology Foresight Workshop*, please refer to Paragraph 16.6.1.

11.7. Recommended supporting tools

- *Miro Board* (see Chapter 18)

Figure 23: *Example insights collected via the Rip Van Winkle method.*



12. Futures Wheel

12.1. The method, its purpose and objectives

The *Futures Wheel* is a participatory method that uses a structured brainstorming process to uncover multiple levels of consequences resulting from all types of key changes. It was originally proposed in 1972 by the futurist Jerome Glenn and has since been developed and applied in many fields and organisations (corporate, military, public and NGO).[57] Its primary purpose is to identify and analyse unforeseen consequences of emerging trends, technological innovations, new policies, and other types of key changes. The method can also be used in decision-making to choose between various options. The objective of this method is the creation of a graph in the form of concentric wheels, which illustrates the unfolding consequences of emerging changes.

In TFP, the *Futures Wheel* method is used in:

- Phase 2, Step 4 – *Building Scenarios for the Future*

12.2. Required input data

To begin an exercise based on the *Futures Wheel*, the key changes that will be analysed need to be identified either in advance or as a first step. Examples include an assumption about the future, a trend, a challenge, an event, a problem, a possible solution. The *Rip Van Winkle* method (described in Chapter 11) is recommended to identify the changes.

12.3. Expected results

By applying the *Futures Wheel* method, the Research Team aims to create an image of a new reality that might emerge if the key changes occur. Therefore, a *Futures Wheel* exercise is a complete, precise, visual picture of the possible direct and indirect consequences of the emergence of key changes. Depending on the number of key changes analysed, several futures could be created. The *Futures Wheel* method is typically applied in the *Insight Hunt* phase – *Building Scenarios for the Future* step of the TFP. The results typically consist of a list of potential actions that could mitigate negative consequences (e.g. by means of technology) and a choice of measures that would allow full benefits to be derived from positive consequences.

12.4. User of the method

The *Futures Wheel* is a relatively simple method, which can easily be performed by anyone. If possible, however, the involvement of an experienced facilitator is recommended.

57 D.N. Bengston, "The Futures Wheel: A Method for Exploring the Implications of Social–Ecological Change", Society & Natural Resources, vol. 29, pp. 374–379, 2015.

A diverse Group of Experts who are knowledgeable about the technological topic under discussion is also needed. Ideally, they should represent various areas of expertise and backgrounds to ensure a highly effective collective intelligence process.

12.5. Modality of implementation

The *Futures Wheel* method consists of a series of tasks executed by the Group of Experts involved in the TF study, either online or in a traditional workshop setting, with the support of a facilitator.

The sequence of tasks below is typically executed by the facilitators and/or the participating Group of Experts when the *Futures Wheel* method is implemented:

1. *Identify the changes* (facilitators): The facilitators write the key changes in the circle at the centre of the *Futures Wheel*. Use a paper, a flipchart, or a virtual brainstorming tool (e.g. the *Miro Board*).
2. *Identify direct, first-order consequences* (Group of Experts): the Group of Experts brainstorm on possible direct consequences of those changes. They have to write each consequence in a circle and connect it to the relevant key change with an arrow; alternatively, they may write it on a sticky note and place it in the inner circle of the *Futures Wheel*.
3. *Identify indirect, second-order consequences* (Group of Experts): the Group of Experts brainstorm on all the possible second-order consequences of each of the first-order direct consequences that they wrote down in Point 2. They add them to the *Futures Wheel* in the same way as before (in the outer circle).
4. (optional) (Group of Experts): Repeat Point 3 if it is necessary to identify third-order consequences, fourth-order consequences and so on.
5. *Analyse implications* (facilitators and Group of Experts): once all the levels of the *Futures Wheel* are complete, participants discuss all the possible direct and indirect consequences of the changes.
6. *Identify actions (optional)* (Group of Experts): the Group of Experts brainstorm on the possible actions that would allow management of negative consequences and suggest measures that would allow the benefits of positive consequences to be enjoyed.

12.6. Example of implementation

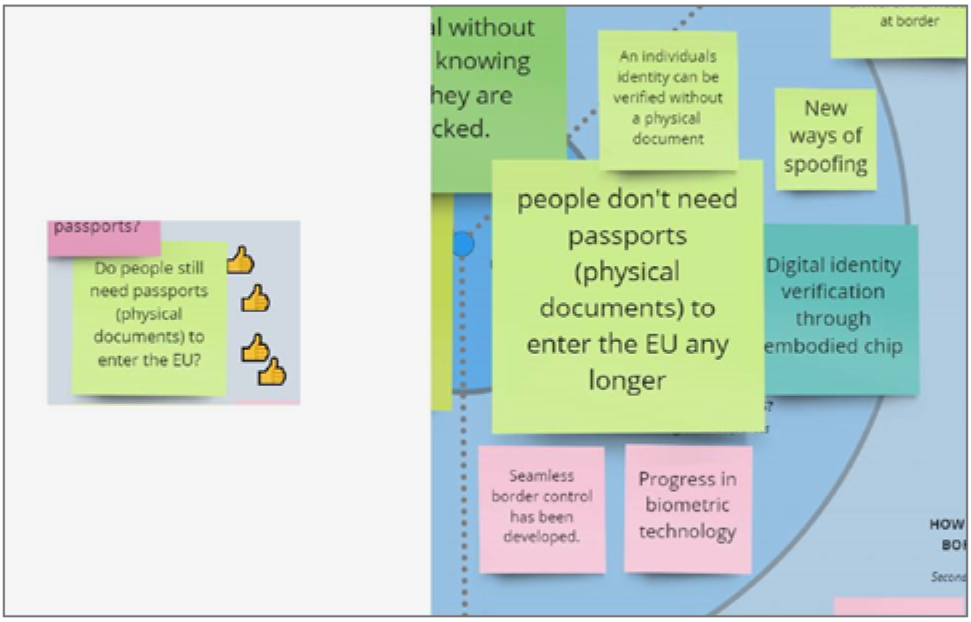
In the *Technology Foresight on Biometrics for the Future of Travel*, the *Futures Wheel* method was applied, with the support of the Group of Experts, during the first part of the *First Technology Foresight Workshop on Scenario Building*, which was conducted online using the *Miro Board*. The main goals of the exercise were to:

1. Identify (through the *Rip Van Winkle* method) the three most relevant key changes in the reality of the border check processes;
2. List the possible direct and indirect consequences of such changes (through the *Futures Wheel*);
3. Capture the possible futures of border check processes based on the three key changes identified by the participants in Step 1 and the possible consequences listed in Step 2.

The Group of Experts was divided into virtual breakout rooms. In each room, a facilitator was present to explain the tasks. This exercise took 30-40 minutes.

The first step of the exercise, identification of the three key changes, was conducted using the *Rip Van Winkle* method (see Chapter 11). The result was a list of the vulnerable uncertainties in the form of "yes/no" questions about the state of border checks in 2040. Then participants were asked to select the most important uncertainties by popular vote. Once the top three uncertainties were chosen, the participants were asked to rephrase them into affirmative sentences and to decide (by joint agreement) on an answer to the "yes/no" question and thus to produce statements indicating key changes compared to the current state of affairs (see the example in Figure 24).

Figure 24: *An example of transforming one of the voted uncertainties into an affirmative statement that differs from the current state of affairs.*



Subsequently, each participant proposed first- and second-order consequences of the statements for the border check process. The proposals were written on sticky notes and posted onto the *Futures Wheel* canvas created on the *Miro Board*. The *Futures Wheel* canvas was divided into three sectors (one for each of the three key questions) and participants used each sector for adding sticky notes describing the first- and second-order consequences. First-order consequences were placed in the inner circle, while second-order consequences were put in the outer ring of the *Futures Wheel*.

The results of the *Futures Wheel* exercise (Figure 25) were then used by the Group of Experts to brainstorm the technological innovations in the field of biometrics that could emerge to address at least one of the consequences described in the *Futures Wheel*.

For a schematic sequence of the methods used during the *First Technology Foresight Workshop*, please refer to Paragraph 16.6.1.

12.7. Recommended supporting tools

- *Miro Board* (see Chapter 18)

Figure 25: *An example of a final result obtained through the Futures Wheel exercise.*

13. Forecasting/Backcasting

13.1. The method, its purpose and objectives

Forecasting and *Backcasting*[58, 59] are similar processes that aim to create a cause-and-effect sequence of events and thus to describe a chronological path from the present to a selected time in the future. Forecasting is carried out in accordance with the normal progression of time, usually starting from the present day. The analysts strive to answer the question "How present events will shape the reality of a specified point in the future?", in other words: "What will be the result of today's state of affairs in the specified future period of time?" Once an answer is obtained, the process is iterated for a more distant point in time. Forecasting is usually performed for a 20-30-year horizon with iteration periods of approximately five years.

