Ubiquitous Expert Systems

Targeted scenario N°5

Glimpses of the future
from the BOHEMIA study

| PDF | ISBN 978-92-79-81042-8 | doi: 10.2777/387939 | KI-01-18-272-EN-N |

EUROPEAN COMMISSION

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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

Target scenario N° 5
Ubiquitous expert systems

Summary

It is now 2040. There is an abundance of advice based on collected experience, using simulations, data analytics and learning systems. With just-in-time data available all around, expert systems are used routinely in the prediction and management of complex situations, as well as for organizational and individual activity.

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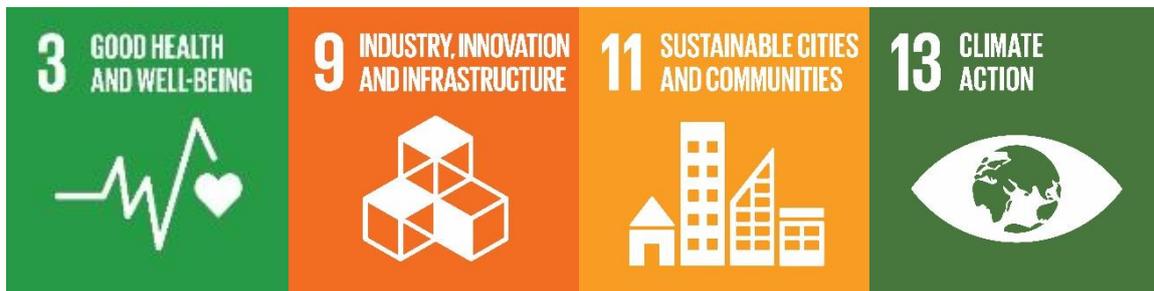
The scenario

It is 2040. Computing is literally ubiquitous and new powerful computers (quantum and DNA-based) are available. Distributed (including 'grid' and 'opportunistic') systems have expanded dramatically. The leap in computing power has led to widespread use of sophisticated simulations and data analytics for the prediction and management of complex systems (environmental, social, (geo)political etc.). Expert systems of increasing complexity, incorporating big data analytics and artificial intelligence, now assist in decisions at any level of intricacy.

With just-in-time data available all around, accessible counselling systems improve decisions and are found everywhere. Some expert systems have a sectoral scope (for example, in health, agriculture or legal services) and are tied to major global actors – corporations as well as non-commercial players. Other systems are community-based wikis. Some are simply personal creations of individuals. All those coexist, compete and learn from one another. These systems are commonly used for purposes of work, entertainment, and more generally in competitive and collaborative activity.

Distinctions between work and leisure have dissipated as personal expert systems plug directly into organizational systems, for "work" or to handle "personal" commercial transactions. People express personal preferences by entrusting more decision-making power to some systems and using others as advisors only. "Full transparency" and "total confidentiality" are still competing as the best defence against 'manipulative attacks' by other actors – commercial, political, and so on. Machine decision-power in public systems continues to be a contentious issue that fuels public debate and calls for the advice of expert ethicists.

Relevance for Europe

High-performance computing is key for competitive advantages in knowledge creation and in innovation. Quantum computing is an area of rising importance for safety-critical systems, and represents a paradigm change in computing. DNA computing is at this stage a vision but possibly another paradigmatic shift. Ubiquitous computing, artificial intelligence, internet of things, are evolving giving every individual more power to help, to contribute and to compete. Such transformations represent areas of future challenge and opportunity for Europe. With greater power at the disposal of every individual comes greater responsibility. People - citizens, migrants, inhabitants and visitors - may come to lead more productive and effective lives, or antisocial behaviour may amplify, with rising mental stress and conflict.

Contribution towards the UN Sustainable Development Goals (SDGs)

Improving decision-making across the board can certainly contribute to improving sustainability, dramatically reduce hunger, better manage natural resources, make employment more productive and advance general wellbeing. Depending on governance, decision systems can increase or help decrease inequality, within and among societies. Thus, all SDGs would be impacted.

Implications for EU policy

The EU has a long standing policy for the modernization of information and communication systems and infrastructures across the Union, and for pursuing global leadership in high-performance computing. This scenario clearly relates to this policy, illustrating the centrality of computing and related infrastructures in the functioning of contemporary and future societies. The distribution of computing power and of sophisticated decision systems may cause dramatic power asymmetries within societies and among countries. Access to supercomputers will enable national and international actors to strengthen their security (e.g., by improving communications and cryptography, or weapons design and testing) and thus exert more clout on global politics; to influence markets through detailed simulations as well as the competitive advantage they bring to national industries; and to shape public opinion, for example by analysing the flow of information in real-time, modelling the spread of news, and thus fighting fake news.

