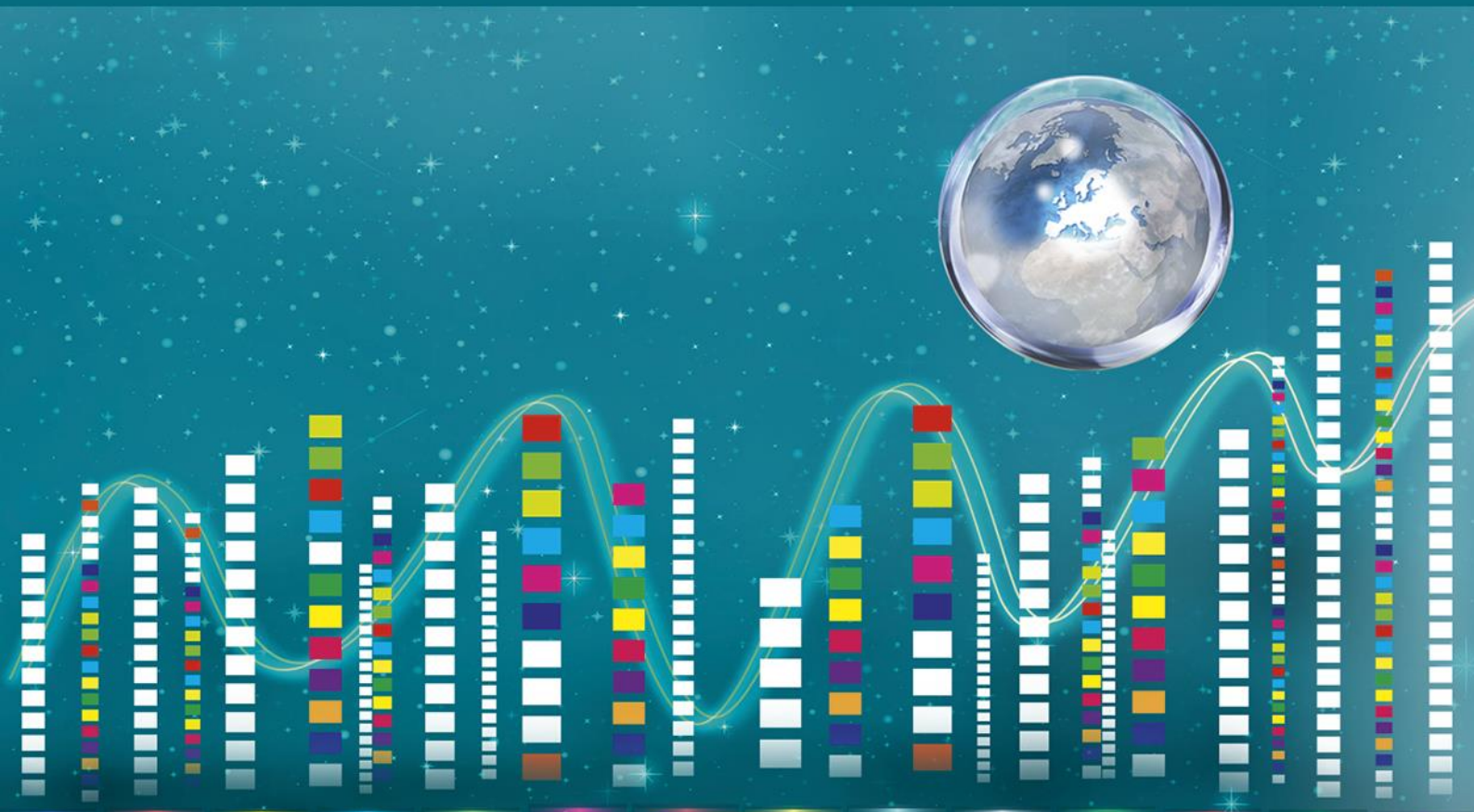
European Commission

Foresight

The Electrosphere of Sensors

Targeted scenario N°17

Glimpses of the future from the BOHEMIA study



***The Electrosphere of Sensors* - Targeted scenario N°17**

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EUROPEAN COMMISSION

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from the BOHEMIA study

Directorate-General for Research and Innovation

2018

About BOHEMIA

BOHEMIA is a foresight study (contract N° Contract PP-03021-2015) designed specifically to support the preparation of the next framework programme.

The study put forward policy recommendations for the next framework programme, based on a foresight processes involving scenario development, a Delphi survey and an online consultation.

As part of its recommendations, the study identified 19 likely future scenarios with disruptive implications and associated priority directions for EU research and innovation.

The full range of the results of the study is available at https://ec.europa.eu/research/foresight

Targeted scenario N° 17

The Electrosphere of Sensors

Summary

As energy-harvesting technology makes substantial leaps and sensors are further miniaturized, self-sufficient micro-sensors flood public spaces as well as individual and corporate premises. Valuable data are constantly generated, but personal and organizational environments are exposed to predatory information-gathering practices.

UN Sustainable Development Goals (SDGs) most relevant to this scenario:

The scenario

It is now 2040. As energy-harvesting technology improved and sensors were continuously miniaturized, self-sufficient micro-sensors have flooded cities and the countryside, amassing vast quantities of information. The combination of energy-harvesting technologies, wireless charging and self-healing materials has made autonomous sensors resilient to all kinds of challenges.

As the number of sensors scattered in the environment exploded, valuable data were generated. Environmental conditions are sensed and decoded in real time. Sensors linked to security networks scan the molecular composition of things in public spaces seeking hidden explosives and other regulated substances. People are scanned continuously for identification purposes as well as for reasons of health, safety and security, their own and of the public.

Communities collect and share data for their benefit while efforts are being made to preserve privacy through adequate encryption systems. On the flipside, personal and organizational environments are exposed to predatory information-gathering practices. Some of these – such as industrial espionage – generate international concerns.

While the market generates a variety of protective solutions (such as sensor scanning and neutralization devices), questions of usage transparency and sensor-identification remain prominent. A black market for unregulated sensors emerges.

The EU has been forced to take steps to police the use of micro-sensors so as to limit the spread of unauthorized sensors. In particular it has built a system of regulations and practices ensuring 'sensor transparency and responsibility'. This entails the self-identification of micro-sensors, rendering it possible for average individuals to costless detect the sensors in their environment. All sensors must provide information about the types of data transmitted and the recipients of such data.

Relevance for Europe

The benefits of diverse sensors and sensor networks across the key policy fields can hardly be overemphasized. Remote sensing is the front end of the big data revolution, a field of fierce international competition.

