Project Overview

1. Analysis of Research Context
2. Insight Hunt
3. Filtering Results
4. Deep Analysis
5. Mapping Capabilities
Project Overview

Research Team

Steinbeis 2i
Germany

4CF
Poland

Erre Quadro
Italy

Institute of Optoelectronics
Military University of Technology
Poland

>40 Stakeholders actively involved (strong focus on EU and EBCG)

2021

JANUARY
Kickoff Meeting

SEPTEMBER
Final Project Meeting

MAY
Delphi Survey

JUNE
2nd Technology Foresight Workshop on Roadmapping

APRIL
1st Technology Foresight Workshop on Scenario Building

Stakeholders actively involved
EU Institutions, Bodies or Agencies
EC-DE-G-HOME
EC-DE-JRC
eu-LISA
EUROPOL
FRA
EU-funded Projects
D4FLY
eBORDER
iMARS

12% EBCG community
50%
16% Industry
19% Research
Others
INTERPOL
ICAO
U.S. DHS
Frontex
Belgium
Estonia
Finland
France
Latvia
Romania
Norway
Switzerland

EU Institutions, Bodies or Agencies
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EU-funded Projects
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Others
INTERPOL
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U.S. DHS
Frontex
Belgium
Estonia
Finland
France
Latvia
Romania
Norway
Switzerland
Motivation

Growing mobility of individuals and need for Seamless Border Checks pushing towards implementing:

- Digital Identity Management Solutions
- No-Gate physical solutions for seamless border checks at BCPs

COVID-19 pandemic

- need for technological solutions compatible with policies and measures typically taken in case of pandemics

Biometric Technologies

Border checks will have to transform to:

- Effectively safeguard EU’s external borders
- Improve border crossing experience (seamless & contactless travel)

Biometrics is key enabler for automated recognition of individuals at BCPs

Use of biometrics in large-scale IT systems is a major priority for the EU

Foresight for pre-acting rather than re-acting
Research study

Research study on the future opportunities that biometric technologies could provide to the European Border and Coast Guard (EBCG) community

- Identify specific research and innovation activities
- Knowledge on how to maximize future benefits of biometric technologies

Desired outputs

- TF Methodology and Supporting Tools
- Taxonomy of biometric technologies
- Research Study
Methodological Framework

**STAGES**
- **EXPLORATION**
  - DISCOVER (Expansion of options)
  - DEFINE (Narrowing options down)
- **UNDERSTANDING**
  - DEVELOP (Expansion of understanding)
  - DELIVER (Actionable insights)

**PHASES**
1. **ANALYSIS OF RESEARCH CONTEXT**
   - Identification of Needs
2. **INSIGHT HUNT**
   - State-of-the-Art Review
   - Clustering of Technologies
   - Identification of Stakeholders
   - Building Scenarios for the Future
3. **FILTERING RESULTS**
   - Filtering by Key Strategic Factors
   - Filtering by Other Relevant Factors
   - Filtering by Future Scenarios
4. **DEEP ANALYSIS**
   - Modelling the Roadmaps
5. **MAPPING CAPABILITIES**
   - Capability Readiness Analysis

**METHODS**
- Matrixes of needs & functional requirements
- Desk research
- Patentometric & bibliometric analyses
- Delphi Survey
- 4CF Matrix
- Rip Van Winkle Method
- Futures Wheel
- Forecasting/Backcasting
- Scenario Analysis
- Weighted Criteria Matrix
- Workshops

**TOOLS**
- 4CF HalnyX
- Miro Board
- Domain Terminology Extractor
- Smart Ranker
- Weighted Clusterer
1. Analysis of Research Context

- Project Overview
- 1. Analysis of Research Context
- 2. Insight Hunt
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Identification of Needs

Analysis of Frontex needs for key functions of biometric technologies

1. **ANALYSIS OF RESEARCH CONTEXT**

   **Aim**
   - Needs analysis to specify the field and scope of the research and to set the goals for the study
   - Tailor the Technology Foresight Methodology to Frontex needs

   **4 “must-haves” for biometric technologies identified for reference in later phases of the project**
   - Seamlessness
   - Compliancy with fundamental EU values and regulations
   - Applicability within pandemic-specific restrictions
   - Low vulnerability to adversary attacks
2. Insight Hunt

Project Overview
1. Analysis of Research Context

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State-of-the-art Review

Taxonomies

Aim

- Establish a common systematic understanding of the biometrics domain
- Create reference documents which could enable future R&I activities

Output

- Taxonomy of biometric technologies
- Taxonomy of biometrics-enabled technological systems