As expert systems become widely used, responsibility, liability, transparency and confidentiality are going to become important, contentious political issues. Europe will have to build accessible open data repositories in order to make expert systems socially accessible and equitable. The matter raises questions of both funding and data governance, and goes directly to the heart of the crucial importance of learning resources – which are both extremely valuable and potentially exposed to abuse.

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

- **Development of better machine-learning algorithms**
- **Research and development in micro and nano-electronics, particularly on scaling-up experiments, and at the intersection with quantum computing**
- **Understanding digitalization and developing Industry 4.0 as bases for a sustainable and competitive European industry**
- **Research and development into quantum computing**
- **Research into the relationship between computing and intelligence**
- **Creating solutions for the accountability of expert systems, and more generally for the governance of public expert systems**
- **Identifying and evidencing abuses in the use of expert systems for decision-making**
- **Research and development in Natural Language Processing covering the entire spectrum of EU languages**
- **ICT solutions for autonomous systems, including systems deployed in remote and extreme environments**
- **Understanding and steering the use of decision systems to strengthen citizen participation in policy-making**

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.

Quantum computers are available on the European market

Time of realization (No. of votes)
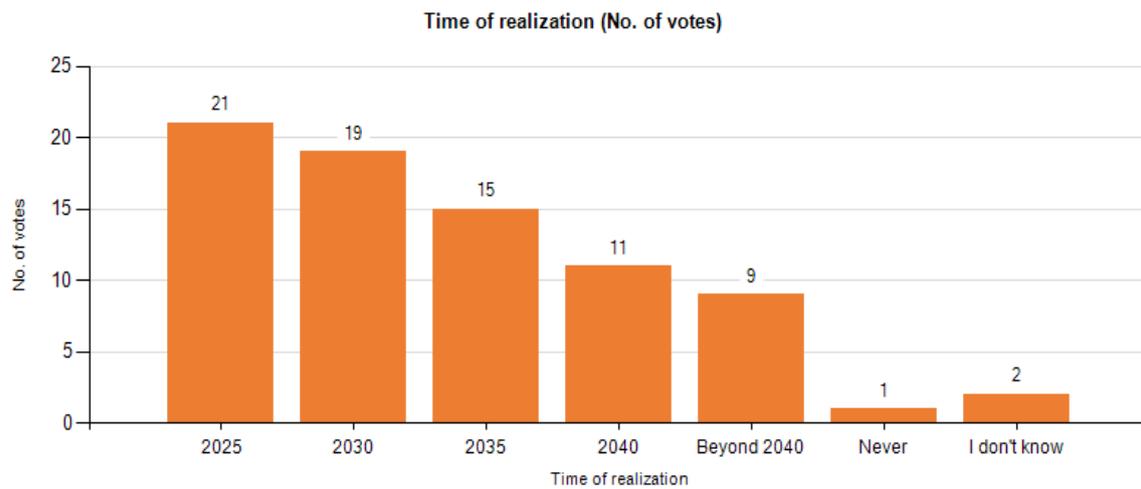
Number of respondents: 76

Arguments regarding the time of realization	No. of votes
Breakthroughs are slow but steady in quantum computers (according to Michio Kaku).	61
Google open sourced its quantum computing software.	22
Quantum computers will be taken in use in very/rather narrow niche applications, possibly as special extra devices to traditional computers.	22
Quantum computers are commercially available today, limited to a small number of qubits and specialised hardware (e.g., DWave). The scale and generality will keep steadily improving.	18
Experts from Maryland University have created a five qubits trapped ion device that can be expanded up to 100 qubits.	15
Quantum algorithms must be developed before Quantum computers can surpass traditional ones in general-purpose applications.	14
Unless solid state portable solutions become available, quantum computers will be used in niche applications.	10
Cost and size of a general purpose quantum computer with known technologies a barrier - $10 billion plus size equal to a football field (https://www.osa-opn.org/home/articles/volume_27/october_2016/f).	5
Quantum simulators by 2035, general purpose quantum computers cannot be forecast at this time with high confidence. 2 decades? 5?	3

Relevance of R&I (number of votes)