However, without responsible use the opportunities may easily become a threat to the quality of life and even to general safety. Security and privacy issues loom large, and Europeans need increased awareness about the ubiquity of sensors, the nature of information being transmitted, and the potential for manipulation of apparently harmless information.

Contribution towards the UN Sustainable Development Goals (SDGs)

Sensors are an important driver of developing ambient intelligence, smart cities and agriculture 4.0, contributing to Sustainable cities and communities (SDG 11). They can provide key information in support of "sustainable urbanization and [enhance the] capacity for participatory, integrated and sustainable human settlement planning and management" (SDG 11.3).

Self-sufficient micro-sensors in particular will be crucial to personalized health-care systems, thus ensuring healthy lives and promote well-being for all at all ages (SDG 3). The improvements to climate policy made possible by environment sensor networks through the vast amounts of information they provide will lead to better Climate action (SDG 14).

Implications for EU policy

Autonomous sensors are very important for the implementation of all policies, enabling continuous management of all kinds of affairs, from security, environmental monitoring, health and law enforcement across the board. The management of sensor network systems is part of a broader trend towards learning and managing complex phenomena. At the same time they raise important concerns in policies related to communications and science, security and justice, privacy and governance. Sensor regulation is likely to be part of privacy regulation, which however is likely to become more pervasive. For example, the harmonization of standards and the smuggling of non-standard micro-devices could become thorny issues in global politics.

Future Directions for EU R&I policy recommended by the public consultation

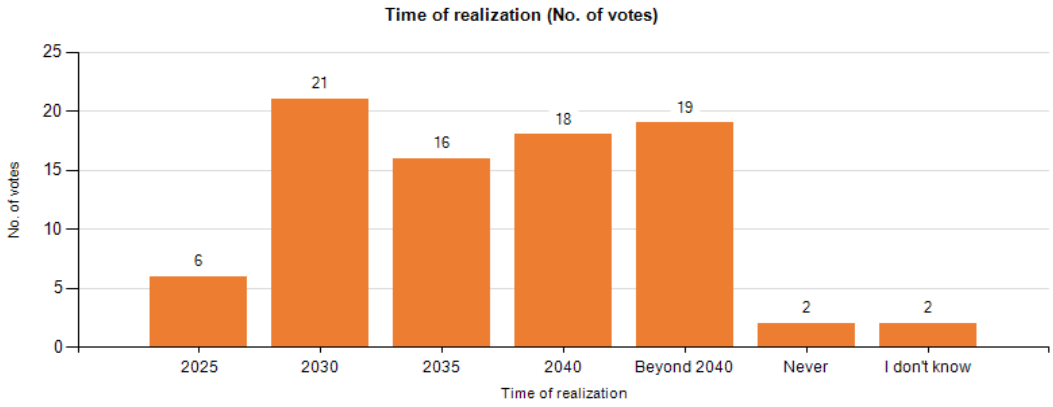
- **Development of new sensors based on a better understanding of the relation between sensing and knowing**
- **New solutions for energy harvesting (e.g., to ensure self-powering sensors)**
- **Exploring the rights and obligations of the sensor owners**
- **Exploring 'participatory sensing' (group contributions of sensory information) and its ability to empower local communities, as well as the dangers of exclusion**
- **Solutions and protocols for the identification of sensors (where they are, what they do, who they belong to)**
- **Understanding the social, behavioural and ethical aspects related to ubiquitous sensing technologies**
- **The study and production of biodegradable sensors**
- **Developing resilient sensors & data networks for autonomous systems, including those deployed at remote places and in extreme environments**

Annex: Relevant Data from the Delphi Survey

The Delphi survey of the BOHEMIA study asked experts about the time of realization of 143 statements about the future, and about the relevance of Research and Innovation for that realization, or about the relevance of the realization for Research and Innovation policy. The experts were asked to justify their judgements with arguments. The whole data set has been published and can be found at: https://ec.europa.eu/research/foresight

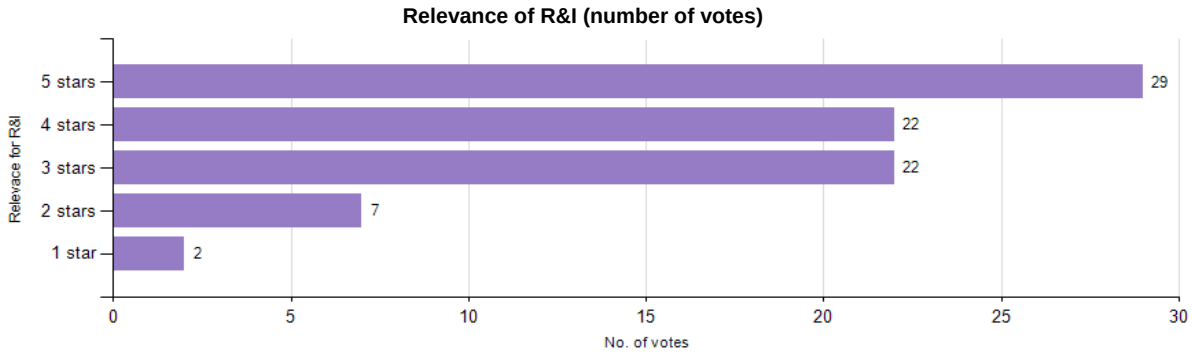
This annex includes the parts of the data set that are relevant to this scenario.

Half of the formerly passive materials and things (walls, streets, furniture, signs) become interactive and react to their surroundings via sensors, adaptive materials and ubiquitous electronics