While forecasting assumes a forward-thinking strategy, backcasting goes back in time. The starting point of an analysis is an assumed future reality, i.e. a description of a future world from one of the future scenarios. As in forecasting, the time horizon is about 20-30 years. Treating the description of a distant future reality as a point of departure, the analyst's objective is to answer the question "What must have occurred for such a reality to exist?", in other words: "What was the cause of this future state of events?" As in forecasting, the analysed intervals cover a span of about five years, and each time period is analysed separately. The backcasting exercise is slightly more complex since the analyst needs to deduce a logical course of events to connect two often drastically different realities – the present and future.

The purpose of both methods is to broaden the analysis of a present or future reality by extending its timeframe. The objective is to deduce a logical course of events that unfolds over several decades. Forecasting is used when a TFP requires the creation of a new scenario for the future. Backcasting is useful when a TFP requires adapting existing future scenarios (e.g. products of other foresight projects and analyses) to a new (more recent) timeframe. For example, a backcasting exercise can be performed on a set of four scenarios that describe a 2050 reality to create scenarios suitable for a project with a 2030 horizon.

In TFP, the *Forecasting/Backcasting* method is used in:

- Phase 2, Step 4 – *Building Scenarios for the Future*
- Phase 4, Step 1 – *Modelling the Roadmaps*

58 A. Hines, J. Schutte, M. Romero, "Transition Scenarios via Backcasting", Journal of Futures Studies, vol. 24, no. 1, pp. 1–14, 2019.

59 United Nations Development Programme (UNDP) Global Centre for Public Service Excellence, "Foresight Manual. Empowered Futures for the 2030 Agenda", Singapore, January 2018.

13.2. Required input data

A forecasting exercise requires specified time constraints (time horizon and time intervals) and a starting point in time that precedes the time constraints (usually the present).

Instead, at least one future scenario (in the form of a snapshot of the future) and a specified timeframe (time horizon and time intervals) that precede the time of the scenario are the prerequisites for a successful backcasting exercise.

13.3. Expected results

The outcome of a *Forecasting/Backcasting* exercise is a sequence of cause-and-effect events describing the development of reality from the present to a specified future point in time.

13.4. User of the method

Forecasting/Backcasting should be carried out by a group composed of at least one foresight practitioner and at least one subject-matter expert, typically belonging to the Group of Experts involved in the TF study. The role of the foresight practitioner is to facilitate and guide the process by posing questions, while the role of the expert(s) is to seek answers based on their knowledge.

13.5. Modality of implementation

The following sequence of steps are required to perform a forecasting exercise:

1. Selection of a specific future point in time.
2. Choice of the length of time periods to be used within the exercise. The periods should evenly divide the time between the specified future date and the present.
3. Drawing the timeline. It may be helpful, though not essential, to draw a timeline with specific dates. This is a good visual aid to facilitate cause-and-effect thinking. The timeline can be used to record snapshots of reality at a given time, e.g. in the form of sticky notes attached to the timeline.
4. Forecasting. The first forecasting iteration is carried out to answer "What will be the result of today's state of affairs after the first time interval?"
5. Step 4 is repeated for each time interval until the specified time horizon is reached.

The following steps are required to perform a backcasting exercise:

1. Selection of a snapshot scenario describing a specific future point in time.
2. Choice of the length of time periods to be used within the exercise. The periods should evenly divide the time between the specified future date and the present.
3. Drawing the timeline. It may be helpful, though not essential, to draw a timeline with specific dates. This is a good visual aid to facilitate thinking in terms of cause and effect. The timeline can be used to record snapshots of reality at a given time, e.g. in the form of sticky notes attached to the timeline.

4. Backcasting. The first iteration is carried out to answer "What had to happen in the period from the year X to the year Y for the world described in the scenario (at time Y) to come into existence?"
5. Step 4 is repeated for each time interval until the specified time horizon is reached.

13.6. Example of implementation

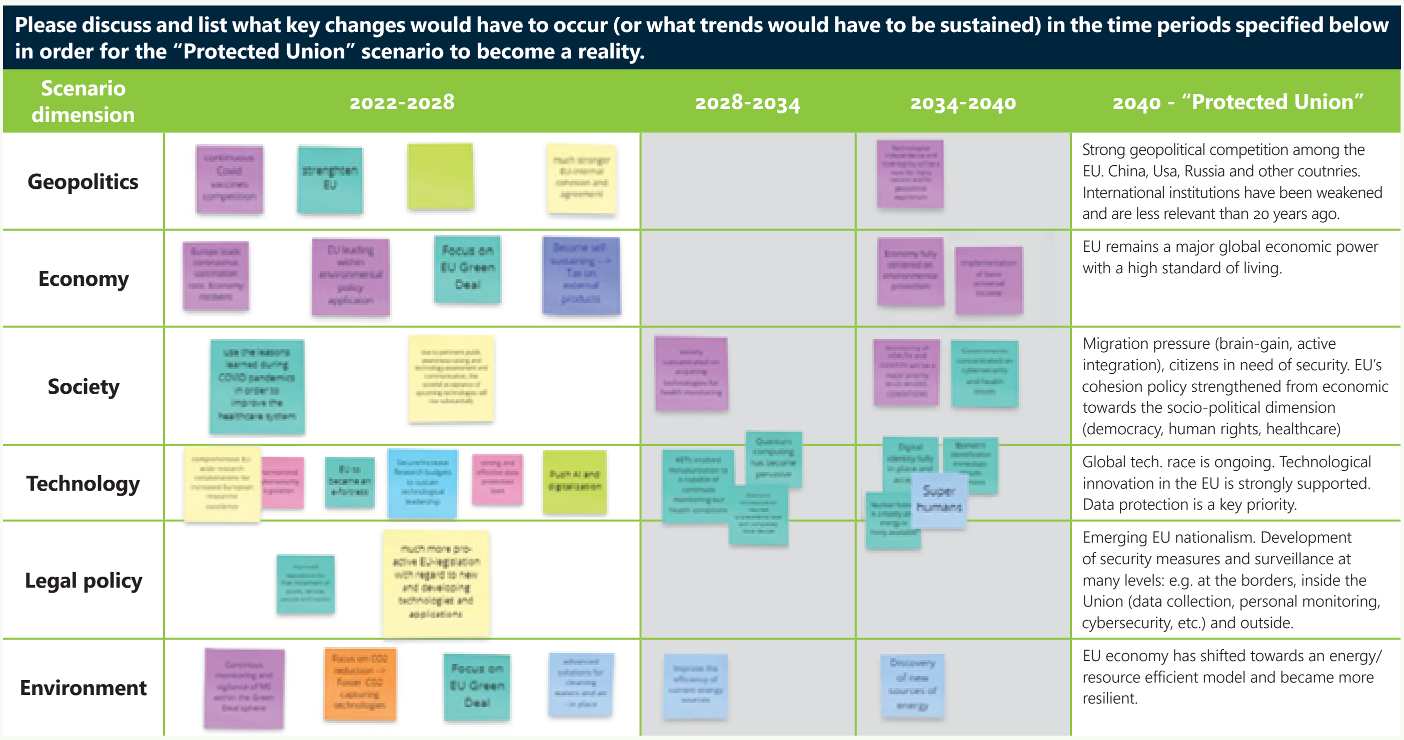
The exercise was carried out during the *First Technology Foresight Workshop on Scenario Building* to prepare (customise) the previously selected general scenarios of the future in 2040 for roadmapping and capability mapping, which require continuous descriptions of the future developing along the timeline up to the desired time horizon. Since the general baseline scenarios selected for the exercise were all set in 2040, only the *Backcasting* method was used to create continuous timeframes. The *Miro Board* was used as an aid in conducting the exercise. An example outcome of the backcasting exercise indicating insights on the hypothetical sequence of cause-and-effect events from the present to 2040 is shown in Figure 26.

For a schematic sequence of the methods used during the *First Technology Foresight Workshop*, please refer to Paragraph 16.6.1.