Relevance for R&I	No. of votes
5 stars	44
4 stars	21
3 stars	6
2 stars	3
1 star	1
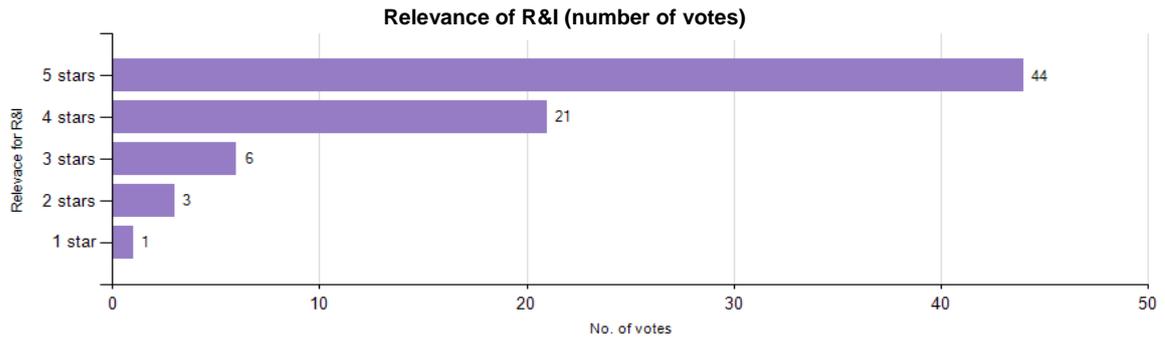
Average: 4.39   **Dispersion:** 0.77

Arguments regarding the relevance of R&I	No. of votes
There is need for basic research to understand quantum logic.	56
There needs to be further development before general purpose quantum computers are scalable.	37
Quantum computing requires a radically new way of thinking about algorithms development and programming.	29
The decoherence problem still awaits new technical solutions.	27
Computing with mixed quantum states need to be understood.	6
Error correction is a major factor in scaling quantum computers.	4

DNA computing allows a new era of environmental scanning

Time of realization (No. of votes)
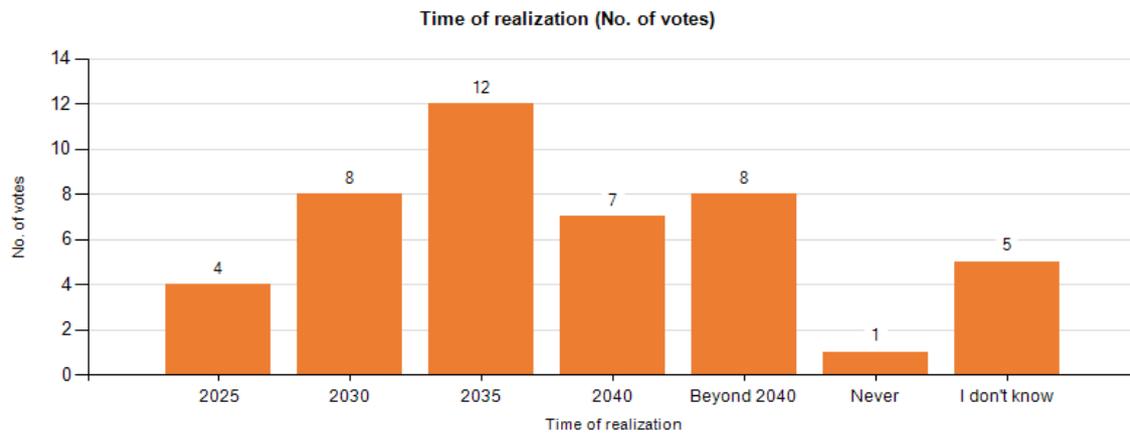
Number of respondents: 45

Arguments regarding the time of realization	No. of votes
Silicon-based computing and its applications are not an adequate reference for what DNA computing could achieve.	34
Most of the hype around DNA computing is based on the theoretical potential of the underlying physical resource.	30
Before we use DNA computers "in the wild" there are huge societal issues that need to be understood and solved.	11
A few years ago already, Israeli researchers inserted DNA 'nanobots' in living cockroaches and used them to accomplish a basic pre-programmed task.	6
DNA computers can potentially identify biotoxins or dangerous infectious diseases and potentially counter the toxic agent replicating copies as required.	4
DNA computers appear to have applications to detect and potentially destroy cancerous cells.	3

