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Anticipatory governance of emerging technologies: White paper

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Anticipatory governance of emerging technologies

Summary

Anticipatory governance addresses governance challenges of emerging technologies, which offer benefits but also pose risks to the environment, health and security. In this white paper, we present the results of a literature review on key anticipatory governance approaches and methods found in the literature. We also consider how wicked problems associated with emerging technologies are addressed.

Anticipatory governance entails proactive engagement with stakeholders and interactive processes in the early phases of technology development. The core approaches of anticipatory governance are foresight, stakeholder engagement and ethical considerations, which are closely intertwined.

Foresight involves structured methods like scenario planning, horizon scanning and systems thinking to anticipate future developments and manage risks. Stakeholder engagement ensures the involvement of diverse stakeholders in decision-making processes, aligning emerging technologies with societal values and needs. Ethical considerations address transparency, responsibility and the broader societal implications of emerging technologies.

The literature suggests that addressing wicked problems associated with emerging technologies requires new forms of collaborative strategies, stakeholder engagement and cross-sectoral learning, as well as a mix of problem-solving and problem-finding approaches.

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Glossary

Adaptive governance: A governance framework involving open decision-making, community initiatives and integration of different types of knowledge.

Anticipatory governance: A proactive approach to govern emerging technologies by involving stakeholders, using foresight methods and considering ethical aspects in the early stages of technology development.

Anticipatory Governance Compass (AG Compass): A heuristic tool developed within the GOWELL project to help policy makers systematically engage in foresight and anticipatory governance of emerging technologies.

Constructive Alignment (CA): An outcomes-based approach to learning, in which the learning outcomes are defined beforehand.

Constructive Technology Assessment (CTA): A technology assessment approach that involves diverse stakeholder groups to address societal issues related to technology.

Double-loop learning: A learning process where actors change their underlying perceptions and assumptions of the system, reflecting on and potentially changing beliefs and assumptions based on new information and perspectives.

Ethical, Legal and Social Implications (ELSI): Programmatic anticipation of ethical, legal and social issues that arise from emerging technologies and scientific advancements.

Ethical considerations: Addressing transparency, responsibility and the broader societal implications of emerging technologies.

Ethics by design: Embedding principles of ethics early on in the implementation of technological solutions, such as AI products.

Evidence-informed policy making: An approach to policy-making that aims to inform policy deliberations and decisions with the best available evidence, including quantitative data, qualitative data, stakeholder input and scientific and expert advice.

Foresight: Structured methods like scenario planning, horizon scanning and systems thinking to anticipate future developments and manage risks.

Governance: Overarching frameworks, processes and mechanisms through which organisations, institutions or societies are directed, controlled and held accountable.

Horizon scanning: A foresight method of examining the external environment to identify early signals of change.

Humble governance: A governance approach characterised by adaptability, openness and a willingness to learn and adjust policies based on new information and feedback.

Regulatory preparedness: An anticipatory and collaborative risk management tool involving dialogue and knowledge-sharing among regulators, innovators and other stakeholders.

Regulatory sandbox: A controlled environment where companies can test new ideas, products or services without being immediately subject to all regulatory requirements.

Responsible Research and Innovation (RRI): Guidelines for ensuring that research and innovation are conducted in a way that is ethically acceptable, socially desirable and sustainable.

Safety by design: A standardisation process, in which safety information regarding a certain material, substance or product is integrated from initial research and development phases onward.

Scenario planning: A foresight method involving the development of plausible future scenarios to prepare for potential developments.

Science for policy: Integration of scientific evidence and knowledge into the policy-making process, see Evidence-informed policy making.

Societal Risk Evaluation Scheme (SRES): A multi-criteria approach that considers various societal risk factors associated with emerging technologies, particularly in the field of synthetic biology.

Stakeholder engagement: Involvement of diverse stakeholders in decision-making processes to align emerging technologies with societal values and needs.

Strategic foresight: A foresight approach that embeds futures studies methods with strategic management and/or policy making, especially in the EU policy context.

Systems thinking: In the context of anticipatory governance, systems thinking refers to addressing systemic challenges through coordinated and adaptive governance approaches, including a broad policy mix, real-world experimentation and transformative coalitions.

Technology Assessment (TA): An assessment of short- and long-term consequences of the application of technology, including societal, economic, ethical and legal issues.

Tentative governance: A governance process for emerging science and technology, with a focus on facilitating exploration and learning opportunities rather than establishing definitive objectives.

Transparency by design: Promotion of transparency from the beginning of the life cycle of technological solutions, particularly AI products, taking into account potential negative impacts on the fundamental rights of users.