13.7. Recommended supporting tools

- *Miro Board* (see Chapter 18)

Figure 26: *Example use of the Backcasting method to collect insights regarding geopolitical, economic, societal, technological, legal and environmental trends and events occurring in the 2022-2040 time frame.*



14. Scenario Analysis

14.1. The method, its purpose and objectives

Scenario Analysis is one of the most widely used methods in strategic foresight. It aims to gain insights into how alternative futures, called scenarios, might influence the subject of analysis. *Scenario Analysis* usually serves two primary purposes:

- **a)** to stress-test the subject of analysis, typically consisting in strategies, insights, and solutions, to check whether ideas are *future-proof*. To do this effectively, users of the method must become very familiar with the scenarios and be able to relate them to the issue under analysis. It is important that they consider not only the direct impact of the events described on the subject of analysis but also the phenomena/actions that would be the consequences of such events.
- **b)** to *reframe* the users of the method, to make them aware of the boundaries and assumptions they have about the current and future reality, which may influence their ideas and actions. Reframing often leads to higher awareness for decision-making.

For the *Scenario Analysis* method to be most effective, the scenarios should ideally be plausible yet challenging. They should aim to challenge not only the current state of affairs but also how the future of a given topic is usually imagined or considered probable, while at the same time remaining believable enough to be seriously considered for strategic purposes.

In TFP, the *Scenario Analysis* method is used in:

- Phase 3, Step 3 – *Filtering by Compliance with Future Scenarios*
- Phase 4, Step 1 – *Modelling the Roadmaps*
- Phase 5, Step 1 – *Capability Readiness Analysis*

14.2. Required input data

The input needed for conducting a *Scenario Analysis* consists of:

1. *A set of future scenarios*. These might be the outcome of an earlier process within the TF project, or they may be obtained from external sources. The scenarios should be plausible, challenging (for the participants and/or the topic), and useful for the recipient of the study and their intended purpose.
2. *The subject to be analysed*. For the sake of brevity this is simply indicated as "solution" in the following parts of this chapter. However, this can take different forms depending on the topic of interest and can range from entities, through strategic documents, to specific technologies, products, or practices. Regardless of the choice, the common element is that each of these subjects must then be put under the stress conditions of all the scenarios to identify previously unknown or disregarded strengths and weaknesses, as well as related opportunities and threats.

14.3. Expected results

A *Scenario Analysis* results in knowledge about the solution being analysed, typically categorised into strengths, weaknesses, opportunities and threats (SWOT).

14.4. User of the method

Scenario Analysis does not necessarily require a facilitator. Participants, typically the Research Team Experts, the Experts of the Recipient or the Group of Experts involved in the TF study, may conduct the analysis on their own if they have appropriate experience. Otherwise, professional facilitation might be needed.

14.5. Modality of implementation

Once input data is collected, *Scenario Analysis* is conducted as follows:

1. The performance of each solution under analysis is tested in each of the prepared scenarios by answering questions, such as:
    - Is it possible to use this solution in the scenario (e.g. due to legal conditions or the state of technological development)?
    - Are there any obstacles in the scenario that might make the solution ineffective even though it's usable?
    - Are there any circumstances described in the scenario that would favour the solution (e.g. a scenario might favour environmentally friendly solutions)?
    - Does the solution address the biggest challenges in the scenario?
    - It is also possible to use a scale to assess how well a solution fits into each scenario, either in a numerical form (e.g. -5 for a solution that does not fit into the described reality, +5 for the opposite situation) or in a qualitative +/- form (+ for fitting in the scenario, - for the opposite).
2. Once the entire set of solutions has been evaluated, it is possible to identify those most resistant to the different versions of the future. It must be noted, however, that these are not necessarily the "best" solutions to pursue: *Scenario Analysis* uncovers previously undetected weak spots and opportunities, which once properly addressed may improve the solution's chances of success. Therefore, poor performance in many scenarios may be a warning sign that further research and/or development is needed to address the identified issues.

14.6. Example of implementation

Desk Research conducted within the *Technology Foresight on Biometrics for the Future of Travel* revealed a lack of EU development scenarios on the future of travel, border checks and biometric technologies. Therefore, considering the expected output of the TFP, a set of already-available general EU scenarios for the year 2040 were customised during the *First Technology Foresight Workshop on Scenario Building* (see Section 2.4).

Once the general scenarios were adapted to the need and topic of the research study, the *Scenario Analysis* method was used:

a) in Phase 3, Step 3 – *Filtering by Compliance with Future Scenarios*. Since two previous filtering steps (Step 1 and Step 2 of Phase 3) resulted in a shortlist of five key technological clusters, no additional filtering was needed, but technological clusters were analysed anyway in relation to the specific scenarios to provide a more thorough picture of their compatibility with the conditions described in the scenarios.

b) in Phase 4, Step 1 – *Modelling the Roadmaps*, during the *Second Technology Foresight Workshop on Roadmapping* (see Paragraph 16.6.2). More specifically, in this case, the role of *Scenario Analysis* in the TFP process was to stress-test the baseline (under BAU conditions) technology roadmaps illustrating the projected development of the five key biometric technological clusters identified through the *Filtering Results* phase. Plausible yet challenging scenarios provided realities that differed from the current state of affairs. Thus, they offered an opportunity to deepen and broaden the knowledge about the future of each technological cluster by pinpointing key turning points, challenges and opportunities inherent to their development in diverse future scenarios.

c) in Phase 5, Step 1 – *Capability Readiness Analysis*, the expected future capability readiness for the key technological clusters was assessed by evaluating the degree to which the cluster-specific needs, identified during the *Second Technology Foresight Workshop*, will be met under the four customised scenarios.

For details on the process of selection and adaptation of scenarios see Section 2.4 and the Research Study – Chapter 5; the outcomes of the performed *Scenario Analyses* are detailed in the Research Study – Chapters 6, 8 and 9.

14.7. Recommended supporting tools

- *Miro Board* (see Chapter 18)

15. Weighted Criteria Matrix

15.1. The method, its purpose and objectives

The *Mapping Capabilities* phase is an element of Technology Foresight that aims to identify capabilities relevant to the selected technological clusters. They are defined and assessed in relation to the objectives (including the target state for the clusters and the time when this state will be reached) and capability needs. This step highlights capability gaps and opportunities that can serve as a basis for the recipient's strategic planning with regard to individual technological clusters. Within a 7-step approach (see details in Paragraph 5.1.4), capability gaps and opportunities are prioritised based on a specific recipient's requirements. Thus, an in-depth foundation for strategic planning is provided. The *Weighted Criteria Matrix* method is recommended for the prioritisation of the identified capability gaps and opportunities.

In TFP, the *Weighted Criteria Matrix* method is used in:

- Phase 5, Step 1 – *Capability Readiness Analysis*

15.2. Required input data

The capability-related needs identified in the *Mapping Capabilities* phase serve as input for this method. Further input includes the requirements for the strategic development of technological clusters as defined by the recipient of the TF study. These serve as criteria for the analysis.

15.3. Expected results

As a result of the exercise, a prioritised list of capability-related needs is produced for each category (research, institutional, industrial). The results provide valuable input for the strategic development of the selected technological clusters. Considering the specific needs of the recipient of the study, they outline the key capability gaps and opportunities which should be primarily addressed by the recipient itself.

15.4. User of the method

Obtaining input for this method requires the participation of the Research Team and the Group of Experts involved in the TF study. They should represent diverse areas of expertise (e.g. technology, operations, industry, ethics, fundamental rights and social acceptance) and thus offer a wide range of perspectives on the capabilities being analysed.

The exercise itself can be performed by the Experts of the Recipient of the study by applying the described method.

15.5. Modality of implementation

First of all, a list of criteria that reflect the recipient's crucial requirements must be created, along with the *weight* value (e.g. a number 1 to 5, the latter representing the highest importance) assigned to each criterion. In addition, all the capability-related needs relevant to a technological cluster are assigned a score (e.g. a number 1 to 5, the latter representing the highest relevance) in the context of each criterion. The total score for each capability-related need can then be calculated by summing the values obtained by multiplying the weight of each criterion by the rating of that capability-related need in the context of that criterion. The highest values highlight the capability-related needs that should be prioritised within capability development. Alternatively, a pairwise comparison table can be used.

15.6. Example of implementation

An example of a *Weighted Criteria Matrix* is shown in Table 8.

Table 8: *Example of a Weighted Criteria Matrix.*

		Research				Industrial				Institutional			
Frontex requirements (criteria)	**Weight of criteria**	**Res1**	**Res2**	**Res3**	**…**	**Ind1**	**Ind2**	**Ind3**	**…**	**Inst1**	**Inst2**	**Inst3**	**…**
Criterion 1	1	5	3	4		3	3	4		5	2	5	
Criterion 2	4	3	5	3		1	2	2		2	4	3	
Criterion 3	5	4	5	4		4	5	1		5	4	5	
Criterion 4	2	5	1	4		1	5	5		2	1	1	
Criterion 5	4	1	4	1		1	4	4		5	3	3	
Sum		18	18	16		10	19	16		19	14	17	
Weighted Sum		51	66	48		33	62	43		62	52	56	

15.7. Recommended supporting tools

- Any spreadsheet (e.g. Microsoft Excel, Google Sheets or Apple Tables) can be used to implement the *Weighted Criteria Matrix*.