Relevance of R&I (number of votes)
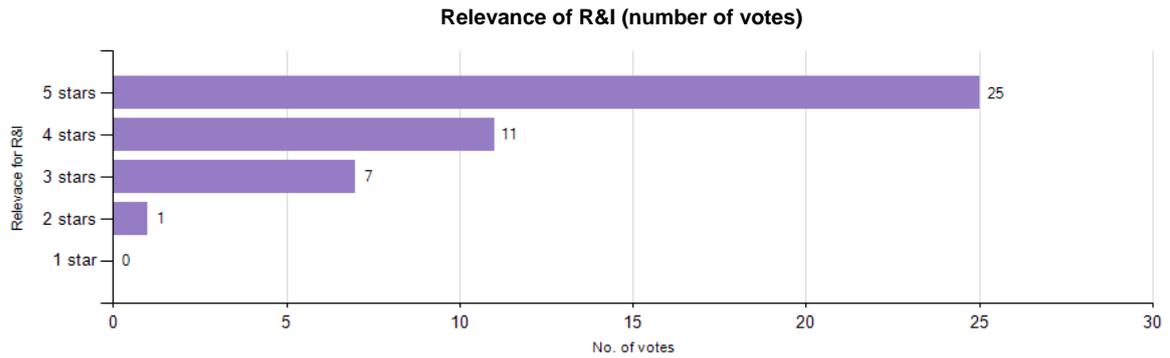

**Average:** 4.36   **Dispersion:** 0.72

Arguments regarding the relevance of R&I	No. of votes
Research on DNA computers capable of detecting several antibodies in the blood and performing subsequent calculations based on this input needs to advance.	32
The current technologies used for DNA nanobots leave them exposed (and unworkable) to the biology of animal (including human) bodies - so solutions to this problem should be explored first.	15
Research on DNA computers may improve early detection of serious diseases	10
DNA/RNA mechanisms may be used for many promising applications, using biological mechanisms for sensing/controlling/actuating synthetic bio-logical systems that interact with ICT.	9
DNA computing is far beyond quantum computing. It will require totally new computation paradigms, training of people to understand how to build such computer physically, materials, etc.	1

Computers with graphene micro-processors are sold for the first time on the European market

Time of realization (No. of votes)
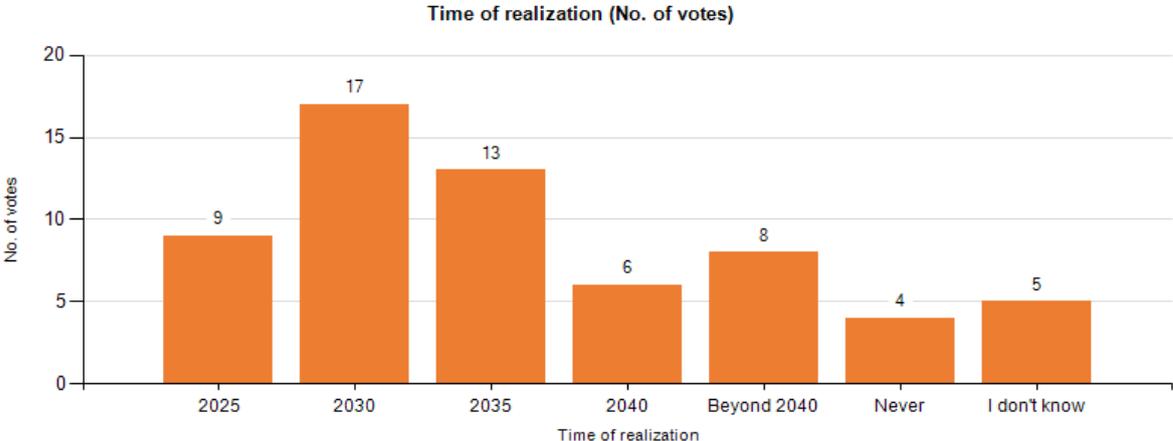
Number of respondents: 61

| Arguments regarding the time of realization	No. of votes
Graphene is still at the stage of basic research, and its use in a computer is still just theory.	42
There are other, better possibilities than graphene for the building of micro-processors.	27
There will be graphene elements in the processors but they will still largely be based on silicon technology.	25
The past teaches that technological revolutions are generally faster than expected.	18
Graphene processors hold the promise of higher clock speed, improved temperature management, lower power consumption and potentially lower cost of production with 2D materials.	5
Graphene processors are at least 10 000 faster than traditional, and will create new fields.	3
Lower heat opens promise for more compact packing and applications such smart sensors.	1