Highly iterative process based on the extraction of terminology from patents and scientific literature

Automatic tools (embedding NLP) for analysis of massive technical and scientific documentation

Three-level Taxonomy of Biometric Technologies

- 57 biometric technologies
  - 5 biomolecular
  - 39 morphological
  - 13 behavioural

Two-level Taxonomy of Biometrics-Enabled Technological Systems

1. Search query design
2. Technologies extraction
3. Technologies validation

NLP
State-of-the-art Review

Taxonomies

1. **BIOMETRICS TECHNOLOGIES**
   - 1.1 DNA biometrics
   - 1.2 Other biomolecular biometrics
   - 2.1 Face recognition
   - 2.2 Friction ridge recognition
   - 2.3 Iris recognition
   - 2.4 Vascular pattern recognition
   - 2.5 Physiological signals biometrics
   - 2.6 Hand geometry recognition
   - 2.7 Other minor morphological biometrics
   - 3.1 Keystroke recognition
   - 3.2 Gait recognition
   - 3.3 Handwriting recognition
   - 3.4 Speaker recognition
   - 3.5 Other minor behavioural biometrics

2. **BIOMETRICS-ENABLED TECHNOLOGICAL SYSTEMS**
   - 1. Self-service systems
   - 2. Identity document readers and verification sub-systems
   - 3. Full-body scanning systems
   - 4. Systems based on personal devices
   - 5. Movable systems
   - 6. Large-scale IT systems
   - 7. Virtual traveller identity schemes

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1. **BIOMOLECULAR BIOMETRICS**
2. **MORPHOLOGICAL BIOMETRICS**
3. **BEHAVIOURAL BIOMETRICS**

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FRONTEX
EUROPEAN BORDER AND COAST GUARD AGENCY

2. INSIGHT HUNT
Clustering of Technologies

Identification of Technological Clusters

**Aim**
- Group the large set of biometric technologies into **clusters** to assure the usability of the taxonomy in the different phases of the Tech Foresight
- Create homogeneous datasets of patents and scientific publications suitable to conduct patentometric and bibliometric analyses

**PRELIMINARY AUTOMATIC STEP**
- NLP TOOLS
  - Domain Terminology Extractor
  - Weighted Clusterer
  - Smart Ranker

**CONTROL STEP**
- 3 evaluation criteria:
  - numerosity
  - technological affinity
  - relevance

- 20 technological clusters
- Refined datasets
Clustering of Technologies

Identification of Technological Clusters

<table>
<thead>
<tr>
<th>1. DNA biometrics</th>
<th>6. 3D friction ridge recognition</th>
<th>11. Iris recognition at a distance</th>
<th>16. Periocular recognition</th>
</tr>
</thead>
<tbody>
<tr>
<td>3. 2D face recognition in the visible spectrum</td>
<td>8. Contact-based friction ridge recognition</td>
<td>13. Hand vein recognition</td>
<td>18. Gait recognition</td>
</tr>
</tbody>
</table>
Clustering of Technologies

Patentometric and bibliometric analyses of Clusters

Aim

• Analyse the lifecycle of 20 Biometric Technological Clusters to gather information about their evolution

• Theory of Technology Lifecycle applied

• Datasets of patent families and scientific publications were used to study technological evolution

DATA ANALYSIS

Technological life-cycle assessment

Geographical distribution of R&D, manufacturing and commercial activities

Most prolific R&D entities

Proprietary patent database (based on EPO's Database)

OpenAIRE database (scientific publications)