16. Workshops

16.1. The method, its purpose and objectives

Technology Foresight Workshop is an umbrella term for many tools and methods, albeit with one common characteristic: *Workshops* are highly collaborative and creative processes that use the collective intelligence of a number of experts.

In TFP, the *Workshop* method is used in:

- Phase 2, Step 4 – *Building Scenarios for the Future*
- Phase 3, Step 3 – *Filtering by Compliance with Future Scenarios*
- Phase 4, Step 1 – *Modelling the Roadmaps*
- Phase 5, Step 1 – *Capability Readiness Analysis*

16.2. Required input data

This is highly dependent on the topic and aims of the workshop. The required input data can range from virtually none (in the case of highly creative brainstorming workshops), to highly detailed and elaborate information provided to participants before (read-ahead packages) or during a workshop.

16.3. Expected results

Dependent on the topic and aims of the workshop.

16.4. User of the method

Workshops should ideally be prepared and facilitated by experienced foresight practitioners, either from the recipient of the TF study or an ad-hoc Research Team.

16.5. Modality of implementation

In the proposed TFP, at least two workshops should be planned involving the Group of Experts, and some members of the Research Team covering the role of moderators. If the workshops are conducted online (by videoconference), the *Miro Board* (or an equivalent tool) should be used as a virtual working environment.

The first workshop's primary goal is to prepare the Group of Experts to work efficiently with the future, to make them aware of their assumptions about it, biases, as well as a multitude of different futures available to use in TFP. The first workshop should always take place before the *Delphi Survey* (part of the *Filtering Results* phase), so the Group of Experts may perform it with a better understanding of how different futures may impact their assessment of the insights they are analysing.

The second workshop should take place during the *Deep Analysis* and the *Mapping Capabilities* phases. Its primary goal is to use the collective intelligence of the Group of Experts to broaden the understanding of the outcomes of the *Filtering Results* phase.

Depending on the topic, the needs, and specific secondary goals of the workshops, their design may vary, as well as the tools and methods used.

In the next chapter the specific design used in the *Technology Foresight on Biometrics for the Future of Travel* is described in detail.

16.6. Example of implementation

16.6.1. First Technology Foresight Workshop

The *First Technology Foresight Workshop on Scenario Building* was dedicated to eliciting experts' insights regarding the future of technologies:

- First, experts shared their visions of the future. They also developed and discussed their assumptions about the future of the topic in question. The *Rip Van Winkle* and the *Futures Wheel* techniques (both described in previous chapters) were employed at this stage;
- Second, experts were asked to customise a set of scenarios that were pre-selected for the purposes of the project (as described in Section 2.4);
- Finally, a backcasting exercise was conducted. Its purpose was to deduce the details of cause-and-effect chains of events that might lead to the different scenarios.

The *First Technology Foresight Workshop*, which took place on 13-14 April 2021, is a good example of a workshop approach within the framework of the *Technology Foresight on Biometrics for the Future of Travel*. Almost 40 participants, including the Group of Experts and the Research Team (as facilitators), participated in this virtual event. After an opening speech by the Head of the Frontex Research and Innovation Unit, the participants were divided into eight groups. The Workshop was conducted by a team of eight facilitators (one per group), coordinated by a master facilitator, all from the Research Team. The workshop was held online (experts participated via Zoom), and the Miro virtual whiteboard was utilised during the interactive sessions. Templates for each exercise were prepared on Miro by the Research Team before the workshop.

The following Workshop Agenda was proposed**:**

- Day 1 (13.04.2021 10:00-15:00 CET)
  - 10:00-10:05 Welcome by Frontex Research and Innovation Unit
  - 10:05-10:15 Workshop objectives and methodology
  - 10:15-12:00 Future of biometrics: visions, assumptions and trends
  - 12:00-13:00 Lunch break
  - 13:00-15:00 Customisation of scenarios
    - Impact of scenarios on travellers' experience
    - Impact of scenarios on border checks
- Day 2 (14.04.2021 10:00-15:00 CET)
  - 10:00-12:00 Customisation of scenarios
    - Impact of scenarios on border checks – cont.
    - Backcasting

- 12:00-13:00 Lunch break
- 13:00-14:00 Backcasting – cont.
- 14:00-15:00 Report-back & open discussion

The following series of exercises was conducted in sequence:

1. Check-in: warm-up exercise
The workshop began with a so-called *Check-in*. This is a warm-up exercise that encourages individual contributions and stimulates the cooperative behaviours of participants. Such introductory exercises contribute to establishing a collaborative atmosphere that encourages in-depth thinking. They provide a good foundation for sharing personal insights with other participants as the workshop unfolds.

In this particular exercise, the participants were asked to provide a one-word description of how they felt about the future. The results showed that perceptions differed significantly. This simple exercise revealed a wide spectrum of statements of the Experts' hopes and fears, suggesting a variety of assumptions on how events may unfold. The last step was a discussion of these assumptions, which introduced participants to the discipline of Futures Studies.

2. Rip Van Winkle exercise: search for uncertainties
The participants were given five minutes to individually propose 3 to 5 "yes/no" questions about the 2040 reality regarding biometric technologies in border security. The participants wrote their questions in turns, on separate virtual sticky notes and put them on a virtual board. Then, the participants voted for the most important questions. The vote revealed the top three uncertainties in each group. The results were used as a starting point for the next exercise.

Details about the *Rip Van Winkle* method are provided in Chapter 11.

3. Futures Wheel: exercise on deriving consequences
The *Futures Wheel* exercise was designed to encourage a "consequence-driven" approach to thinking about the future.

For each of the top three uncertainties obtained in the previous exercise, participants were asked to select a 2040 outcome which would be different from the current (2021) state of affairs.

Once the three outcomes were selected, participants were asked to propose as many direct (first-degree) consequences of each outcome as they could think of and to write them on sticky notes. Once all the participants had contributed, the process was repeated to derive second-degree consequences (a first-degree consequence became the starting point).

Details about the *Futures Wheel* methodology are provided in Chapter 12.

4. Technological insights

During the workshop, the participants were also asked to propose technologies that would be applicable in the three 2040 realities envisaged during the *Futures Wheel* exercise. The results of this part were used as an additional cross-check of the *Insight Hunt* results.

5. Customising scenarios and backcasting

The main aim of the workshop was to expand and adjust a set of pre-selected general scenarios to the realm of biometrics, border checks and the experience of travellers crossing a border. The preparation step for this exercise was conducted using the *Rip Van Winkle* and *Futures Wheel* methods (see Points 2 & 3), which gave participants the broad context for further customisation. Additionally, workshop participants were asked to envision steps, measures and conditions which could affect biometrics and the future of travel in the 2021-2040 timeframe. The *Backcasting* method was used for this stage of analysis. Thus, users provided crucial contextual information for the roadmapping of technological clusters, which was to take place during the *Second Technology Foresight Workshop*.

Each general EU development scenario was analysed simultaneously by two separate groups of experts. Once both groups had completed the exercise, they discussed each other's ideas and developed a consensus.

The scenario customisation was then conducted in two stages:

- First, participants were asked to imagine how the needs of border checks changed in 2040 in a particular scenario from the four different perspectives of travellers, the EBCG community, carriers and other entities. They were also asked to consider the consequences of those changes on border control;
- The next stage was based on PESTLE categories. The participants were asked to provide as many details describing each of the PESTLE categories as they could. The list of individual proposals was subsequently developed and expanded during a group discussion facilitated by moderators. The details provided by the experts described how the scenarios would change the border check experience by 2040. The proposals were written on sticky notes and pinned to the *Miro Board*.

Based on the four customised scenarios for the future of border checks, the original eight groups of participants were merged into four and asked to perform a backcasting exercise (see Section 2.4 and Chapter 13). Each group was asked to create a timeline for their scenario by deducing the 2034-2040 chain of events for each of the PESTLE categories. The results of the previous exercise served as the initial input. Once all the events were documented on the *Miro Board*, the process was repeated two more times, for the 2028-2033 and 2021-2027 intervals. The aim of the exercise was to reveal potentially disruptive events, as well as opportunities and threats that could have led to the outcome of each scenario.