Relevance of R&I (number of votes)
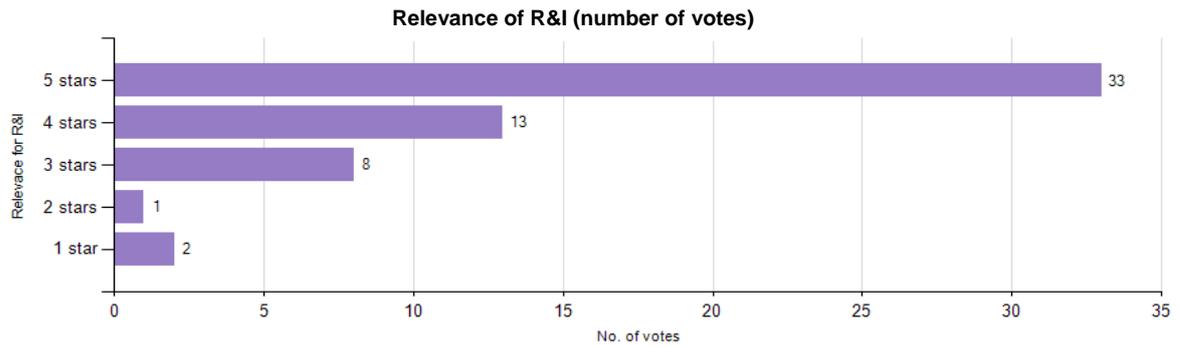
**Average:** 4.30   **Dispersion:** 1.00

Arguments regarding the relevance of R&I	No. of votes
Given the basic state of achievements, future R&I will play a crucial role.	40
If such a computer really works, it is very fast and offers new possibilities in research.	24
With the speed of graphene-based processors, new technical applications of the material will boom.	21
Given that it is still in basic research and quite theoretical, practical applications are highly unlikely.	13
Research efforts on graphene should aim high speed signals transport rather than computation itself (Graphene-based transistors). Even more interesting are 2D materials beyond Graphene.	8
Graphene-based transistors due to low heat may be able to yield multiple smart devices and incorporation into graphene based supercapacitors to improve power management / optimization of smart grids	5
Given that only a single transistor has been shown working, we are still very early in the chain.	2
Much R&I will be needed to build microprocessors from transistors. And then to manufacture them.	1

Artificial Intelligence is used in systems that support policy-makers' decisions across the EU

Time of realization (No. of votes)
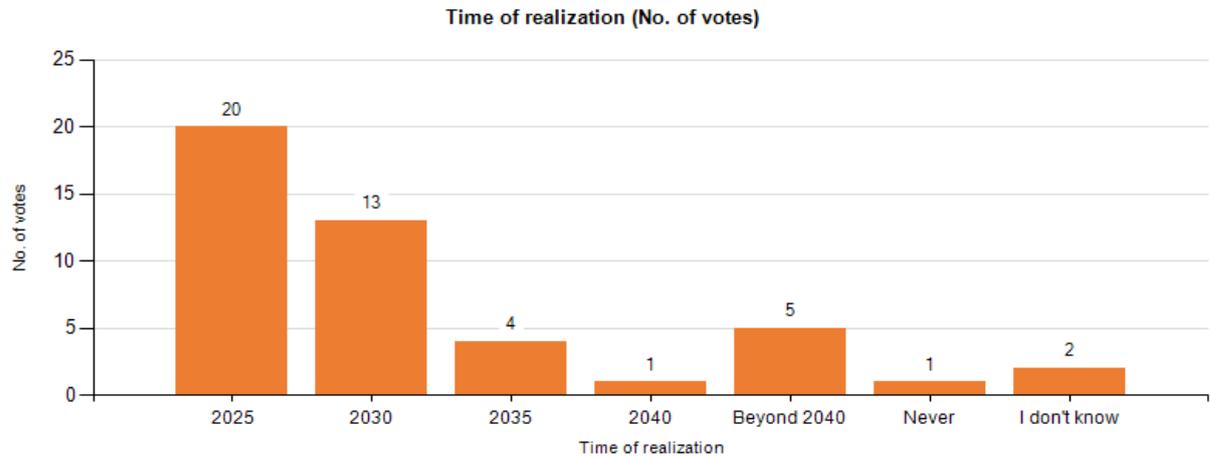
Number of respondents: 46

| Arguments regarding the time of realization	No. of votes
Artificial intelligence is already used and will be used to support decisions, but not as a substitute for human decision-makers.	38
Artificial Intelligence - sophisticated models, or models developed by learning machines - are already used on a routine basis in all sorts of decisions.	33
Any policy decision can be supported by AI if fed with carefully selected data and criteria.	19
AI is used in elections and that use will grow and poses dangers for democratic governance as information bubbles are created to manipulate decision-making.	10
Siri, Google Assistant, Alexa, Cortana: individuals will naturally move from personal assistants to assistants in public decision-making.	7
Decision-makers will never defer to robots (especially when they don't like the latter's decisions).	4