Wicked problems: A complex, ill-defined issue with no final solution, characterised by constantly changing parameters, conflicting perspectives and the need for suboptimal, context-dependent resolutions, e.g. health problems.

Introduction

This white paper contributes to innovation policy development and research by presenting the results of a systematic literature review on **anticipatory governance and problem framing of emerging technologies**. Anticipatory governance addresses governance challenges of emerging technologies, such as artificial intelligence (AI) applications, which offer benefits but also pose risks to the environment, health and security (OECD 2024). The review also covers framing of wicked problems associated with these technologies, focusing on the literature on challenge-driven cases with clear societal needs but uncertain solutions, as seen in many health and well-being problems (cf. Wanzenböck et al. 2020).[1]

Lately, anticipatory governance has been a keen object of policy development work of the **OECD**, which has actively promoted the use of anticipatory governance framework for emerging technologies "to support technology development for societal good, whilst safeguarding against, or preparing mitigation strategies for, potential negative societal impacts of new and emerging technologies" (Robinson et al. 2023, 26). The policy discussion of the **EU**, on the other hand, has addressed similar governance challenges with slightly different terminology. Notably, **"strategic foresight"**, which shares many similarities with anticipatory governance, has been a key EU approach to emerging technologies as it can "help anticipate trends, risks, emerging issues, and their potential implications and opportunities to draw useful insights for strategic planning, policymaking, and preparedness" (EC 2023, 157).

We recognise that there are also other "neighbouring" concepts to anticipatory governance, such as **"tentative governance"** (Kuhlmann et al. 2019) and **"adaptive governance"** (Steelman 2022). We are also aware that anticipatory governance frameworks are used beyond innovation policy, even for large-scale conflict prevention measures during social upheavals (e.g. Milojević 2024). We chose anticipatory governance due to its focus on technology and innovation, addressing both the benefits and risks of emerging technologies. We see anticipatory governance as a promising paradigm shift in governance, relating to fundamental changes in the way we perceive knowledge, decision-making and coming to a shared understanding of the essential societal goals.

Our key question is **what can be learned from international best practices of anticipatory governance** in terms of supporting new technology development, making informed policy choices and improving the use of new technologies. To answer this question, we deemed it necessary to explore **both academic and policy research** on anticipatory governance. The literature review follows standard literature review procedures, including protocol development, comprehensive search, study selection, content analysis and synthesis (Rotolo et al. 2015; 2022).

Two Scopus database searches were performed (Table 1). The first search identified 34 research articles on "emerging technologies" and "anticipatory governance," with 32 deemed suitable for content analysis. The second search found 47 articles on "emerging technologies" and "wicked problems" / "societal challenges" / "problem framing," with 12 suitable for analysis. Additionally, 17 policy documents (reports or report chapters) from the OECD and EU publication platforms were selected for the content analysis after reviewing executive summaries.[2] **In total, 61 publications published between 2009 and 2024 were selected for the core set**.[3]

[1] We thank Matthias Weber, Gabriela Bodea, Susanne Stenberg, Håkan Burden and Katri Valkokari for commenting on an earlier version of this manuscript.
[2] The Scopus article searches were performed on 25.9.2024. Search conditions: search within article title, abstract and keywords; cover all subject areas; no year range (search 1); from 2009 onwards (search 2); limit to articles. The policy document searches on the publication platforms of the OECD and the EU were performed on 15.10.2024.
[3] For the full list of publications, see Annex 1.

Table 1. Sources and search strategies of the literature review.

Target	Source	Search terms	Sample	Core set
Academic research	Scopus	"emerg* technol*" OR "emergence of technolog*" OR "techn* emergence" AND anticipator* W/5 governanc*	34	32
		"emerg* technol*" OR "emergence of technolog*" OR "techn* emergence" AND "wicked prob*"/"soci* challeng*"/"problem fram*"	47	12
Policy research	OECD	"anticipatory governance" OR "anticipatory innovation"	116	11
	EU	"anticipatory governance" OR "anticipatory innovation"	172	6
Total			**369**	**61**

In the content analysis, which forms the main body of our review, we examined the framework of anticipatory governance and its key methodological components employed in the core set of publications.[4] A word frequency analysis supported this enquiry by identifying common topics and their differences over time.

Next, we present an overview of the results, followed by the detailed findings of the content analysis. We also provide standalone reviews of AI applications in health care, the UK's anticipatory governance policy and the EU's Science-for-policy approach in text boxes. In conclusion, we outline the next steps of the GOWELL project, including case studies and developing a shared methodology and tool for anticipatory governance, called the **Anticipatory Governance Compass (AG Compass)**.