The output of the *First Technology Foresight Workshop*, consisting in the customised scenarios, was used in the *Second Technology Foresight Workshop*, devoted primarily to roadmapping and, to a lesser extent, to capability mapping.

Details of the scenario customisation approach and outputs have also been described in Section 2.4.

6. Report-back

The workshop ended with a report-back session, where representatives of each group shared the results of their work.

16.6.2. Second Technology Foresight Workshop

The *Second Technology Foresight Workshop on Roadmapping* focused on the scenarios developed during the first workshop and the key clusters of technological solutions selected during the preceding *Delphi Survey*. Roadmapping provided insights regarding the expected turning points in the development of the clusters. It also produced estimates of the technology's potential effectiveness in operational implementation and of its market availability. Once completed, roadmaps were stress-tested using the customised scenarios by considering how each scenario would affect the developments envisaged in the roadmaps.

This second workshop took place on 10-11 June 2021. Almost 30 participants took part in this online event, including the Group of Experts and the Research Team (as facilitators), as in the first workshop. After an opening speech by a representative of the Frontex Research and Innovation Unit and an introduction by a master facilitator from the Research Team, participants were divided into five sub-groups.[60] The workshop was conducted by a team of five facilitators (1 per group), coordinated by a master facilitator. The event was held as a videoconference. The Miro virtual whiteboard was used for interactive sessions, and the same tool was also used to prepare templates for each exercise.

Workshop agenda:

- Day 1 (10.06.2021 10:00-15:00 CET)
  - 10:00-10:05 Welcome by Frontex Research and Innovation Unit
  - 10:05-10:15 Workshop objectives and methodology
  - 10:15-11:30 Modelling the roadmap for each key biometric technological cluster
  - 11:30-12:00 Report-back
  - 12:00-13:00 Lunch break
  - 13:00-15:00 Group brainwriting: Contributing ideas and insights to each technology roadmap in iterative manner
- Day 2 (11.06.2021 10:00-15:00 CET)
  - 10:00-12:00 Confronting envisioned technological developments with alternative scenarios
  - 12:00-13:00 Lunch break
  - 13:00-14:00 Confronting envisioned technological developments with alternative scenarios – cont.
  - 14:00-14:45 Report-back & open discussion
  - 14:45-15:00 Closing remarks by Frontex Research and Innovation Unit

60 The number of the groups was decided based on the number of participants and the number of technological clusters.

The following exercises were conducted:

1. Modelling baseline roadmaps for each key technological cluster

The first day was devoted to modelling the development of key biometric technological clusters in three timeframes (2022-2027, 2028-2033, 2034-2040) and four layers: future application areas, evolving functions, future products and systems, and capability-related needs.

Each of the five groups of participants developed a roadmap for one of the clusters selected in the earlier stages of the project:

- A: Contactless friction ridge recognition
- B: 3D face recognition
- C: 2D infrared face recognition
- D: Iris recognition in the NIR spectrum
- E: Iris recognition in the visible spectrum

First, group members discussed the evolution of their cluster by sharing ideas about the general vision of the cluster and its role in the border check process in 2040. Participants were asked the following supporting questions:

- Current application areas will no longer play a major role: which ones, if any?
- New application areas will appear (also beyond the border check processes): which ones, if any?
- A key functionality which is now under development will be attained: which one, if any?
- New systems and products using this technology will be created: what will they be, if any?
- What crucial capabilities may contribute to achieving this vision? Will there be any capability-related needs that should still be addressed?

Secondly, participants discussed and agreed upon the state of their cluster's development in 2021 and continued to envision developments in the three timeframes for the four layers of the roadmap:

- **Layer 1, ideation of application areas.** Example application areas within the border-check process were provided as supporting materials on the *Miro Board*. Participants were also asked to add potential applications beyond border checks, out of the scope of the *Tech Foresight on Biometrics*, such as surveillance and commercial services (e.g. public, business, and consumer services).
- **Layer 2, ideation of functions.** Brainstorming regarding the developments within this layer was initiated by a question about the possible new functions achievable using cluster. The answers also sparked a discussion about possible new products (Layer 3) based on these new technological functions and potential new application areas (Layer 1) which would appear for the new products.
- **Layer 3, ideation of products.** To stimulate a discussion regarding this layer, participants were provided with the taxonomy of biometrics-enabled technological systems as supporting material on the *Miro Board*.

- **Layer 4, capability-related needs.**[61] Participants were asked about the needs for the development of their cluster. As a guideline, pre-defined capability categories were displayed on the *Miro Board* in the supporting materials sections. They included industrial, research and institutional capabilities. At least one capability-related need for each of the three categories had to be indicated by each group.

The roadmap was filled out in the course of a discussion moderated by a facilitator. Depending on each group's dynamic, participants were free to either populate all layers simultaneously or complete them one by one.

Finally, the participants shared their ideas regarding possible connections between layers. In some cases, depending on the dynamic of specific groups, connections between the application areas, functions, products, and capability needs could have already been discussed and marked on the roadmap in the previous step.

The result of this exercise was a set of baseline roadmaps meant to be understood as roadmaps without *Scenario Analysis*.

2. Group brainwriting: Contributing ideas and insights to each technology roadmap in an iterative manner

After a report-back, the groups returned to contributing ideas and insights to each of the four remaining technology roadmaps in an iterative manner. They spent 25 minutes discussing the roadmaps developed by other groups before going back to their own roadmap. Four iterations of feedback took place, during which participants commented, posed questions or challenges regarding specific elements of the roadmap, proposed connections between the ideas, envisioned timeframes etc. They were asked to add new ideas (elements) to each layer (e.g. missing applications, functions, products, and needs). They were also invited to share ideas about potential links to the tech cluster that their group was originally working on.

All comments were added with the use of a commenting function rather than by adding sticky notes to the original roadmap. Thus, replies to the comments could be posted in the same thread (which made it easier to follow all the contributions after each iteration of the exercise).

After four iterations took place, each group analysed their "enriched" baseline roadmap, discussed the comments and additions, and decided on the final content of the roadmap.

3. Confronting the envisioned technological developments with alternative scenarios

The second day of the workshop was devoted to stress-testing the enriched baseline roadmaps of key technological clusters in the context of the four scenarios customised during the *First Technology Foresight Workshop*.

At the beginning, the participants got acquainted with the processed results of the *First Technology Foresight Workshop:* the four customised scenarios of the future of travel,

61 Additional to general roadmap design presented in Paragraph 4.1.4.

border checks and biometric technologies in 2040. Next, a brainstorming session was conducted to discuss how each scenario would affect the evolution (roadmap) of a technological cluster. The participants discussed the potential threats and opportunities that would likely appear as a result of specific scenario conditions and brainstormed on how these threats and opportunities would affect the development of each tech cluster. The participants were also asked to consider the possible impact of the scenarios on the timeframes of specific developments (in each roadmap layer). Changes in the timelines included delays or advances in the introduction of specific applications, functions and products due to more/less favourable conditions than those envisioned in the baseline technology roadmap.

Finally, the roadmap analysis assessed the readiness of capabilities within the 4 scenarios. The participants offered their opinions on whether a specific capability-related need (identified during the first day of the workshop) would be met fully, partly or unmet. This part of the workshop was conducted with the aid of a voting function on the Miro platform.

All the suggested changes were clearly distinguished from the original roadmap input. The original elements of the baseline roadmap were retained while participants added further comments next to them. Participants were also asked to indicate critical opportunities and threats resulting from each scenario by placing star or skull icons on the roadmap.

4. Report-back
During the report-back session in the second day of the workshop, participants presented the results of their group work by describing the baseline technology roadmap they developed and the changes that would occur in the context of the four scenarios.

The detailed description of the outcomes of the second workshop can be found in the Research Study – Chapters 8 and 9.

16.7. Recommended supporting tools

- *Miro Board* (Chapter 18)

Part 3 – Technology Foresight Tools

This manual describes the IT tools used during the *Technology Foresight on Biometrics for the Future of Travel*. Brief instructions on their interfaces, setup and operation are also included.

17. 4CF HalnyX

17.1. Brief description of the tool and its features

4CF HalnyX is an online real-time platform for conducting *Delphi Surveys* (see Chapter 9) that provides the Research Team with the advantage of accessing collective intelligence whilst displaying a solid discussion structure, which does not allow for the omission of any crucial information. Thus, the platform is suitable for multiple purposes, including:

- Strategic foresight and scenario-building activities,
- Engagement of stakeholders in the process of strategic decision-making,
- Consultations with individual and institutional stakeholders in spatial or infrastructural planning,
- Broad evaluation of possible policy options,
- Identification and assessment of developing trends,
- Formulation of forecasts of the impact of technology on strategic positioning,
- Social participation (e.g. consultations with local stakeholders),
- Review of legislative drafts and other normative documents using analytical tools for the assessment and reporting of results.