Number of respondents: 84

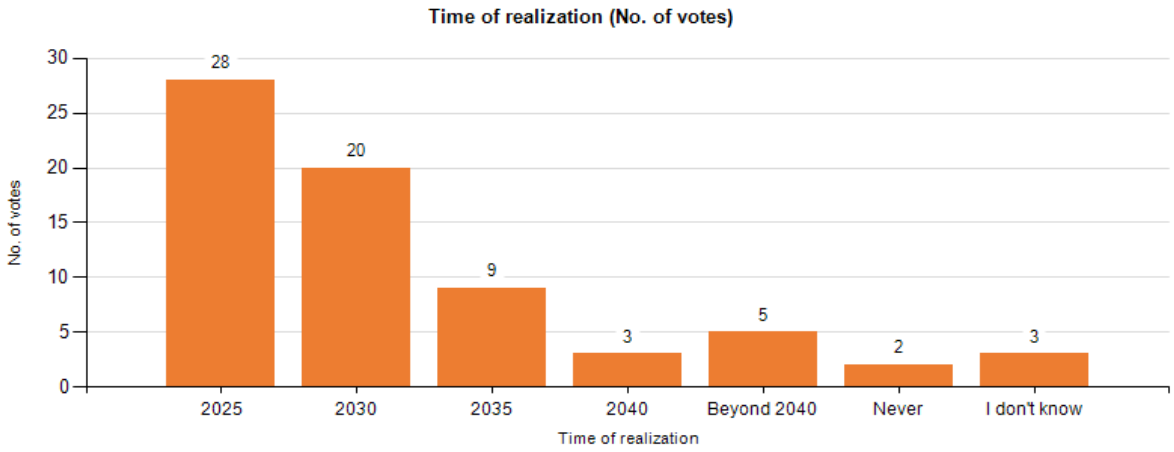
Arguments regarding the time of realization	**No. of votes**
Tiny sensors that can be attached to any object about which they can provide wirelessly different types of data are already on the market.	66
To reach "half of" (50%) the materials and things is very ambitious and will take a long time.	55
Value of sensors requires also automated data processing, information management and artificial intelligence. And a similar set of actuators. Evidently our physical environment becomes active.	28
Privacy and security concerns will limit diffusion to specific applications and environments.	24
Researchers already managed to combine photo-responsive fibers with thermo-responsive gels, modelling a new hybrid material that can reconfigure itself multiple times into different shapes when exposed to light and heat.	10
A large-scale use of "active material" is economic nonsense.	8
It is technologically easier and cheaper to build robots to maintain passive things, than to make the things themselves active. Over 50% active maintenance will happen, but 50% active things may never.	4
Natural ecosystems already include many such features and may provide models for achievement.	2
This will only happen because stock-keeping labels (a la NFC) count here; apart from that, most things won't profit from such interaction.	1



Average: 3.84 **Dispersion:** 1.17

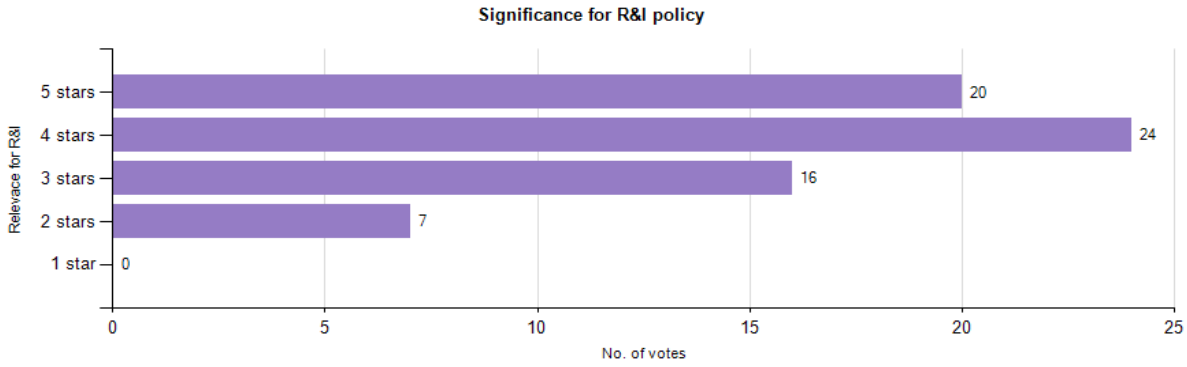
Arguments regarding the relevance of R&I	**No. of votes**
A lot of specific research on individual materials is needed to clarify where sensors can be placed or how the material can be used directly as an active one.	66
Social implications and individual acceptance/rejection factors need to be investigated.	34
Research is needed on autonomous data processing and knowledge creation.	24
There is no need for all equipment and furniture to be active - no more R&I needed.	14
Sensors will be connected which means that each piece of material may not need its own sensor or actuator. Example: Video camera over the table is a sensor for table even if it is not embedded.	12
Research is needed in heterogeneous integration of smart sensors into materials as well as heterogeneous integration of such systems to provide useful functions (e.g., resource & energy optimisation)	9
Research should focus on multi-modal (gesture recogn., speech, etc.) human-machine interfaces.	7
Citizens will pose limits to selfish economy-driven market push that just serves to collect data about them.	3
Research on development of our brain capacity is more important	2

Data literacy (personal privacy, handling data etc.) is taught in all primary schools in the EU



Number of respondents: 69

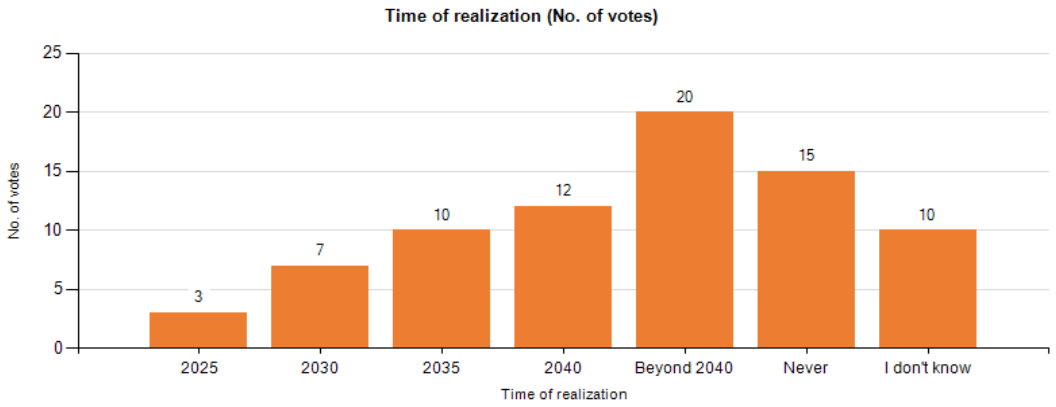
Arguments for time of realization	**No. of votes**
The nature of "facts", "data", and "sources of knowledge" is becoming very quickly an item of fundamental public debate that needs to be addressed in education as part of teaching critical thinking.	64
The mission of schools is not per se the teaching of data privacy but how data privacy links up to a life in civil society, freedom and democracy.	40
The fact that most adults have no clear idea of it will hamper its teaching in schools.	14
There are already training courses in data literacy targeting educators specifically.	11
The educational system is very resistant to change, so this will take (too) long.	9
As people get more and more immersed in electronic and virtual media, individual concern for data privacy will be seen as a thing of the past.	9
As generations as well as learning and work environments change, data literacy will be acquired naturally by most individuals - almost everybody will be data literate at a basic level - with no need for formal education.	7