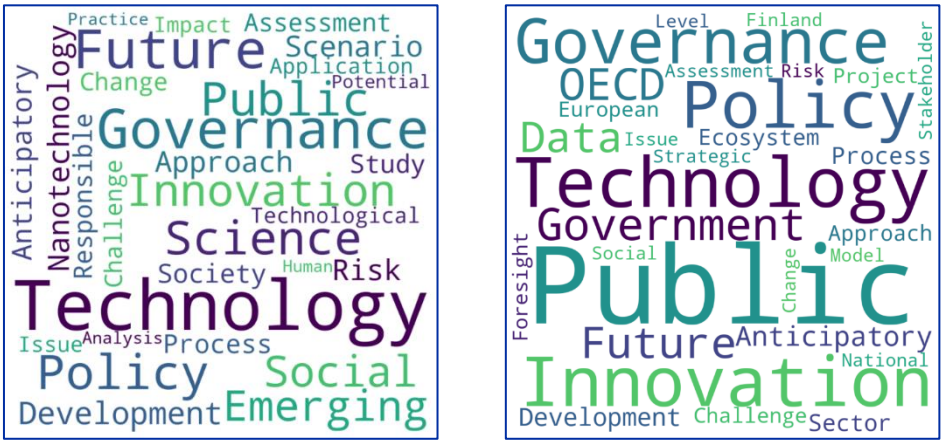
Overview of results

Both research articles (n=44) and policy documents (n=17) included in our core set began appearing at the turn of the 2010s, with publishing activity increasing gradually throughout the decade. There has been a notable increase in publishing activities in recent years: Over half of the research articles were published between 2018-2024, while over half of policy documents between 2021-2024. Eleven research articles were published in journals dedicated to future studies, such as *Futures*. Otherwise, the publication venues varied significantly, from ethics journals to engineering journals. All articles employed social sciences methodologies, regardless of where they were published. These methodologies were usually qualitative in nature. In terms of technology areas, **health and biotechnologies, nanotechnologies and AI applications** were the most frequently addressed emerging technologies. Somewhat surprisingly, **quantum technologies** were addressed only in one policy document and in none of the articles. This might be due to the novelty of the topic and the situation is likely to change in the coming years.[5]

We were interested to know whether the key concepts and terms used in research articles differed from those found in policy documents, and to what extent. The word clouds below (Figure 1) describe the top 30 most frequent terms in research articles vs. policy documents within our core set. **The most frequent terms are much alike in research articles and policy documents**, with policy research being more concentrated on the use of a few terms than academic research, which is more dispersed. Some differences can be observed, however. Policy documents rely on

[4] For the guiding questions of the content analysis, see Annex 2.
[5] Other technologies addressed in the literature reviewed: 3D printing, autonomous vehicles, blockchain and other digital platforms, drones, energy technologies, nuclear weapons, robotics, smart materials and solar radiation management.

policy terminology that is not common in research articles, such as “government, “OECD”, “sector” and “ecosystem”.



Academic research **Policy research**

Figure 1. Word cloud comparison of academic and policy research.[6]

Notably, nanotechnology, which is one of the earliest focus areas of anticipatory governance, ranks high among the most common terms in research articles, while it is less discussed in policy documents, most of which have been published recently. We took a closer look at the research articles if we could see a similar difference between recent research articles (published in the 2020s) and older ones but noticed no difference: **Nanotechnology is as current term in present-day research on anticipatory governance as it was in the 2010s.** Regarding other technologies, the rise of AI and drone technologies is also evident in the increasing use of terms related to these technologies in current research.

The content analysis, which will be further discussed in the following section, revealed that the most common approaches and methods to address emerging technologies are foresight, stakeholder engagement and ethical considerations:

- **Foresight** refers to a structured method for anticipating and preparing for future developments concerning emerging technologies, often through scenario development.

- **Engagement**, also known as inclusion, is about involving diverse stakeholder groups, from experts to citizens, in decision-making processes, ensuring that emerging technologies align with societal values and needs.

- **Ethics** emphasises the importance of considering the broader societal, legal and moral implications of emerging technologies and their use.