4CF HalnyX is a fourth-generation Delphi platform. The first-generation Delphi, developed in the 1960s, was updated in the 1990s with the introduction of the first online *Delphi Surveys* (second generation). The third generation introduced real-time Delphis, which did not need to be organised into consecutive rounds. The current (fourth) generation focuses on streamlining the survey and minimising information overload by using new capabilities of application design, such as dynamic forms. The goals include facilitating the identification of new and relevant information, improving the discussion structure, and many more.

Key features:

- Up to three levels of assessable subsequent comments for in-depth argumentation and discussion of answers
- Scalability for broad participation and open-access studies
- Dynamic forms for many different types of questions, comments, and evaluations
- Built-in refined comparability of dispersion between different assessment scales
- Geotagging function for incorporated assessment of geographic locations

- Function for automatically generating research questions based on the respondents' comments
- Two levels of administration for flawless moderation
- Adjustable prefixes and suffixes of comments for improved clarity of discussion
- Possibility of adding new questions to a study in progress

17.2. Property rights and accessibility

The *4CF HalnyX* is a proprietary tool of 4CF and can be accessed and used for developing a *Delphi Survey* only by the 4CF team. Access to surveys administrated by the 4CF team is granted by 4CF.

17.3. Application in the Technology Foresight Process

4CF HalnyX is used for conducting online real-time *Delphi Surveys*, to which the Group of Experts involved in the TF study was called to participate. Using an online platform is a more cost-effective and time-efficient approach than the traditional "pen & paper" method. A real-time Delphi system further facilitates the setup and improves time efficiency by eliminating the need for separate "rounds" during the survey. In TFP, the *4CF HalnyX* is used in the *Filtering Results* phase (see Chapter 3).

17.4. User interface, setup, and operation

The *4CF HalnyX* platform is intuitive and easy to navigate for its users. The entire survey is displayed to the participating Group of Experts on a single, dynamic web page, where the following key elements are clearly visible (see Figure 27):

1. Survey's title bar.
2. *Delphi Thesis*: each Delphi thesis is presented by means of a cascading set of text boxes, each headed with a blue title bar. The text boxes contain:
    - **a)** a description of the Delphi thesis;
    - **b)** the metrics to be assessed by the Group of Experts, comprised of a short description of the metric and a slider for numerical assessment;
    - **c)** a "Next" button that acts both as a "Save" button for saving changes in the external expert's assessment and as a navigation tool that transfers the external expert to the next point of interest;
    - **d)** additional information such as the difference between the average assessment and the expert's assessment, a current average value (within the expert group) of the first metric to be assessed (3), and the values of the metrics previously assessed by the external expert.
3. *Text box* with information concerning the survey: days remaining until the end of the survey, number of questions unanswered by the expert, number of comments unrated by the expert, number of comments added by the expert.
4. *Logotype box:* a placeholder for logotypes.
5. *Comment text box:* each external expert may write a comment to explain the reasoning behind their assessment. Three levels of nested comments are available, and each comment can be evaluated (by a thumbs up/down icon, although other metrics are also available).

6. The experts can add a comment or Delphi thesis to their favourites by clicking the star icon. Additionally, they can edit or delete their comments.

17.5. Alternative solutions

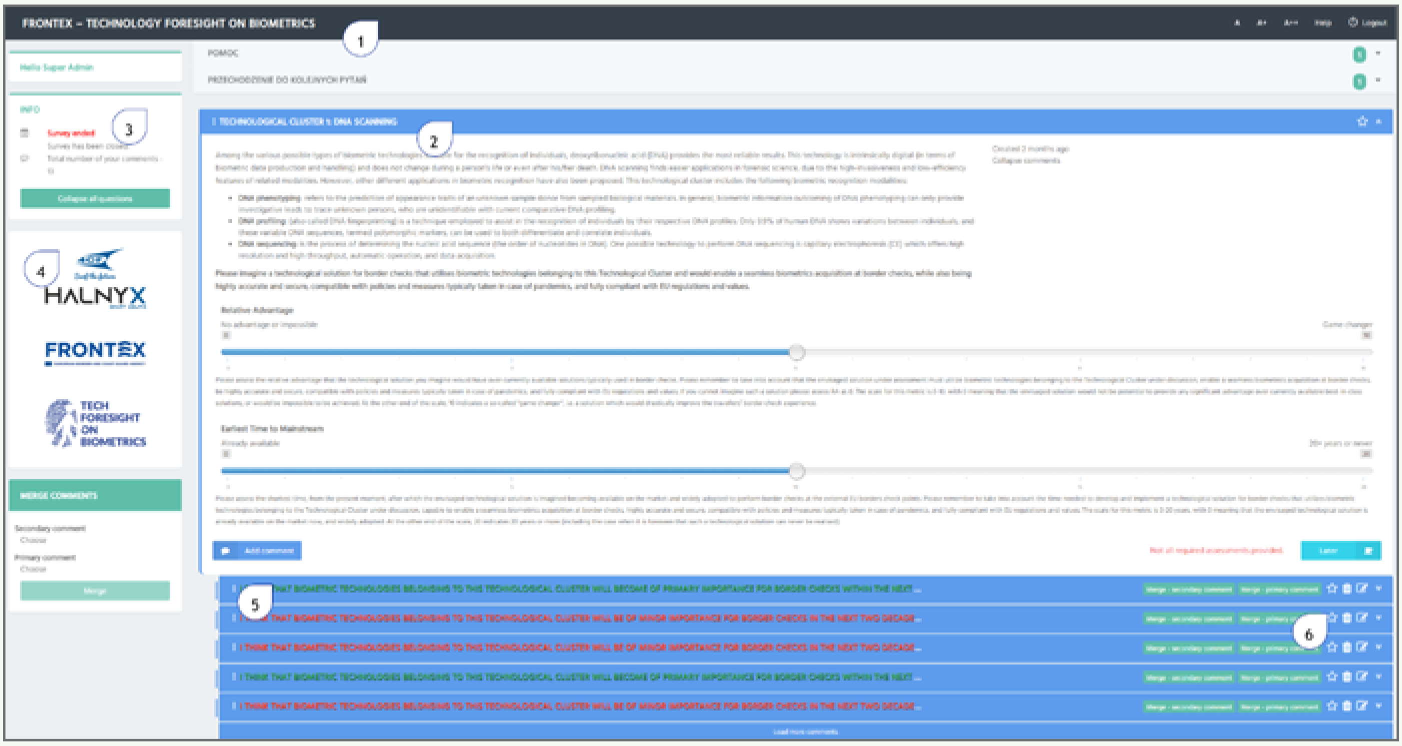
Must-have features:

- Ability to conduct an anonymous, multi-user *Delphi Survey* online and in real-time.

Examples of alternative solutions:

- Conduct the survey by e-mail, using pre-defined forms for text documents.
- Other *Delphi Survey* solutions, like the Welphi platform[62] and the EDelphi platform[63].

Figure 27: *Key elements of the user interface of the 4CF HalnyX Delphi platform.*



62 https://www.welphi.com/

63 https://www.edelphi.org/

18. Miro Board

18.1. Brief description of the tool and its features

Miro Board[64] is a virtual online whiteboard that facilitates group collaboration. It provides users with an unlimited canvas and a set of digital tools that allow the transfer of most traditional workshop methods and tools (e.g. brainstorming, collaborative drawing, sticky notes) into an online environment.

Key features:
- Unlimited canvas
- Many different templates for traditional workshop methods
- Large and active user community which provides additional ready-to-use templates

18.2. Property rights and accessibility

Miro Board is a proprietary tool of the Miro company. A subscription is required to use the tool.

18.3. Application in the Technology Foresight Process

Miro Board is used to conduct online collaborative workshops. Its primary purpose is to substitute traditional live workshops whenever it is impossible or unfeasible to conduct them. As regards the TFP, it is used in the *Insight Hunt* phase (see Chapter 2) for the development of case-specific scenarios, as well as in the *Deep Analysis* phase (see Chapter 4) and the *Mapping Capabilities* phase (see Chapter 5) for roadmapping and to identify cluster-specific capability-related needs.

18.4. User interface, setup, and operation

Guidelines and setup manuals are available online, on the Miro webpage: https://miro.com/guides/

18.5. Alternative solutions

A blank PowerPoint or Google Slides presentation or even an empty text document with online sharing may be used as a virtual brainstorming whiteboard.