Relevance of R&I (number of votes)

Relevance for R&I	No. of votes
5 stars	19
4 stars	14
3 stars	9
2 stars	3
1 star	0
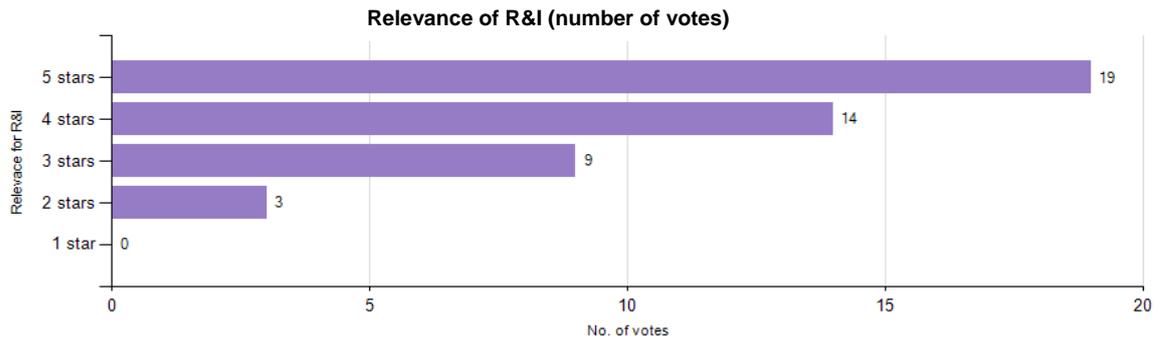
Average: 4.09   **Dispersion:** 0.87

| Arguments regarding the relevance of R&I	No. of votes
We need to understand the blind spots of algorithmic decision-making in specific decisional contexts.	38
Research is needed to identify the elements of the decision process under the control of AI so that humans have the potential to review decisions on demand and understand drivers influencing the AI.	21
Scientists have only now begun to look into whether, how, and when humans trust robots' advice; more research is needed.	18
Also the basic R&I is needed. The algorithms and practices are developing fast and these competences are critical in global competition.	10
Security concerns over data abuse/misuse and other aspects of adversarial machine learning and AI need to be researched.	8
Decision making process will become to require AI tools, because they will become to be not able to decide without them.	2

The right to disconnect from work e-mail in free time is incorporated into the labour regulations of all EU countries

Time of realization (No. of votes)
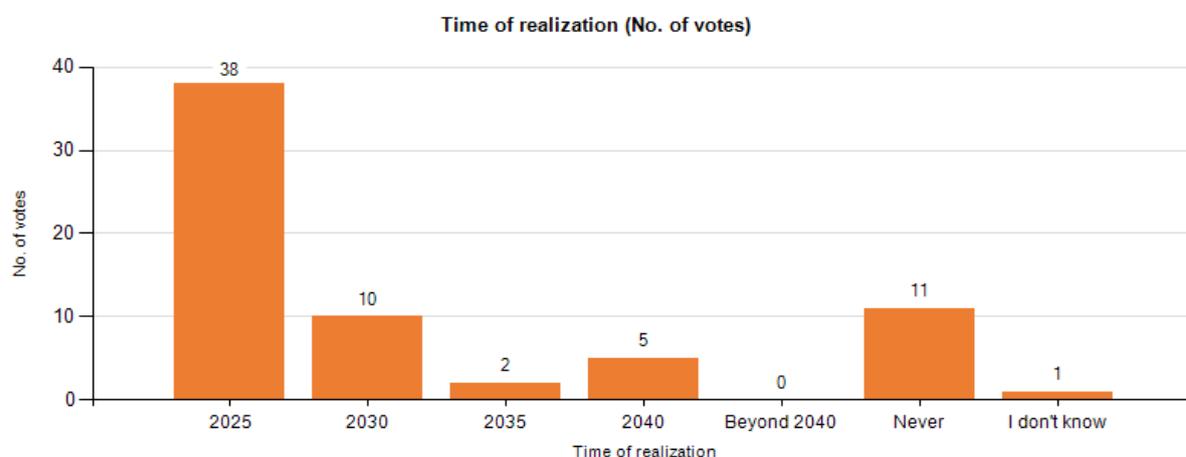
Number of respondents: 66