Average: 3.85 **Dispersion:** 0.94

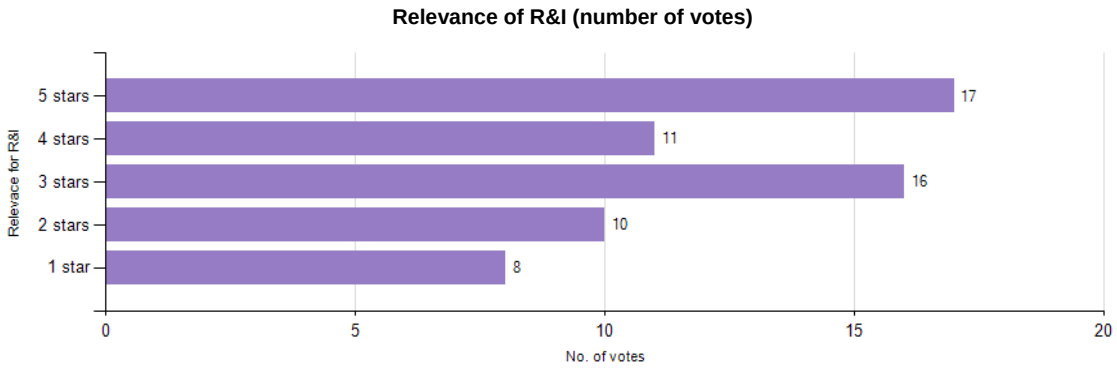
Arguments regarding the significance for R&I policy	**No. of votes**
Data literacy will become crucial as we get surrounded by sensors - education and training programmes are essential.	56
Data literacy will facilitate the uptake of citizen-science at a large scale.	36
Understanding the usages of data is key to governing societies. Data privacy and willingness to share specific data is part of the process.	31
All researchers will be quite adept at handling data. Education policy has to change.	12
This is a matter of education policy more than of R&I policy, even if "usability" will have to be part of Technology design.	4

Implants (small chips under the skin) or smart-ink tattoos for access control, replacement of keys, or the control of therapies are used by the majority of the EU population



Number of respondents: 76

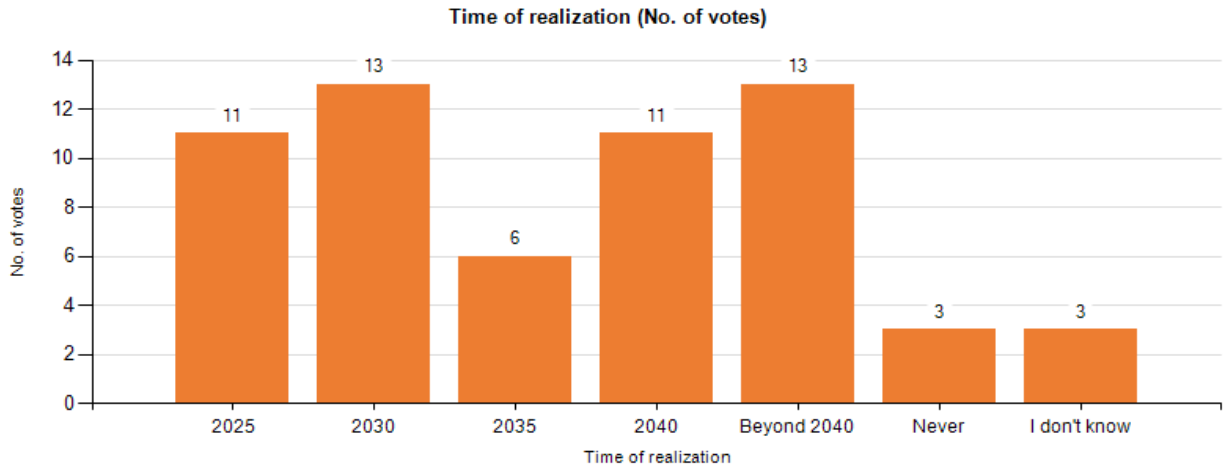
Arguments regarding the time of realization	**No. of votes**
The majority of population will reject such implants, fearing reduced privacy.	50
Issues relating to long-term use of such devices are largely unknown, such as biological impact, device life time, security updates and maintenance.	47
There will never be a single solution that fits all needs, is accepted by everybody (unless imposed) and lasts forever.	34
The endless diversity of identification systems: magnetic strips, passwords, PIN numbers, security questions, and dongles will be replaced by a single machine readable chip.	19
Fixed solutions may not be needed. Wearable, detachable solutions (rings, pendants...) are useful in case of multiple different identities. One identity only for a human being is too restrictive.	10
Biometrics are such a "chip".	10
A Swedish company already uses microchips for its staff, allowing them to use the photocopier and pay in the canteen.	6
For identification only, machine reading facial recognition may be enough and no added digital technology is needed or they complement each other.	4
Long-term health risk of implants will favor non-invasive technologies.	2
Some of these things can already be done today. It is likely that the technologies take off if privacy issues are solved.	2
QC code is cheaper and is widely used in Asia - http://www.scmp.com/news/china/society/article/2095576/rise-qr-code-and-how-it-has-forever-changed-chinas-social-habits	1



Average: 3.31 **Dispersion:** 1.83

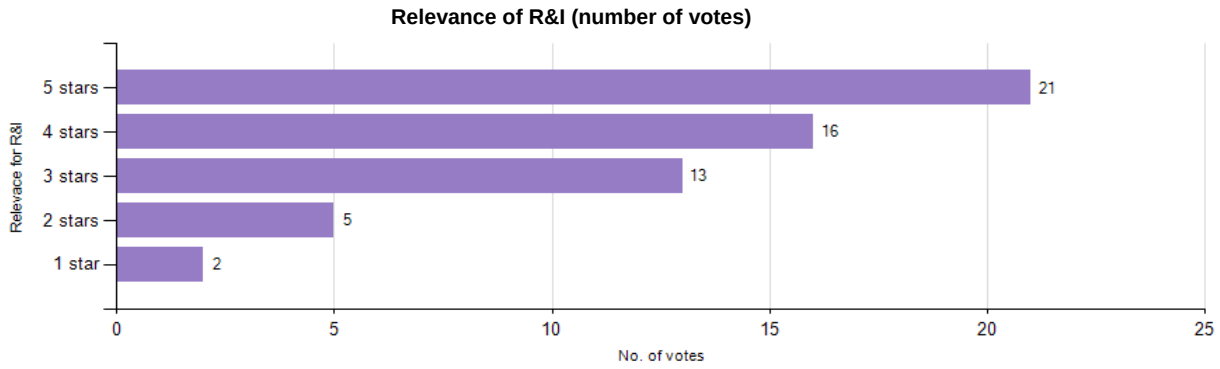
Arguments regarding the relevance of R&I	**No. of votes**
It is more a problem of acceptance and regulation than of technology.	54
Security of these implants is a promising research field.	31
There is interest in this area of research from big tech players (e.g., Google is exploring the idea of electronics in the eye, held on a contact lens, to monitor health).	18
Research on biometrics controlled devices	8
The integration of such implants with human-machine interfaces could be considered	5
Non of the above	1