64 https://miro.com

Must-have features:

- Enables real-time online collaboration
- Emulates a real-world workshop experience

Examples of alternative solutions:

- Google Jamboard[65]
- MURAL[66]
- Shared documents (Google docs/SharePoint)[67]

65 https://jamboard.google.com
66 https://www.mural.co
67 https://docs.google.com

19. Domain Terminology Extractor

19.1. Brief description of the tool and its features

There is a fundamental requirement for creating the taxonomy of a technological field: the set of technologies to be classified needs to be exhaustive. To ensure a high level of completeness, the Research Team Experts must be consulted, and technical documentation (i.e. patents and scientific publications) needs to be analysed. Aside from describing state-of-the-art technical solutions and research outcomes, patents and scientific publications may mention emerging solutions, technologies or methodologies. Since it is not advisable to read the entirety of each document to extract valuable data, automatic tools are typically used to retrieve the necessary information.

The *Domain Terminology Extractor* is used for this information extraction process. It uses built-in TM algorithms and NLP logic.

Key features:
The *Domain Terminology Extractor* has a built-in:
- POS (Part of Speech) tagging algorithm
- Chunking algorithm
- Knowledge base used to classify the extracted chunks and terms into multiple classes according to grammar or functional principles

19.2. Property rights and accessibility

The *Domain Terminology Extractor* is a proprietary tool of Erre Quadro and can be accessed and used only by Erre Quadro's team.

19.3. Application in the Technology Foresight Process

The *Domain Terminology Extractor* may be used whenever a refinement of the terminology used to query document databases is needed. The tool automatically extracts relevant chunks from the texts and clusters them into multiple technical categories by applying Natural Language Processing algorithms. The categories are selected based on their relevance to a technological domain: functions, functional behaviours, etc.

The tool is used after a preliminary retrieval of patents and papers from the patents database[68] and OpenAIRE open-access database of scientific publications. In the applied foresight methodology, this occurs during the *Development of a Technological Taxono-*

68 Erre Quadro's proprietary patents database.

my within the *State-of-the-Art Review* (see Section 2.1) and in the *Clustering of Technologies* (see Section 2.2), which are all part of the *Insight Hunt* phase. The initial queries are based on information provided by the Research Team Experts, leading to a preliminary list of keywords. Once a dataset of patents or papers is obtained, the *Domain Terminology Extractor* may be applied for the:

1. Selection of the terms and chunks of text, which are most relevant to the scope of the analysis;
2. Clustering of the terms and chunks into technically relevant groups.

When the *Domain Terminology Extractor* was applied in the *Technology Foresight on Biometrics for the Future of Travel*, the Research Team:

1. Consulted their experts to obtain a preliminary list of research areas and technical terms in the field of biometrics;
2. Created the terminology suitable for querying the patents and papers databases with a set of relevant keywords;
3. Queried the patents database and OpenAIRE open-access database to extract a preliminary set of patents and papers relevant to the predefined research areas and technical terms;
4. Applied the *Domain Terminology Extractor* to retrieve the most relevant terms/chunks from the patent and paper sets;
5. Enriched both the query and the list of preliminary research areas and technologies;
6. Conducted a preliminary classification of technologies into an initial taxonomy and iterated the process from Step 2;
7. Once no additional value was created by reiterating Steps 2-6 (meaning that no additional technologies, relationships between the encountered technologies or relevant keywords were found), the Research Team Experts and Frontex Representatives were consulted to validate/integrate the results.

19.4. User interface, setup, and operation

Not disclosable, as the *Domain Terminology Extractor* tool can only be accessed and used by Erre Quadro's team.

19.5. Alternative solutions

If Frontex wished to conduct this step autonomously, the terminology extraction functionalities of open-access automated tools could be used. Such tools are not necessarily specifically dedicated to the extraction of relevant terms from text, but such functionality may be embedded.

Open-access tools are generally capable of extracting terms from a single document or text pasted from a local source (e.g. a .txt file) into the tool's interface. There are usually limitations as to the number of characters that a tool can analyse simultaneously. Furthermore, such alternative solutions are usually not configurable and employ general-purpose algorithms whose effectiveness might be limited when applied to technical documentation.

Must-have features:

- Any alternative tool must be able to:
  - Extract tokens or chunks from a text;
  - Distinguish between different classes of terms, according to at least one useful logic (e.g. distinguish verbs from nouns);
  - Count occurrences of the extracted terms or chunks.

Examples of alternative solutions:

- *Google Patents*[69, 70] automatically extracts the most relevant chunks from a single patent. It also indicates the placement of relevant terms within a document. The output is provided in a downloadable form.
- *Wordcloud/Tagcloud tools*[71] automatically extract relevant terms/chunks from a text. The output is usually provided in a downloadable form.
- *The KeywordExtraction*[72] *online tool* may be used to extract single terms or chunks from a text automatically. The tool permits the user to decide how many terms or chunks are to be extracted.

69 Google Patents' home page may be found at: https://patents.google.com/

70 An example of how Google Patents may be used to extract useful terminology may be found at: https://patents.google.com/patent/JP4403426B2/en?q=biometric&oq=biometric%22+\. In particular, take a look at the 'Concepts' Section at the bottom of the web page.

71 A free online wordcloud generator may be found at: https://www.freewordcloudgenerator.com/

72 KeywordExtraction's term extractor page may be found at: https://keywordextraction.net/key-word-extractor

20. Smart Ranker

20.1. Brief description of the tool and its features

Once a dataset is formed, a common issue during the process of information retrieval is the need to "clean" the collected data. This includes the identification of inaccurate or irrelevant records and their correction.

In text-document analyses, non-relevant records might be created due to textual ambiguities, unintended relations between keywords used to query the database or the database's limitation. As a result, not all documents within an obtained dataset discuss the topics of interest, and not all the relevant existing documents are initially acquired. Therefore, two quality indicators are usually employed to control the cleaning process:

- *Precision*: the fraction of retrieved documents that are relevant to the query. In other words, precision tries to answer *how many retrieved documents are relevant*? To measure this parameter, sample checks are conducted, wherein the number of relevant documents within the gathered dataset is determined.
- *Recall*: the fraction of overall relevant documents that are successfully retrieved. In other terms, precision tries to answer *how many pertinent documents have been retrieved*? Since the exact total number of relevant existing documents is unknown, this parameter may only be estimated. To obtain such an estimate, one may use a control dataset formed solely of documents relevant to the search. The control dataset must be created independently by an alternative approach. Its purpose is to assess the recall of the original dataset by checking how many of the fully relevant documents are found and included in the dataset under evaluation.

Multiple iterations are generally needed to increase these parameters.

The *Smart Ranker* supports dataset cleaning and is intended for the refinement of patent sets retrieved during the Technology Foresight process from the patents database as well as scientific publication sets retrieved from OpenAIRE.

Key features:

- Configurability: the evaluation criteria for cleaning document datasets are highly adjustable. Thus, the *Smart Ranker* can be used for multiple purposes and on multiple types of documents.
- A built-in ranking algorithm that uses NLP mechanisms was specifically developed to be applied to technical documentation. Although the algorithm may be applied to any generic kind of textual documentation, it has been optimised for patent literature.
- Analyst-friendly output: the correlation between a document and the selected evaluation criteria is clearly indicated, thus providing a significant level of control over the results.

20.2. Property rights and accessibility

The *Smart Ranker* is a proprietary tool of Erre Quadro and can only be accessed and used by Erre Quadro's team.

20.3. Application in the Technology Foresight Process

The tool is used after the retrieval of patents from the proprietary database and of scientific publications from OpenAIRE. Both datasets usually require a cleaning process, which is conducted during the *Clustering of Technologies* step within the *Insight Hunt* phase of the Technology Foresight process (see Section 2.2).

To use the *Smart Ranker*, the Research Team:

1. Extracted patents from the patents database and scientific publications from OpenAIRE;
2. Configured the *Smart Ranker*, setting a list of evaluation criteria;
3. Launched the *Smart Ranker;*
4. Examined the output and re-iterated the process, when necessary.

The output produced by the tool was a matrix of the documents' metadata that showed the level of relevance to each of the aforementioned evaluation criteria. Thus, it enabled the cleaning and prioritisation of documents through multiple iterations, and the resulting dataset was characterised by high precision and recall indicators.

20.4. User interface, setup, and operation

Not disclosable, as the *Smart Ranker* tool can be accessed and used by Erre Quadro's team only.

20.5. Alternative solutions

The Research Team is not aware of any open-access tools or methodologies that could be used autonomously by Frontex to perform the same task, even if the results were to be obtained differently.