Regarding the key literature references, we found two references cited in most of the publications under review: a book chapter “Anticipatory Governance of Nanotechnology: Foresight, Engagement, and Integration” by Barben et al. (2008), published in *The Handbook of Science and Technology Studies*, and a research article “Understanding 'anticipatory governance'” by Guston (2014). These publications present

[6] The word clouds were generated from 44 scientific literature documents and 17 policy documents published between 2009 and 2024. Common stopwords, punctuation, digit-only words and one- or two-character words were removed based on NLTK and Stopwords ISO stopword collections (Bird et al. 2009; Diaz & Suriyawongkul 2016). The remaining words were lemmatised before calculating word counts.

the basic tenets of the influential anticipatory governance approach developed at the **Center for Nanotechnology in Society at Arizona State University (CNS-ASU)**. This approach has many theoretical roots, the most important being Constructive Technology Assessment (CTA) (Schot & Rip 1997).[7]

The anticipatory governance approach advocated by CNS-ASU builds on three components called "capacities," which should be developed in concert (Guston 2014; Barben et al. 2008):

1) **Foresight** that is non-predictive, i.e. "a methodologically pluralist approach to plausible futures with an emphasis on such methods as scenario development" (Guston 2014, 226).

2) **Engagement** referring to the exchange of ideas between lay people and scientists/policy makers.

3) **Integration** that is about collaboration and dialogue between social and natural scientists.

The foresight and engagement capacities have been a keen focus of literature, as discussed earlier, while integration has received less attention. Instead, ethical considerations, which are missing from the CNS-ASU's capacity list, have played a key role in the methodological development in general. Nevertheless, CNS-ASU's anticipatory governance approach has continued to be influential. Although it was first developed for the governance of nanotechnologies, particularly in the US context, our literature review shows that its basic tenets have been applied and further developed to address governance issues of various emerging technologies in Europe, the USA, Latin America and Australia.[8]

Regarding the framing of wicked problems associated with emerging technologies, the literature suggests that **addressing wicked problems requires a combination of collaborative strategies, stakeholder engagement, cross-sectoral learning and a mix of problem-solving and problem-finding approaches**. For instance, Alford et al. (2012) discuss three alternative strategies for addressing wicked problems of emerging technologies: 1) egalitarian/ collaborative, 2) competitive and 3) hierarchical/authoritative. The first includes public engagement, the second is market-driven and the third is based on scientific authority.

Interestingly, Alford et al. suggest a pluralistic approach to wicked problems by asking "How could a variety of strategies be used for specific wicked problems, such as for risk assessment of nanotechnologies?" (Alford et al. 2012, 79). Another example is a problem-finding framework for AI governance by Liu and Maas (2021). They stress the importance of combining problem-solving and problem-finding approaches to better prepare for unforeseen impacts. The problem-finding approach refers to an active and systematic search for potential problems that AI might raise for regulation and governance.

[7] Unlike traditional technology assessment, which focuses on assessing the impacts of new technologies, CTA emphasizes early interaction and dialogue among various actors, including consumers and producers, to affect ongoing technological developments (Schot & Rip 1997).

[8] It is not a coincidence that the anticipatory governance approach of CNS-ASU focuses on nanotechnologies. CNS-ASU itself was founded in 2005 under the US National Nanotechnology Initiative (NNI) (Guston 2014). Funding research on the anticipatory governance of societal implications of nanotechnologies has been a top priority of the NNI since its outset in 2003 (Roco 2023).

In focus: AI and healthcare

The integration of artificial intelligence (AI) with various disciplines and its ability to analyse vast amounts of data quickly and accurately is revolutionizing the healthcare system. AI offers numerous benefits, including real-time patient monitoring by virtual health assistants, improved diagnostic imaging accuracy and faster drug development.

Health technologies are also becoming deeply integrated with emerging technologies (e.g. AI, gene editing, nanotechnology, neurotechnology and robotics), creating a need to evaluate their potential impacts. Helbing and Lenca (2024) argue that the boundaries between the physical-biological and the cyber-digital worlds are no longer well-defined, resulting in fundamental implications for individuals and societies. Therefore, the use of AI in healthcare requires consideration of its ethical, legal and social aspects. Discussions with various stakeholders are needed regarding their implications, as well.

In the literature reviewed, health-related anticipatory governance approaches have concentrated on synthetic biology, genetics, neurotechnology and bioengineering. There is, however, a lack of literature on AI applications in healthcare settings. Although studies like Cremer and Whittlestone (2021) have explored the futures of AI, offering insights for the healthcare sector, there is still a **need for dedicated research on AI and healthcare** specifically from the perspective of anticipatory governance.

Core approaches

In this section, we present the results of the content analysis by analysing the key characteristics of the most common approaches and methods employed in the literature under review: **foresight, engagement and ethics.** Foresight refers to the use of scenario methodologies, but also other foresight methods in use, such as risk assessment schemes, narratives and identification of early warning signs. Engagement, also known as inclusion, aims to engage stakeholders early on and takes place through multiple means, including workshops, stakeholder platforms and partnerships. Ethical questions are addressed within the Ethical, Legal and Social Implications (ELSI) approach, as well as within the Responsible Research and Innovation (RRI) scheme. In the research process, the **core approaches are closely intertwined**, e.g. ethical questions can be addressed in a stakeholder workshop utilising results from scenario work.