Data on interactions between patients and their personal environment (including abiotic and biotic factors) are routinely and systematically collected for diagnosis and the creation of personalized therapy plans



Number of respondents: 59

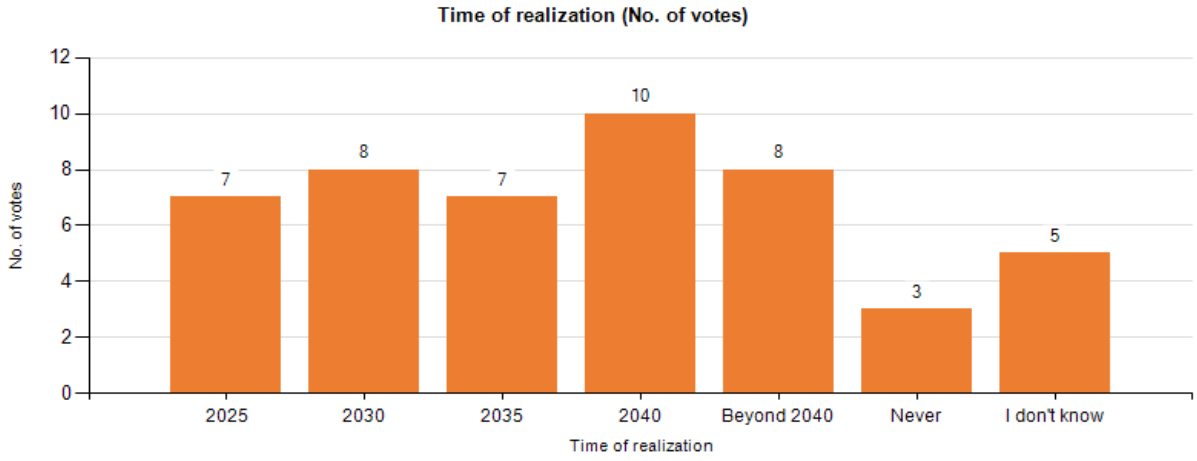
Arguments regarding the time of realization	**No. of votes**
Combining structured data (genotype, phenotype, genomics) with semi- or unstructured data (lifestyle, environmental, health economics data) still poses multiple challenges.	48
There is a huge step between the identification and collection of data, on the one hand, and the creation of therapy plans as a common practice, on the other.	40
This asks for a holistic human perspective that is much broader than the medical perspective on health.	13
Deep learning will help in the analysis of the data, structured data and unstructured data are quite helpful, if pattern can be found.	9
This is inevitable provided the ethical use of data can be properly managed.	8
The combination of structured and unstructured data will be extremely useful in the quest for patterns by means of AI strategies.	7
The US government's Precision Medicine Initiative (PMI) supports research looking beyond genetics and biology, at behavioral and environmental factors.	5
A clear legal and ethical framework is needed to prevent misuse and misinterpretation of such complex data sets, including IT security measures.	5
Just because data collection is uninformative does not mean it will not be done.	3



Average: 3.86 **Dispersion:** 1.24

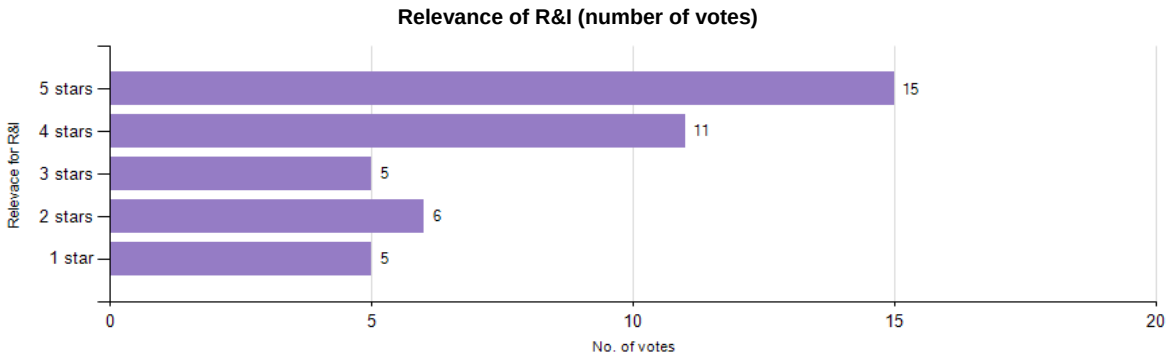
Arguments regarding the relevance of R&I	**No. of votes**
The correlations between the different factors still have to be identified and analyzed on a scientific basis.	49
Scientific databases have to be build up and filled with data.	33
The EU needs something analogous to the U.S. Precision Medicine Initiative involving 1 million volunteers providing genetic, environmental and other data to succeed.	12
Self-learning systems such as IBM Watson will drive this development.	10
Sharing of data between countries is difficult and a barrier for innovation in this field. Data on register level and easier collaboration between EU countries id needed and discussed ethically.	8

Energy harnessed from the human body is used in applications such as heart pacemakers, organ or brain implants