In general terms, the following high-level steps should be conducted to replicate the functionalities of the tool:

1. A document set or corpus must be extracted;
2. A set of evaluation criteria for assessing and ranking documents within the set must be selected. This can be done, for example, by analysing and comparing a group of documents that are fully relevant to the research topic and a group of irrelevant documents;
3. An evaluation algorithm must be developed. The evaluation criteria defined in Step 2 should be used as the primary input. Thus, the correlation between the semantic content of every document and each of the aforementioned criteria can be determined.

However, a cleaning procedure does not necessarily require an automated algorithm. Depending on the size of the dataset to be cleaned, the acceptable accuracy level and the controllability of the search engine used, non-automated approaches could be adopted. They would need to rely on multiple iterations and refinements of the search query, expanding the list of relevant terms and/or adding constraints (e.g. 'blacklist' terms) at every iteration.

Must have features:

- Any alternative tool must:
    - Be able to automatically assess the correlation of every document in a dataset with a set of evaluation criteria;
    - Embed a ranking algorithm which can be parametrised.

Examples of alternative solutions:

As the Research Team is not aware of any comprehensive alternatives, only generic alternatives are listed below:

- Patent search engines (e.g. EPO's Espacenet[73] or the USPTO's search engine[74]) typically embed a ranking algorithm that can sort the acquired documents in several ways. Usually, the most relevant documents (according to a set of evaluation criteria) are shown at the top of the list. However, these algorithms cannot be configured.
- As previously stated, an automated algorithm is not indispensable in a cleaning procedure. It is possible to refine the data by manually adjusting the search query multiple times and enriching it at every iteration. The following guidelines are useful in designing a search query:[75]
    - A sufficient understanding of the field of analysis should be acquired before designing a search query. This will enhance the employed lexicon and improve the comprehension of research objectives by highlighting 'borderline' concepts and areas that require thorough evaluation.
    - Search queries should be segmented, i.e. sub-divided into semantic units representing logic areas that may be combined through Boolean operators to find the defining characteristics of the analysed documents. Segmenting a search query helps the analyst focus on one concept at a time, with the end goal of creating a final query (usually composed of hundreds or thousands of terms).
    - It should always be verified how the search engine copes with:
        - *Lemmatisation*: the process of grouping the inflected forms of a word to analyse them as a single item.
        - *Stemming*: the process of reducing inflected (or sometimes derived) words to their base or root form (e.g. the terms *circle* and *circles* may be stemmed to the root form *circl*). Both stemming and lemmatisation allow analysts to reduce the number of terms included within a search query. The difference between stemming and lemmatisation

73 https://worldwide.espacenet.com/

74 https://patft.uspto.gov/netahtml/PTO/search-adv.htm

75 Espacenet provides a very useful "pocket guide". Find it at: https://documents.epo.org/projects/babylon/eponet.nsf/0/8C12F50E07515DBEC12581B00050BFDA/$File/espacenet-pocket-guide_en.pdf is that a stemmer operates on a single word without knowledge of the context, and therefore cannot discriminate between words that have different meanings depending on the part of speech.[76] For example, the terms *run* and *runner* may both be stemmed to the term *run*. It may be useful to discriminate between the action (*run*) and the actor performing the action (*runner*).

- Special characters and stopwords (such as parentheses, punctuation symbols, conjunctions, adverbs) are necessary to make a text readable. However, they do not add any semantic value and must be treated differently from the rest of the text. A search engine that allows a user to deal with special characters and stopwords is to be preferred.

- The addition of synonyms can be used to increase recall, but they should be added in moderation. Technical synonyms are preferred.
- Generic terms or terms having multiple meanings should be treated with caution. For example, the term *can* (meant as a type of combustor) may also mean "*to be able to*" or indicate a *cylindrical container*.

76 There are eight parts of speech in the English language: noun, pronoun, verb, adjective, adverb, preposition, conjunction, and interjection.

21. Weighted Clusterer

21.1. Brief description of the tool and its features

The *Weighted Clusterer* tool can categorise documents according to their textual content and classify technologies and technological applications. The tool extracts labels (single terms or multi-words, technologies, or generic chunks) from an input document and classifies them using an ML algorithm specifically developed for the analysis of technical literature and patents. The tool may be applied to any textual documentation dataset, but it performs best when applied to patent literature. The documents within the dataset are then correlated to the identified classes, thus creating a weighted classification of documents.

The *Weighted Clusterer* may be used for two purposes:

a) to determine the level of pertinence of documents to a set of predetermined classes (when the classes of labels are known beforehand);

b) to propose, classes are not known *a priori*, clusters of documents with similar features based on their semantic content.

The results of the tool's usage are semantically homogeneous groups of documents, with a high-level and preliminary interpretation of their content (the aforementioned classes of labels). The *Weighted Clusterer*'s ML algorithm produces a reliable classification of patents. The tool may also be used to classify other types of documents but with lower effectiveness. Therefore, it is primarily used to improve the efficiency of patent classification, e.g. it can automatically group documents that discuss technologies with similar applications or physical effects.

Key features:

- ML-based clustering algorithm specifically developed to consider the unique characteristics of patents and technologies
- High reliability in the classification of patents and technologies disclosed within

21.2. Property rights and accessibility

The *Weighted Clusterer* is a proprietary tool of Erre Quadro and can only be used by Erre Quadro's team.

21.3. Application in the Technology Foresight Process

In general terms, the *Weighted Clusterer* may be used whenever a document classification task is needed, whether it is based on relevance to a set of known classes or the creation of clusters according to the textual content of the analysed documentation. Although it can support the clustering of any type of documents, the tool was developed to perform best when applied to patent classification.

In the Technology Foresight process, the tool is used:

- for the *Development of a Technological Taxonomy* within the *State-of-the-Art Review* (see Section 2.1) to support the classification of patent literature in a specific field and the categorisation of technologies they describe. This step may contribute to the taxonomical analysis, following a bottom-up approach.
- in the *Clustering of Technologies* (see Section 2.2), to group the identified technologies into an adequate number of technological clusters, as well as to support the creation of appropriate document sets for each cluster.

These steps, all part of the *Insight Hunt* phase, are essential in preparation for the *Patentometric and Bibliometric Analyses* (see Chapter 8).

21.4. User interface, setup, and operation

Not disclosable, as the *Weighted Clusterer* tool can only be used by Erre Quadro's team.

21.5. Alternative solutions

There are multiple classification methods that may be used for document clustering. It is difficult, however, to assess the level of effectiveness and reliability of generic algorithms when it comes to patents and technologies whose language, logic, and characteristics are highly specific. Generally, any document classification or clustering method can be used to group terms or documents that are semantically similar. A subsequent manual cleaning of the results could then address any possible reliability deficits, although it would be a less efficient procedure.

Alternative solutions (e.g. Carrot2 – see description below) may be used to replicate the functionalities of the *Weighted Clusterer*. Such tools generally allow the user to:

- Select the source of textual data (web, local file, etc.);
- Select a clustering algorithm (k-means, spectral clustering, lingo, etc.);
- Parametrise the algorithm;
- Obtain a graphical representation of the resulting clusters.

Alternatively, multiple clustering algorithms and methods exist (e.g. gravitational clustering) that can be used to calculate the "distance" between documents and/or to suggest or create clusters of documents with similar features or semantic content. These usually rely on the development and programming of tailored clustering algorithms.

Must-have features:

- Any alternative tool must embed at least some of the following:
  - a tokenisation algorithm;
  - a document distance measurement algorithm;
  - a clustering algorithm.

Examples of alternative solutions:

- *Carrot2*[77] is an open-access online tool that can perform clustering operations on textual documentation. The tool may be configured to match the objectives of the analysis.[78] The output is a set of labelled clusters created by considering the textual content of the input (which may be provided in a list, tree-map, or pie-chart format). In addition, a list of documents assigned to each cluster is provided.
- Examples of alternative solutions based on tailored algorithms developed through programming codes include those based on the application of a k-means algorithm[79, 80] or a spectral clustering algorithm.[81]

77 Carrot2's clustering tool may be found at: https://search.carrot2.org/#/workbench

78 More details on the tools, its configurability and the functionalities of the underlying algorithms may be found at: https://search.carrot2.org/#/about

79 https://sanjayasubedi.com.np/nlp/nlp-with-python-document-clustering/

80 https://archive.siam.org/meetings/sdm06/workproceed/Text%20Mining/jing1.pdf

81 R. Janani, S. Vijayarani, "Text document clustering using Spectral Clustering algorithm with Particle Swarm Optimization", Expert Systems with Applications, vol. 134, pp. 192-200, 2019.

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