Foresight

The literature suggests that foresight in policy and governance is crucial for decision-makers to anticipate future scenarios involving emerging technologies. Key foresight methods include **scenario planning, horizon scanning and systems thinking.** A central theme in technology-related foresight literature is risk management and its connection to anticipatory governance, which involves proactive stakeholder engagement and frameworks to manage uncertainties. Examples include 3D printing and nanotechnology, where anticipatory governance helps address potential threats to health, cybersecurity and the environment (Andersen et al. 2024; Schneider et al. 2023; Urueña 2019).

Overall, the foresight methods discussed in the literature range broadly from horizon scanning and scenario building to expert elicitation and narrative foresight. **Each foresight method has its pros and cons.** Horizon scanning and scenario building are strong in exploring and anticipating various future projections, but they do not predict the future and sometimes lack concreteness. Systems thinking helps policy makers understand and control their environments by mapping out possible trends, though it can be complex and resource-intensive (Asquith et al. 2019, 194). Expert

elicitation and causal graphs are useful in converting tacit knowledge into explicit knowledge and providing early warning signs, but they can introduce biases and be challenging to map (Böhle et al. 2012). Narrative foresight, exploring and shaping future possibilities through storytelling, uses citizen-driven narratives to explore potential future uses of technologies, which can highlight risks and benefits but may lack the rigour of more structured methods (Frederiksen et al. 2024). There is an identified need to use various methods for dealing with the uncertainty of foresight, such as stress-testing methods or Societal Risk Evaluation Scheme (SRES), which is useful for anticipatory governance but can be complex and require extensive data (Cummings & Kuzma 2017).

Which methods and tools are most appropriate depends on the intention and goals of foresight. For this reason, foresight strategies range from "predictivist approaches" (focusing on creating robust epistemic models to predict future scenarios, relying on quantitative data and statistical methods to anticipate future events with a high degree of certainty) to more "strategic approaches" (emphasising future(s)-planning) and "exploratory approaches" (opening up alternative futures and exploring various possibilities, encouraging thinking beyond the conventional), as well as "critical-hermeneutic approaches" (focusing on analysing existing representations and narratives about the future in a critical examination) (Urueña 2019).

Regarding risk management, **regulatory preparedness** is put forward as an anticipatory and collaborative risk management tool. It involves anticipating regulatory challenges posed by new technologies and ensuring safety assessments before market entry. This requires dialogue and knowledge-sharing among regulators, innovators and other stakeholders, but also inherent adaptation ability and capacity in the institutions involved (OECD 2020; Nordmann 2021).

Engagement

Engagement, commonly referred to as inclusion, ensures the involvement of diverse stakeholders in all stages of decision-making, from agenda setting to policy design, implementation and monitoring. **Inclusiveness goes beyond mere participation.** While participation involves engaging stakeholders in discussions and activities, inclusiveness ensures that these engagements are meaningful and impactful. Inclusiveness in anticipatory governance requires active stakeholder engagement, consideration of values and cross-sector collaboration to enhance societal acceptance of technological innovations (e.g. Guston 2012). It addresses power dynamics and ensures meaningful participation, particularly for marginalized groups (Boon et al. 2015). Effective anticipatory governance involves a wide range of stakeholders, ensuring policy decisions reflect societal needs and values (Alford et al. 2012).

According to the literature reviewed, **engaging stakeholders early in the development of emerging technologies is crucial**. Early stakeholder engagement helps align with societal values and needs, building trust and fostering a sense of ownership. This anticipatory approach allows for the consideration of the **Ethical, Legal and Social Implications (ELSI)** approach and helps in shaping technologies that align with societal values and needs (Alford et al. 2012; Andersen et al. 2024). Inclusion is essential for building trust, particularly in projects involving AI and other advanced technologies. By incorporating user feedback and ensuring accessibility, projects and technology development can address societal concerns and foster a sense of ownership among end users.

Effective anticipatory governance involves a wide range of stakeholders, including the government, private sector, non-governmental organisations (NGOs) and the public. **Diversity** ensures that policy decisions are informed by varied viewpoints, supporting outcomes that reflect societal needs and values, which may include addressing the specific needs of vulnerable groups in technology development (Boon et al. 2015).

A recurring theme in the discussion on inclusion is **Responsible Research and Innovation (RRI).** RRI focuses on principles of anticipation and inclusion, involving diverse stakeholders to address societal challenges. Somewhat in contrast, anticipatory governance is often driven by policy makers and experts, aiming to manage the risks and uncertainties linked to emerging technologies (McAslan et al. 2024, 3-4).