Number of respondents: 44

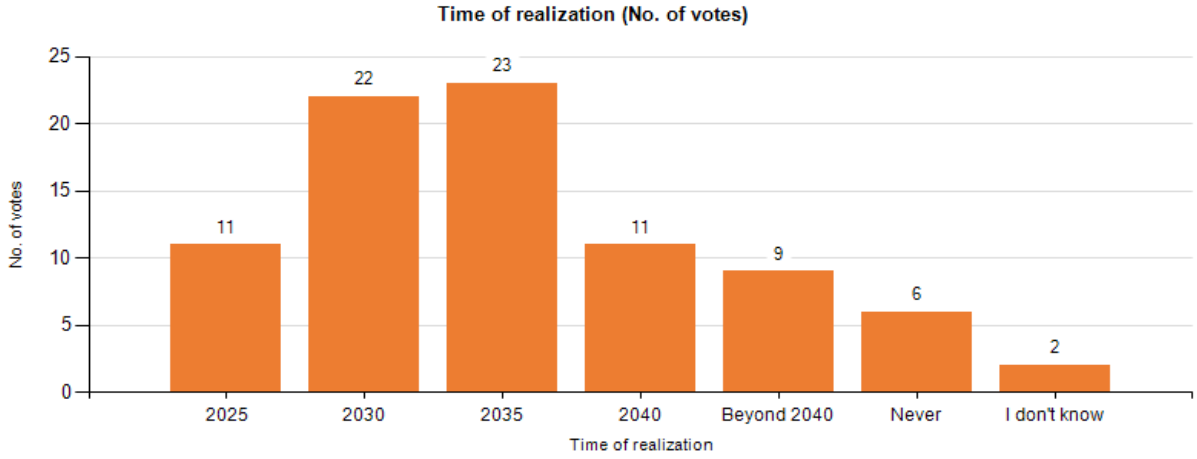
Arguments regarding the time of realization	**No. of votes**
Many potential sources of energy - from body movement to sweat, tears, and even blood - are being explored concurrently, increasing the likelihood of success in at least some of these cases.	28
Companies developed power-generating systems for pavements, football fields and even school corridors using kinetic tiles that harness energy.	12
Science fiction	10
This is not a reasonable solution for the Energy challenges in the EU, it could never be a significant contribution to the energy system compared to energy efficiency and renewables.	8
Bio-mechanical sensors are a hot topic (cfr. 'robotic hand') and already use small electrical signals produced by nerve endings. Next step to small energy production will be possible in near future.	5
Energy harvesting will extend battery life & sometimes eliminate battery replacement, but the power of IoT devices needs to reduce, and harvesting & storage technologies need to improve (HW, SW, system models).	5
Australian and Chinese researchers have recently produced the first 'smart fabric' capable of turning thermal energy into electricity.	4
Life extension made possible by various implants becomes feasible with sources of energy internal to the body that are not at risk of external damage. Cost assurance of safety will pace deployment.	2
A recent Swiss prototype of a skin-like filter uses solar energy to power a pacemaker.	2
People need to understand better the ambient energies available in most use cases and design around this power budget for hardware and software.	2
More energy from humans is available in used water and waste, if you really want to adress this issue. Orders of magnitude are important to keep in mind to really evaluate the potential of the human body.	1
There is already a prototype of a mechanically powered pacemaker. Think self-winding wristwatches...	1



Average: 3.60 **Dispersion:** 1.92

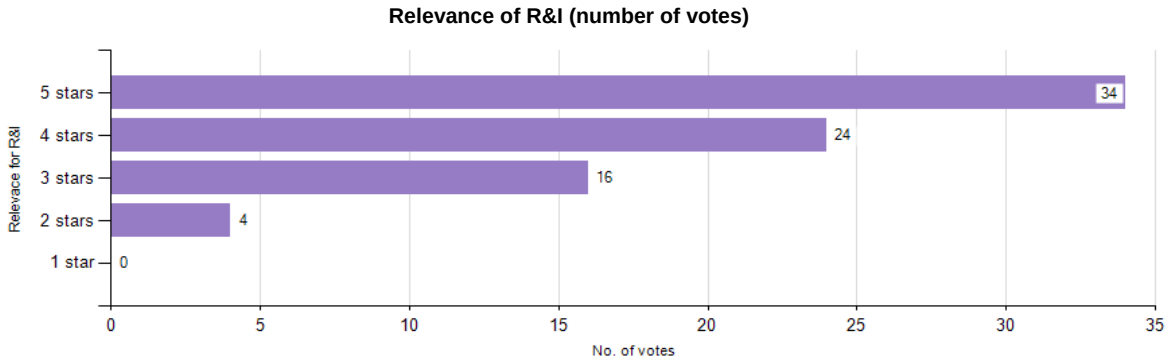
Arguments regarding the relevance of R&I	**No. of votes**
Research has to overcome a substantial efficiency barrier in using human body energy to power implants or wearable devices.	27
A breakthrough is needed in the field of very thin and flexible batteries for the technology to spread widely.	18
Sufficient energy is generated by bodily systems to power implants. Tapping that energy is a major research challenge.	6
Many of the systems which could be realized are based on materials properties, so material improvements are needed to achieve these targets	6
Better power management ICs based on real life ambient energies is needed	5
Lower power sensors and energy harvesting centric software to minimize IoT device power is critical - models to simulate application behavior is also critical	2
Energy saving, energy efficiency and renewables combined to a less consuming life style should be the ambitious goals to reduce our energy bill.	1
Less administration for prototyping can boost research and make the introduction in real practice easy to overwin.	1
Energetic self-sustainability e.g. for pacemakers is a very nice property for patients' well-being, but will not have significant impact to EU energy policy's goals.	1

All mobile and remote electronic devices use technologies that are energy-self-sufficient and completely wireless



Number of respondents: 84

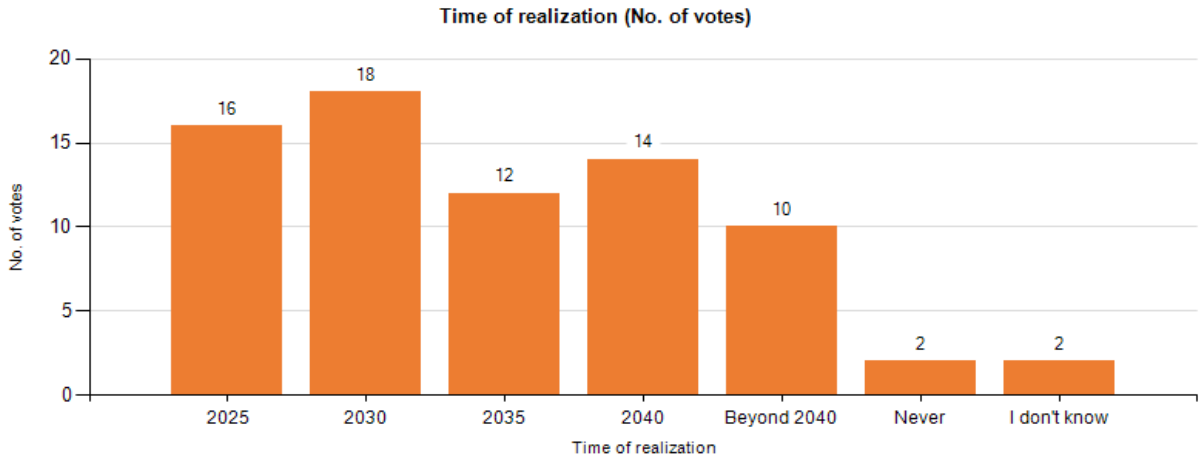
Arguments regarding the time of realization	**No. of votes**
The number of compact, energy-self-sufficient, remote terminal units is increasing.	67
A large spectrum of energy-harnessing solutions from different sources are emerging.	59
Full replacement of existing technologies in this domain (all devices, 100%) will only happen if they are ruled out by regulatory measures.	31
Wireless charging is already on the market	20
Intelligence in combining all available energies in nature will accelerate the progress.	8
I don't consider wireless charging as "energy self-sufficiency", but large-scale availability of wireless power will make it feel as if it was.	7
Disconnected products are useless and therefore any self sufficiency is low value. Wireless solutions are obvious as well as energy harvesting but these do not imply self sufficiency.	6
Short- to medium-range wireless power transfer will charge mobile devices. Such a transfer will be mainly directed on the device itself rather than spread within the environment.	6
Devices become so small/thin/foils that they have no room for connectors, only radio waves (from light to wireless) interfaces with them.	3
Energy self-sufficiency rules out any form of energy made available with the purpose of using it in the device.	2
Very difficult to predict if or when ALL mobile and remote devices will be energy self-sufficient and wireless...	1