CORDIS database of EU-funded projects
## Clustering of Technologies

### Patentometric and bibliometric analyses of Clusters

<table>
<thead>
<tr>
<th>#</th>
<th>Technological clusters</th>
<th>No. Patent families</th>
<th>No. Patents</th>
<th>No. Papers</th>
<th>State in technology lifecycle</th>
<th>Concentration of inventive activity (%)</th>
<th>Concentration of publishing activity (%)</th>
<th>Concentration of editorial activity (%)</th>
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<tbody>
<tr>
<td>20.</td>
<td>Speaker recognition</td>
<td>1,760</td>
<td>7,468</td>
<td>848</td>
<td>Maturity</td>
<td>34.7</td>
<td>6.4</td>
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<td>158</td>
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<td>24.1</td>
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<td>6,347</td>
<td>821</td>
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<td>18.2</td>
<td>15.5</td>
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<td>1,048</td>
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<td>18.4</td>
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<td>3,974</td>
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<td>19.5</td>
<td>40.4</td>
<td>84</td>
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<td>30</td>
<td>56.7</td>
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<td>DNA biometrics</td>
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<td>19.6</td>
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<td>428</td>
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<td>186</td>
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<td>378</td>
<td>1,482</td>
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<td>Maturity – minor relevance</td>
<td>28.8</td>
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<td>79.8</td>
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<td>267</td>
<td>1,207</td>
<td>134</td>
<td>Growth</td>
<td>30.1</td>
<td>32.1</td>
<td>76.9</td>
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<td>1,285</td>
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<td>46.7</td>
<td>39</td>
<td>84.4</td>
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<td>Growth</td>
<td>37.4</td>
<td>47.7</td>
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<td>5.</td>
<td>Infrared friction ridge recognition</td>
<td>195</td>
<td>843</td>
<td>66</td>
<td>Growth</td>
<td>34.2</td>
<td>36.4</td>
<td>84.8</td>
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<td>120</td>
<td>571</td>
<td>41</td>
<td>Growth</td>
<td>54.9</td>
<td>126.8</td>
<td>100</td>
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<td>18.</td>
<td>Gait recognition</td>
<td>32</td>
<td>163</td>
<td>67</td>
<td>Childhood</td>
<td>68.7</td>
<td>73.1</td>
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<td>Periocular recognition</td>
<td>27</td>
<td>197</td>
<td>38</td>
<td>Childhood</td>
<td>88.8</td>
<td>84.2</td>
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</tbody>
</table>
Clustering of Technologies

Patentometric and bibliometric analyses on Clusters

3D face recognition

Geographical distribution of priority patents

Geographical distribution of all patents

<table>
<thead>
<tr>
<th>Assignee</th>
<th>Number of patent families</th>
<th>% of the total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microsoft</td>
<td>21</td>
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<tr>
<td>Amazon Technologies</td>
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<td>3.4</td>
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<tr>
<td>Google</td>
<td>18</td>
<td>3.2</td>
</tr>
<tr>
<td>Apple</td>
<td>13</td>
<td>2.3</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Publisher</th>
<th>Number of scientific publications</th>
<th>% of the total</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEEE</td>
<td>87</td>
<td>32.3</td>
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<tr>
<td>Springer</td>
<td>34</td>
<td>12.6</td>
</tr>
<tr>
<td>Elsevier</td>
<td>25</td>
<td>9.3</td>
</tr>
</tbody>
</table>
Building Scenarios for the Future

Scenarios for the future of travel, border checks and biometrics in 2040

**Aim**
- Reframing visions of the future in order to challenge them
- Assessing how alternative futures might influence the evolution of biometrics.

**Choice of scenarios**
- Based on JRC’s study “The Future of Customs in the EU 2040: A foresight project for EU policy”[^1]
- Adapted to incorporate aspects relevant to the travel and border check context

**Use of scenarios**
- Roadmapping
- Mapping capabilities

3. Filtering Results

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Filtering by Key Strategic Factors

Prioritisation of biometric technologies – The Delphi Survey

Aim

- Select the Key biometric Technological Clusters – KTCs
- Quantitative assessment of the 20 Technological Clusters using 2 metrics: **Relative Advantage** and **Earliest Time to Mainstream** by a real-time Delphi

- Collect experts’ opinions
- Stimulate consensus-oriented structured discussions
- Exploit collective intelligence, not only statistical distribution of answers

FILTERING RESULTS

3.

<table>
<thead>
<tr>
<th>Relative Advantage</th>
<th>Squalls</th>
<th>Pirate Treasure</th>
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</thead>
<tbody>
<tr>
<td>Early Advantage</td>
<td>Coral Reef</td>
<td>Sirens</td>
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</table>