The literature highlights that inclusiveness in anticipatory governance is not just about involving stakeholders but ensuring that their engagement leads to meaningful and impactful outcomes (Gjefsen 2013). Therefore, **inclusiveness in anticipatory governance requires diverse and active stakeholder engagement, consideration of values and beliefs and collaboration across sectors**, which can enhance the societal acceptance of technological innovations and ensure they better meet societal needs and values (Guston 2012).

Ethics

Anticipatory governance is often linked to RRI when ethical questions are discussed. Ethical considerations are mostly addressed implicitly or indirectly, however. When they are addressed, ethical considerations often concern the **transparency and responsibility of policy makers** when adopting new technologies, urging decision-makers to avoid unnecessary "hype" and encouraging them to critically evaluate technological promises and optimism. This ensures that adopted policies are in the public's best interest and openly address any potential shortcomings or other societal issues of interest (Cohen and Jones 2020).

Stakeholder engagement and participatory approaches are part of the ethics agenda, as engaging stakeholders is crucial for ethically alert anticipation. They help to gather diverse perspectives, enhance understanding of future possibilities and foster collaboration in developing strategies and policies, by involving various stakeholders, including citizens, in the governance of emerging technologies (Frederiksen et al. 2024). **Potential negative impacts of emerging technology** are also highlighted (e.g. AI and drones), such as misuse or criminal activities, which may necessitate new regulatory actions and ethical frameworks for security or privacy protection.

Some of the articles also discuss the **impact of AI on democracy** (e.g. Cremer & Whittlestone 2021), including the risk of reinforcing existing societal inequalities and the importance of democratic control over AI technologies. Such issues emphasise the need for transparent communication, ethical research practices and responsiveness to societal concerns, to maintain public trust and ensure that AI technologies contribute positively to society. Also, **privacy issues** are often at the centre of technology ethics, e.g. in the case of distributed ledger technologies (Hassan et al. 2020).

The **ethical importance of building and maintaining public trust** in research and innovation is central to emerging technologies in their early phases. This involves transparent communication, ethical research practices and responsiveness to societal concerns to ensure that technologies (e.g. AI) are developed and used in socially desirable ways. There are concerns raised regarding the impacts and effects of emerging technologies, which are difficult to foresee and fully anticipate, e.g. "If we want AI to benefit society broadly, we must urgently find ways to give democratic control to those who will be impacted" (Cremer & Whittlestone 2021, 100).

How could this be achieved? Technology development must improve in designing and planning processes that consider ethical issues and principles. Solutions and mechanisms, such as **ethics by design, transparency by design** (CNECT 2024) or **safety by design** (Winickoff & Pfotenhauer 2018, 12) are proposed, ensuring that AI systems and autonomous vehicles, for instance, are developed with inherent protections against biases and potential misuse. Initiatives, such as the **regulatory sandbox,** are also identified to encourage ethical experimentation within controlled environments to uphold accountability without stifling innovation (CNECT 2024).

In focus: UKRI and anticipatory governance

As a prime example of national policy work on anticipatory governance of emerging technologies, we highlight the practices of UK Research and Innovation (UKRI), which occur at multiple levels (Grant 2022):

1. Foresight and strategic intelligence: Using horizon scanning, scenario planning and strategic foresight to anticipate future trends, challenges and opportunities, and inform decision-making.

2. Stakeholder engagement: Engaging a wide range of stakeholders, including the public, private sectors, academia and civil society, to gather diverse perspectives and foster collaborative approaches to governance.

3. Agile and adaptive policy frameworks: Developing flexible policies that can adapt to new information and circumstances, such as creating regulatory environments responsive to technological and societal changes.

4. Innovation and experimentation: Encouraging innovation and experimentation within governance structures to test new ideas and approaches and helping identify effective solutions and scaling them up.

5. Ethical and inclusive governance: Ensuring ethical, transparent and inclusive governance practices by considering the ethical, legal and social implications of policies and technologies before implementation.

6. Continuous learning and improvement: Mechanisms for continuous learning and feedback to improve governance practices, including monitoring to assess policy impact, and making necessary adjustments.

Complementary approaches

In addition to the core approaches, we examined the use of additional methods that are of interest for the development of the AG Compass framework that is advanced within the GOWELL project: **learning, consensus building and monitoring and evaluation**. Regarding learning, we are particularly interested in how cross-sectoral learning or knowledge exchange is addressed in the literature. Consensus building refers here to methods that facilitate the development of shared agendas or objectives across societal sectors. Our interest in monitoring and evaluation concerns the development of impact assessment frameworks and indicators, also beyond traditional economic and technological indicators of new technologies.