Average: 4.13 **Dispersion:** 0.81

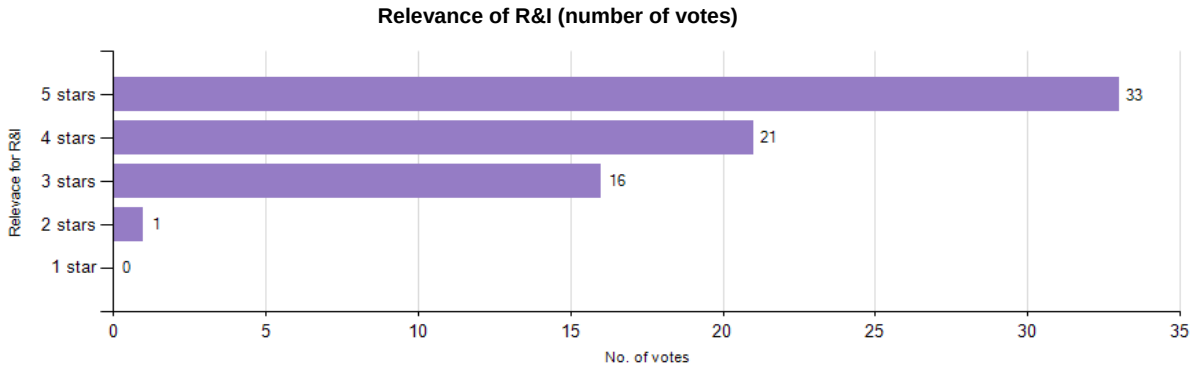
Arguments regarding the relevance of R&I	**No. of votes**
Research is needed for energy harvesting of various types: solar, indoor lighting, vibrational, thermal, biological, chemical, electromagnetic.	76
Wireless Energy Transmission and Battery Management are promising research and innovation fields.	48
Promising research: self-sustainability and virtually perpetual operation of wireless networks.	19
Research is needed on solid-state high-energy and high-power density of micro-energy storage devices (batteries and supercapacitors)	12
One to three main harvesting mechanisms will dominate when mass market adoption takes place. Solar being one of the most likely winners.	11
Energy consumption of devices has to be driven to minimum: research in this area is as important as harvesting.	9
Processing power is further reduces by better chip technologies and integration	4
In case of wireless power transfer, the effects to organic tissues must be understood and regulated. Research should focus on highly directional beams from transmitters to receiver devices.	2
To allow AI to work with mobile devices, the facial, acoustic, etc. recognition algorithms need to work with compression artefacts	1
Graphene-based processors and graphene supercapacitors are a promising pathway to achieve this goal.	1

Precision medicines are prescribed in more than 50% of all prescriptions in the EU



Number of respondents: 71

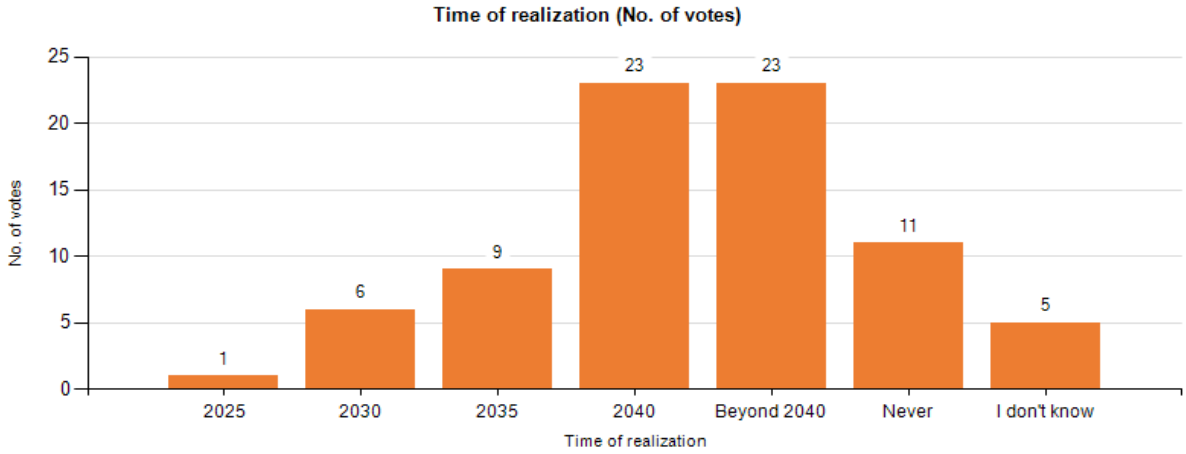
Arguments regarding the time of realization	**No. of votes**
Mobile medicine (use of sensors, apps etc.) will enable much better monitoring of patients and their response to drugs.	57
With the help of big data approaches, individual characteristics of the patients will be taken into account to prescribe the most suitable treatment option.	45
Regulatory measures will take a while to develop and to be adopted consistently across the EU.	35
Rigorously scientific approaches (e.g. biomarkers) are needed to stratify patient groups, draw the right conclusions and then apply or develop appropriate therapies.	28
Pharmaceutical companies are not incentivized to invest in developing drugs that are tailored to a few people.	27
Attention to avoid potential misuse of personal data should be given; maybe the principle of precaution should be applied, ethical frame and regulatory measures are needed.	12
Targeted therapies have already been approved by the FDA.	8
Organ-on-chip technologies will strongly advance the development of precision and personalized medicine.	6
In addition to individual DNA sequencing, for precision medicine to succeed it is likely to require systematic understanding of the microbiome of the individual, which is presently not available.	5
Free access to the clinical trials data, use of AI and a deeper knowledge about causes of diseases will help to develop new strategies of action in precision medicine.	4
Precision medicine requires precise knowledge of the effects of treatments as close to real-time as possible. Patients wanting the benefits will have to agree to provide the data.	3
Precision medicine will help future health outcomes only if it is capable of addressing gaps in access to treatment and health inequalities.	2
Targeted therapies have already been approved by EMA and national authorities.	1
Currently, a lot of funding in the US goes to precision medicine (source: sciencemag).	1