Earliest Time to Mainstream (ETM)
Filtering by Key Strategic Factors

Prioritisation of biometric technologies – The Delphi Survey

<table>
<thead>
<tr>
<th>#</th>
<th>Technological clusters</th>
<th>Delphi Assessment Composite Metric $p=RA-ETM/2$</th>
<th>Relative Advantage</th>
<th>Earliest Time to Mainstream</th>
<th>Number of Assessments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Average</td>
<td>St Dev</td>
<td>Number of assessments</td>
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<tr>
<td>3</td>
<td>2D face recognition in the visible spectrum</td>
<td>3.52</td>
<td>5.17</td>
<td>2.27</td>
<td>30.00</td>
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<td>2</td>
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<td>1.96</td>
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<td>6.81</td>
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<td>9</td>
<td>Iris recognition in the near-Infrared spectrum</td>
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<td>6.48</td>
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<td>8</td>
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<td>4.04</td>
<td>1.99</td>
<td>28.00</td>
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<td>5.18</td>
<td>2.12</td>
<td>28.00</td>
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<tr>
<td>11</td>
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<td>7.11</td>
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<td>27.00</td>
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<tr>
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<td>5.38</td>
<td>2.19</td>
<td>29.00</td>
</tr>
<tr>
<td>16</td>
<td>Periocular scanning</td>
<td>0.44</td>
<td>5.11</td>
<td>2.15</td>
<td>27.00</td>
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<tr>
<td>5</td>
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<td>0.41</td>
<td>3.73</td>
<td>1.93</td>
<td>30.00</td>
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<tr>
<td>20</td>
<td>Speaker recognition</td>
<td>-0.07</td>
<td>3.79</td>
<td>2.18</td>
<td>28.00</td>
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<tr>
<td>13</td>
<td>Hand vein recognition</td>
<td>-0.41</td>
<td>4.52</td>
<td>2.27</td>
<td>29.00</td>
</tr>
<tr>
<td>18</td>
<td>Gait recognition</td>
<td>-0.56</td>
<td>4.52</td>
<td>1.89</td>
<td>27.00</td>
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<tr>
<td>6</td>
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<td>-0.98</td>
<td>4.34</td>
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<td>29.00</td>
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<tr>
<td>15</td>
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<td>12</td>
<td>Eye vein scanning</td>
<td>-2.34</td>
<td>4.25</td>
<td>2.20</td>
<td>28.00</td>
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<td>1</td>
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<td>0.72</td>
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<td>-6.38</td>
<td>1.11</td>
<td>0.77</td>
<td>28.00</td>
</tr>
</tbody>
</table>
Filtering by Other Relevant Factors

**ADDITIONAL CHECKS FOR**
- redundancy
- vulnerability to adversary attacks
- “must-haves” from the needs analysis

**FINAL SELECTION OF 5 KTC**
1. Infrared face recognition
2. 3D face recognition
3. Contactless friction ridge recognition
4. Iris recognition in the NIR spectrum
5. Iris recognition in the visible spectrum

**FILTERING RESULTS**

- [ ] 2. Infrared face recognition
- [ ] 4. 3D face recognition
- [ ] 7. Contactless friction ridge recognition
- [ ] 9. Iris recognition in the NIR spectrum
- [ ] 10. Iris recognition in the visible spectrum
4. Deep Analysis

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Roadmaps of key biometric technological clusters

**Aim**
- In-depth analysis of the key technological clusters
- Envisage potential future developments in terms of:
  - Applications
  - Functions
  - Products and systems

**Outcomes (for each KTC)**
- Visual technology roadmap chart
- List of expected key opportunities and challenges in the today-2040 timeframe
- Comparative analysis to study how the of the hypothetical scenarios might influence the developments envisaged in the roadmaps
## Roadmaps of key biometric technological clusters

### Visual technology roadmap charts – 3D face recognition

<table>
<thead>
<tr>
<th>3D face recognition</th>
<th>2021 (ETM:6,7)</th>
<th>2022-2027</th>
<th>2028-2033</th>
<th>2034-2040</th>
</tr>
</thead>
</table>
| **APPLICATION AREAS OF TECH CLUSTER**
(Where is it used?) | Physical access control | Use in smartphones for unlocking the device, making payments and accessing sensitive data | 3D facial recognition in healthcare (e.g. COVID-19 quarantine apps) | 3D face acquisition (technology capable of searching against biometric enrolment database of 3D faces) | **PRODUCTS / OR SYSTEMS USING TECH CLUSTER**
(what is it?) | Improved sensors for 3D image acquisition | cameras recording 3D videos | 3D cameras to acquire images from afar, with a larger field of view, and to assess distance | 3D facial image stored in the chip of e-passports | 3D image of face integrated in digital identity solutions and digital travel documents |
| **FUNCTIONS OF TECH CLUSTER**
(what can it do?) | Verification of identity | 3D face identification (technology capable of searching against biometric enrolment database of 3D faces) | **EXAMPLE DEVELOPMENTS**
2028 – 2040 Seamless border checks using 2D and 3D face recognition (after check-in, biometric data is acquired and stored; it is removed after the passenger leaves the airport/BCP) | **2026 – 2040** Short-distance 3D face recognition on-the-move for seamless border crossing | **2032 – 2040** Long-distance 3D face recognition on-the-move for seamless border crossing | **2030 – 2040** 3D facial image stored in the chip of e-passports |
| **2022-2023** Pre-enrolment for seamless travel (e.g. mobile-based solutions for starting the passenger check-in remotely) | Physical access control to critical areas (e.g. military zones) | Identity verification for payment and bank account access | Seamless border checks using 2D and 3D face recognition (after check-in, biometric data is acquired and stored; it is removed after the passenger leaves the airport/BCP) | Surveillance and forensics (biometric data collected on specific people e.g. criminals and suspects) | Surveillance and forensics (biometric data collected on specific people e.g. criminals and suspects) | Use in public security for fast detection of aggressive behaviours and attacks | 3D face acquisition used in the mainstream consumer market (e.g. entertainment) |
| **2024-2025** | | | | | | | |
| **2026-2027** | | | | | | | |
| **2028-2029** | | | | | | | |
| **2030-2031** | | | | | | | |
| **2032-2033** | | | | | | | |
| **2034-2035** | | | | | | | |
| **2036-2037** | | | | | | | |
| **2038-2040** | | | | | | | |
The most favourable scenario conditions for the development of biometric solutions:

**Scenario impact analysis**

<table>
<thead>
<tr>
<th>Scenario impact analysis</th>
<th>Key biometric technological clusters</th>
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</thead>
<tbody>
<tr>
<td>1 Union for society</td>
<td>Contactless friction ridge recognition</td>
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<tr>
<td>2 Protected Union</td>
<td>3D face recognition</td>
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<tr>
<td>3 Union under strain</td>
<td>Infrared face recognition</td>
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<tr>
<td>4 No-stop shop</td>
<td>Iris recognition in the NIR spectrum</td>
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<td>Iris recognition in the visible spectrum</td>
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</table>

**Legend**

Compared to the roadmap projections, developments are:

- Highest sensitivity to changing external conditions
- Highest immunity to changing external conditions
- Highest negative immunity to changing external conditions
5. Mapping Capabilities

Project Overview
1. Analysis of Research Context
2. Insight Hunt
3. Filtering Results
4. Deep Analysis

5. Mapping Capabilities
Capability Readiness Analysis

Aim
- Explore existing EU capability landscape
- Identify capability gaps and opportunities across the various timeframes and scenarios

Outcomes (for each KTC)
- Capability readiness heatmaps

METHODOLOGY

Step 1: Definition of objective
Step 2: Definition of capabilities
Step 3: Definition of need
Step 4: Assessment of capability readiness
Step 5: Identification of capability gaps and opportunities
**Capability Readiness Analysis**

**Heatmaps – 3D face recognition**

**Legend**
- Not met at all
- Partially met
- Completely met

**Capability Gaps**
Formulated need is not or will not be met at all

**Capability Opportunities**
Formulated need is/will be completely met

**Capability readiness**
Degree to which specific needs are/will be met

Cluster-specific needs in 3 domains: Research, Industry, Institutions

**Various scenarios**
- Scenario 1
- Scenario 2
- Scenario 3
- Scenario 4

**Various timeframes**
- Present
- 2022-2027
- 2028-2033

<table>
<thead>
<tr>
<th>Capability domain</th>
<th>Capability-related need</th>
<th>Present</th>
<th>2022-2027</th>
<th>2028-2033</th>
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<tbody>
<tr>
<td>Research</td>
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</table>
Conclusions

Project Overview
1. Analysis of Research Context
2. Insight Hunt
3. Filtering Results
4. Deep Analysis
5. Mapping Capabilities
Main Outcomes

Each of the phases of this complex Research Study produced its own set of future-oriented insights with the intention of supporting the EBCG community in decision-making processes that:

- **exploit opportunities**
- **mitigate associated threats**
- result in the implementation of new biometrics-enabled technological solutions

### 5 Key Technological Clusters

- Infrared Face Recognition
- 3D Face Recognition
- Contactless Friction Ridge Recognition
- Iris Recognition in the NIR Spectrum
- Iris Recognition in the Visible Spectrum
Main Outcomes

Technology Foresight Manual describing the TF Process, the Methods and the Tools

Taxonomy of Biometric Technologies and Biometrics-Enabled Technological Systems

Analyses conducted over the patents, scientific literature and EU-funded projects

Set of scenarios for the future of travel and border checks

Prioritisation Matrix of biometric technological clusters

Set of roadmaps developed for the key biometric technological clusters

Heatmaps reflecting capability readiness for the key biometric technological clusters
Thank you for your attention!

If you have any questions regarding this research study please contact Frontex Research and Innovation at research@frontex.europa.eu