Arguments for time of realization	No. of votes
Individual rights such as disconnecting from work e-mail will be granted but will not be easy to implement	40
In connection with movements like downshifting values, ethical consumerism, and simple living, the slow-life-model is preferred by more and more people and accepted by more and more institutions.	30
France just gave workers the 'Right to Disconnect' from work e-mail (as of January 3rd, 2017).	30
More and more people are internet and e-mail addicted. They need to be protected.	21
Common regulations on employment conditions face a lot of opposition from national governments. Some countries will want to keep a flexible work force as an argument to attract investments.	20
The interest of large companies in having their employees working all the time will eventually create a lot of mental illnesses related to work.	15
A "Right to Disconnect" just means fighting the symptoms. We need a change in the way we work together and communicate.	13
This regulation will need to foresee exceptions as not all jobs have the same needs-requirements.	11
Boundaries between work and free time will blur and people don't mind it, because they want work to be completely flexible.	7
The Right to Disconnect will be promoted as a Human Rights issue.	6
Many administrative tasks being automatable will be managed eventually by computer robots and iot. Messages corresponding to these tasks will be between machines.	1

Significance for R&I policy
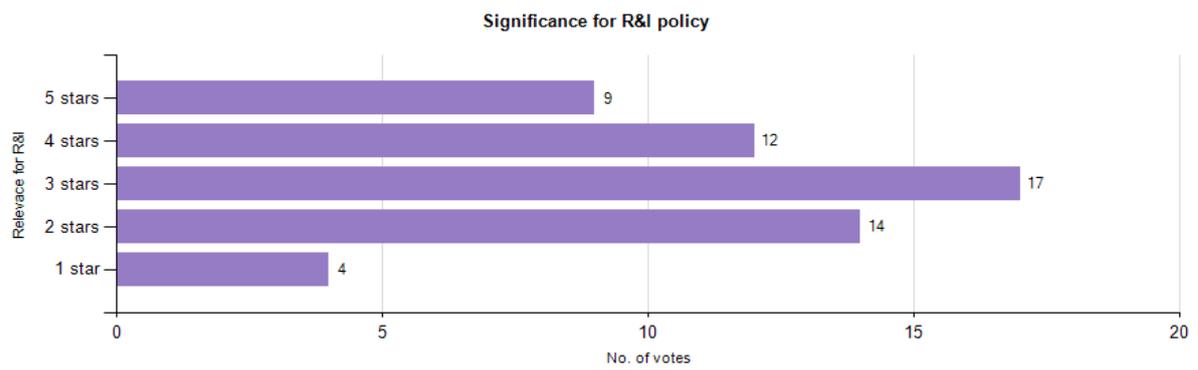

Average: 3.14   Dispersion: 1.39

Arguments regarding the significance for R&I policy	No. of votes
The beginnings of a looming "right to unplug" are already recognizable. The topic is important to all questions concerning work, work-life-balance and health. As life styles within the EU undergo changes, the frame needs to change, too.	43
Unplugging and personal health are increasingly related. More than the right to unplug but training in how to unplug and stay healthy needs attention in company health programs.	30
The development of these individual rights impacts policies in so far as working conditions (and expectations) would change the understanding of productive systems that policies currently address.	27
Developing a right for employees would be a first step.	20
It will make the pursuit of simplification of existing procedures a bit more difficult to achieve, creating more pressure for a radical rethink of the EU R&I policy delivery mechanism.	6
Rethink organization of work in function of necessity of controlling machines' work by human, instead of making basic tasks.	3
Anti-technology movements might require work without 'being connected' at all...	2

Affordable systems using artificial intelligence provide legal and financial advice so that they replace the services of more than 50% of the bankers, lawyers and other employees working in legal and financial advice organizations (compared to 2016)