Learning

Learning is an important part of the anticipatory governance in two ways. First, responding to future uncertainties and challenges posed by emerging technologies requires continuous learning and adaptation. Second, engaging diverse stakeholders in mutual learning processes is essential for addressing societal challenges of technological advancements. In the literature review, **cross-sectoral learning** was the most commonly used way to address learning, either explicitly or implicitly. It emphasizes the importance of collaboration and mutual knowledge exchange between different sectors to address complex societal issues and technological impacts.

Some articles describe experiments that took place to promote mutual learning between civil society, researchers, industrial experts and policy experts. Overall, **learning through experimentation and adaptive approaches to policy and governance** are highlighted as key components of anticipatory governance. These approaches involve a cycle where system boundaries, context, problems and desired goals are identified. It continues with developing hypotheses, implementing policy

strategies, monitoring the results and revisiting the problems and goals based on the findings.

Learning may require **double-loop learning**, but a few articles described processes aimed at promoting this type of learning (e.g. Ribeiro & Shapira 2019). Double-loop learning goes beyond learning the viewpoints of different stakeholders and happens when the actors change their underlying perceptions and assumptions of the system. Double-loop learning includes questioning and changing basic certainties, goals and values making the learning much more difficult. Nevertheless, reflecting on and potentially changing beliefs and assumptions based on new information and perspectives is an important aspect of anticipatory governance.

The literature points out that there are **several difficulties in learning**. Collaboration and knowledge exchange between different sectors, such as public and private actors, can be challenging due to differing priorities, expertise and responsibilities. Engaging diverse stakeholders in mutual learning processes to address societal challenges and technological advancements requires significant effort, resources and coordination. In addition, implementing a cyclical approach to policy and governance, where system boundaries, context, problems and goals are continuously changing, can be difficult to manage and sustain. As for double-loop learning, changing one's beliefs and assumptions is a complex process and does not happen quickly. The same goes for flexibility and openness that are prerequisites of learning.

Another aspect related to double-loop learning is **Constructive Alignment (CA)** (Biggs and Tang 2011; Biggs 2003). CA is a constructive approach to learning, which can also be linked to the strategic alignment of governance structures, policies and practices with the anticipated future developments and challenges. This could also involve the embedding of foresight and anticipatory thinking into the governance processes to ensure that policies are proactive rather than reactive, and that learning is embedded in the institutional learning itself, thereby reflecting a process of double-loop learning or critical thinking. By aligning governance mechanisms with future scenarios in a process of mutual learning, stakeholders could better manage uncertainties, mitigate risks and harness opportunities presented by emerging technologies and societal changes. This approach aims to create a more resilient and adaptive governance framework that can effectively respond to the dynamic and complex nature of future challenges.

Consensus building

Consensus building, reaching an agreement that satisfies the interests of all stakeholders involved, is a structured yet flexible process that entails creating a **shared understanding and agreement through engagement, dialogue and transparency**. In anticipatory governance, consensus-oriented approaches ensure that governance models remain adaptable and inclusive, facilitating continuous improvement and alignment with evolving societal needs and technological advancements. This promotes the formulation of flexible policies and peer learning processes, which are crucial for preparing for and responding to future uncertainties and challenges.

We see consensus building being closely related to **“humble governance”**, which refers to a governance approach characterized by adaptability, openness and a willingness to learn and adjust policies based on new information and feedback. It emphasizes the importance of collaboration, transparency, and inclusivity in decision-making processes. (Annala et al. 2021, 3). This approach is interesting for its focus on fostering trust between the government and its citizens by being more responsive to their needs and concerns, and by acknowledging the limitations and uncertainties inherent in governance (thereby also potentially seeing the knowledge base for societal decision-making in a new light, shifting focus from ex-post to ex-ante and future foresight). Ultimately, humble governance aims to create a more effective and equitable system by continuously improving and evolving through active engagement with all relevant stakeholders.

Creating a common understanding is essential for integrating diverse perspectives and achieving outcomes that are acceptable to various stakeholders. Given their complexity and ethical implications, it's essential to include public values and concerns in these discussions. There is a need for **platforms that facilitate open and transparent discussions** among scientists, NGOs, policy makers, industry representatives and public representatives (e.g., Davies and Schomberg 2010). Transparency also implies inclusiveness and integrating vulnerable groups into the discussions.

Building consensus is often necessary but rarely easy. Achieving consensus is an **iterative process** that may involve multiple discussions and negotiations. Identifying required participants in consensus creation and the method for selecting them are important considerations. The scale of consensus building can vary, including case-specific, sector-specific, national or international levels. However, as the scale broadens, the process to reach consensus targets becomes more comprehensive.