Average: 4.21 **Dispersion:** 0.71

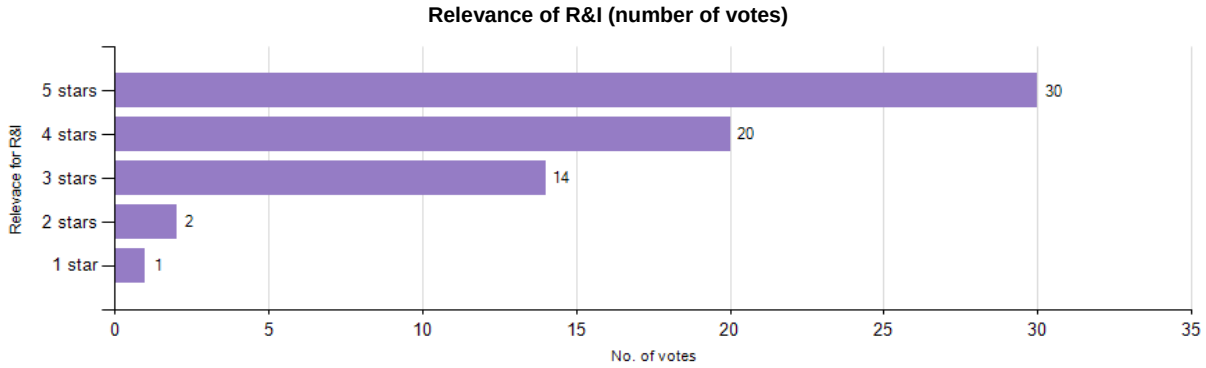
Arguments regarding the relevance of R&I	**No. of votes**
More complex patient profiles that better match individuals will need to be established to enhance predictability of response to treatment.	62
Need for new experimental research for tailored drugs.	32
The current system for classifying diseases will have to be substantially modified in the future.	29
The pharmaceutical industry needs to get research incentives outside the traditional patent system for conditions and diseases that affect few people, and people in poor markets.	24
Improved method for measuring biochemistries in vivo and in real time are required to support better targeting of drugs and improved management of health.	16
Combination of drugs, behavioral changes, digital assistants etc. will personalize health care, with emphasis on prevented, health maintaining part. More responsibilities fall to people themselves.	13
The traditional patent system will need to evolve and adapt to new developments. Pharmaceutical companies will need to find a new business model, public incentives are the solution.	9
Our knowledge of individual patient response & reaction to a given therapy, the impact of lifestyle management and continuous monitoring is too limited. More clinical research is needed.	5
Systematic understanding of the microbiomes of individuals and interaction of same with bodily functions and impact on disease is needed.	4
R&I efforts should consider as early as possible challenges concerning the market access and the healthcare implementation of innovative approaches.	3
Improvement in real time monitoring of precision medication is essential combined with management of the knowledge asset across all individuals with similar diagnosis for continual process improvement	3
Not on individual level - but precision medicine on group level. Big data used for identifying groups of risks	3

More than 20% of the EU population has coupled sensors to their brains to enhance their sense spectrum (infrared, ultraviolet, vibration, magnetic fields etc.)



Number of respondents: 78

Arguments regarding the time of realization	**No. of votes**
Most implants aiming at the expansion of the sensory abilities will be limited to individuals with health problems (such as restoring lost abilities), while sensory- or mood-enhancers will be generally banned.	63
A vast majority of Europeans will remain reticent, fearing interference with other nervous functions.	47
Ethical debates will plague attempts to use or make available commercially, on a large scale, any but the most basic technologies of this type.	26
Neuro-feedback experiments show that the brain can quickly adapt to accommodate new flows of information.	17
New applications will emerge parallel to enhancements in sensor technologies. First "new" senses may be similar to those that some animals have, magnetism, odor detection, wider visibility etc.	13
This will largely depend on whether data transmission is practical without implantation / surgical procedures.	9
If communications is one type of sensing, then new applications in "making sense" in social networks may enhance the capabilities of groups, not only individuals.	4
Sensory enhancements such as glasses and hearing aids will continue to improve and will enable the elderly to maintain functions. A GPS sensor, or an instant readout clock, or similar tech, may find acceptance.	3
Neuro-feedback experiments do not show that the brain can adapt to other types of sensory input, as the sensory modality is still a "standard modality".	3
Enhanced sensing is likely to be in tandem with improvements in B-M interfacing and include computer augmentation for enhanced situation awareness.	2
The sensory enhancements will go through enhancements of peripheral senses (e.g., haptic, interfaces to peripheral nerves), that are easier to interact with.	2
Enhanced situation awareness may be useful for miners, crowd control, other applications such as weather prediction may have occupational advantages.	1



Average: 4.13 **Dispersion:** 0.93

Arguments regarding the relevance of R&I	**No. of votes**
Research will have to demonstrate the complete safety of any sensors / implants altering perception.	55
Current science (mostly) understands how 'typical' human perception works, but still has a long way to go to adequately grasp how the brain might process UV or magnetic fields.	38
Neuro-engineering, even neuro-nanotechnology, could be new promising R&I disciplines for new talented people and disruptive technologies/devices.	11
Sensors alone will not be enough but a significant "artificial distributed pre-processing" is needed, including part of the processing takes place in cloud.	10
This requires us to combine multidisciplinary knowledge and holistic & system thinking to evaluate all possible impacts.	10
Magnetics, ultraviolet and other sensing can become critically important in extreme environments including long duration space missions.	4
This topic will pick up pace quickly beyond EU R&I efforts once any even so simple prototypes are available. When that happens depends on fundamental research.	4

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As energy-harvesting technology makes substantial leaps and sensors are further miniaturized, self-sufficient micro-sensors flood public spaces as well as individual and corporate premises. Valuable data are constantly generated, but personal and organizational environments are exposed to predatory information-gathering practices.

Studies and reports