Time of realization (No. of votes)
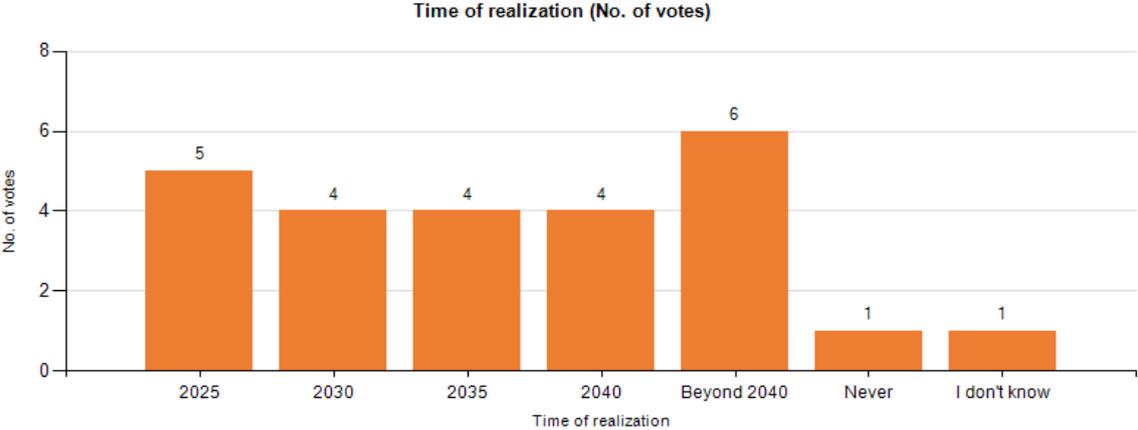
Number of respondents: 25

Arguments for time of realization	No. of votes
Self-learning systems are able to conduct professional service tasks alone in areas like law, science, and financial services; and they are cheaper, more reliable, free of biases … etc.	15
Such artificial intelligence systems are already giving advice in financial services.	14
Artificial intelligence develops strongly but commercial abuses and greed also lead to disasters like the 2008 crisis. Regulation is needed.	12
The digital disruption has come closer for these professions: For the future it means that the qualifications for these jobs need to be adapted to the new digital challenges.	7
It will also impact in other industries, like drivers and transportation etc.	5
"Human advice" will not vanish. It will be of better quality once machines do standardized, repetitive part of the work.	4
Systems like IBM's 'Watson' are improving very fast. They might soon be trusted more than 'human advice'.	3
In 2016 the first robot-lawyer has been hired in the States by one of the country's biggest law firms. The robot will assist with bankruptcy cases.	2

Significance for R&I policy
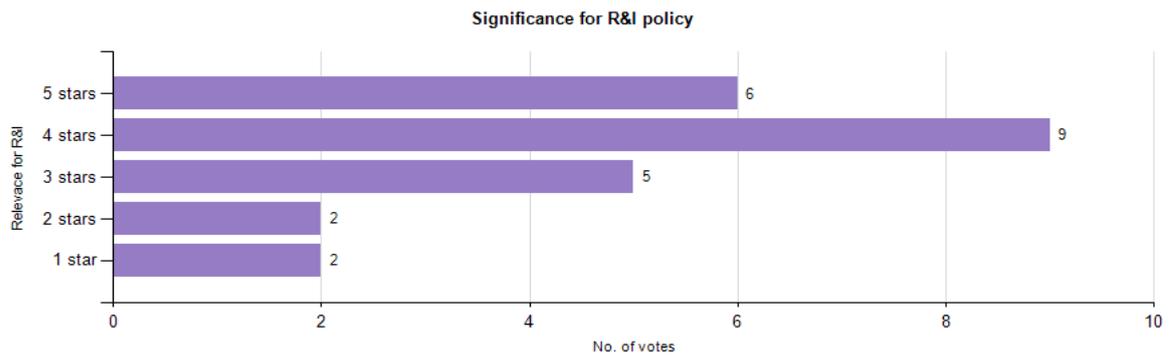
Average: 3.62   **Dispersion:** 1.44

Arguments regarding the significance for R&I policy	No. of votes
Research work on the social, cultural, political and economic limits of artificial intelligence is very much needed.	20
The challenge for tomorrow's workplace is an increase in inequality in employment and pay chances and the question of how to ensure adequate training and qualification for the most affected workers.	11
Regulation is needed to define the limits of the systems - what are they allowed to provide, e.g. advice only or decisions, signatures, send out official letters…	10
Multi-discipline research is needed. Isolated technology, economics, sociological etc. research cannot solve the issues.	8
"Artificial intelligence" is already gradually superseded by "Augmented Intelligence", indicating the role of people is needed but a lot of routine work will be automated.	5
As these systems will replace lawyers, scientists, bankers etc, policies are needed that support the creation of new jobs to avoid unemployment.	3
It is necessary to realize that artificial systems can be of great help, but they never can replace the human expert. The simple reason is that they cannot think in the proper meaning of the word	2
Public-private partnerships between the EU and the resented "tech elite" companies could be one solution.	1

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non-commercial purposes.

It is now 2040. There is an abundance of advice based on collected experience, using simulations, data analytics and learning systems. With just-in-time data available all around, expert systems are used routinely in the prediction and management of complex situations, as well as for organizational and individual activity.

Studies and reports