Monitoring and evaluation

While there is increasing interest in the linkages between foresight, anticipatory capacity and evaluation, the literature provides relatively little food for thought, let alone evidence as to these connections, and how future science and evaluation could have a better dialogue and exchange of knowledge. Some aspects emerged from our analysis, however.

Multi-dimensional and multi-source monitoring is emphasised in connection to the impact assessment in AI projects. This approach includes social, environmental and economic impacts, moving beyond traditional economic indicators. For example, the Mercé project (CNECT 2024) used real-time data to dynamically evaluate urban planning outcomes, showcasing a shift toward proactive and data-driven monitoring.

Scenario planning and soft systems methodologies often contain monitoring (e.g. Cohen & Jones 2020) to evaluate the effectiveness of policy responses. By observing both technology and user responses, policy makers can develop a more adaptable approach that allows for continuous assessment and adjustments.

Cohen et al. (2018) address impact assessment and monitoring indirectly through their emphasis on anticipatory and **experimental governance approaches**. They suggest that the uncertainties surrounding autonomous vehicles (AVs) require a governance strategy that involves broad stakeholder engagement and continuous monitoring. This approach helps identify early warning signs and focus governance attention on areas of AI progress likely to have significant societal impacts.

In focus: Science for policy

There are interesting connections and similarities between anticipatory governance and the EU's Science-for-policy discussion, also referred to as evidence-informed policy making.[9]

First, the Science-for-policy discussion emphasises the use of **diverse knowledge sources** (Sarvaranta et al. 2023, 6), as well as integrating knowledge from various disciplines, policy areas, administrative levels and public-private connections to influence science and policy making. Second, the **interests and involvement of multiple stakeholders** (ibid., 34) are deemed important, including advocating for the inclusion of various NGOs, grassroots movements and citizens in policy advice

[9] Evidence-informed policy making refers to an approach to policy making that aims at informing policy deliberations and decisions with the best available evidence. Evidence, in general, refers to data, information, and knowledge from multiple sources, including quantitative data such as statistics and measurements, qualitative data such as opinions, stakeholder input, conclusions of evaluations, as well as scientific and expert advice (EC 2023).

and encouraging meaningful co-creation and future-oriented deliberation. Third, another similarity lies in **ethics,** as the preservation of knowledge mechanisms and secure spaces for diverse, mainstream and less popular but well-founded opinions in scientific advice is put forward. Fourth, the **value-based approach** proposed in the science-for-policy discussion entails robust debates on the role of values in providing scientific evidence. Fifth, **deliberation and alignment** in the science-for-policy discussion call for recognising the need for better deliberation and policy coordination of research and innovation policy with other public policies when addressing complex challenges (ibid., 28).

Conclusions and discussion

Our literature review showed that there is a **growing body of academic research on anticipatory governance of emerging technologies, as well as a keen policy interest.** Policy discussion and academic research share surprisingly many similar topics, concepts and key references, even though there are some differences in emphasis. The most common methodological components of anticipatory governance are foresight, stakeholder engagement (inclusion) and ethical considerations. In addition to these core approaches, which are usually closely intertwined, our review showed that the literature has addressed questions on learning and consensus building in cross-sectoral contexts. There are also efforts to renew impact assessment frameworks beyond traditional indicator work. Regarding wicked problems associated with emerging technologies, the literature suggests that addressing them requires new forms of collaborative strategies, stakeholder engagement and cross-sectoral learning, as well as a mix of problem-solving and problem-finding approaches.

While there is considerable coherence in the use of the core approaches of foresight, engagement and ethics, some **variations in methodological priority** could be observed. In the case of AI applications, ethical issues, such as transparency and accountability, were emphasized. Ensuring that the use of AI is ethically sustainable and meets societal needs was considered a high priority. Concerning nanotechnologies, risk management, stakeholder engagement and regulatory readiness were more predominant. It was considered crucial to anticipate potential risks and ensure that regulatory frameworks are flexible enough to respond to the rapid development of nanotechnologies. In health and biotechnologies, on the other hand, the need to address ethical questions and interdisciplinary collaboration was emphasized. Overall, these variations reflect the particular societal expectations and concerns associated with each emerging technology.

One of the central themes in the literature reviewed relates to risk management and its linkages with anticipatory governance. Whilst risk management most often has a core focus on identifying and addressing potential risks associated with new technologies, anticipatory governance, in turn, involves **proactive engagement with stakeholders and interactive processes**, such as developing guiding principles or frameworks designed to manage uncertainties and potential impacts.

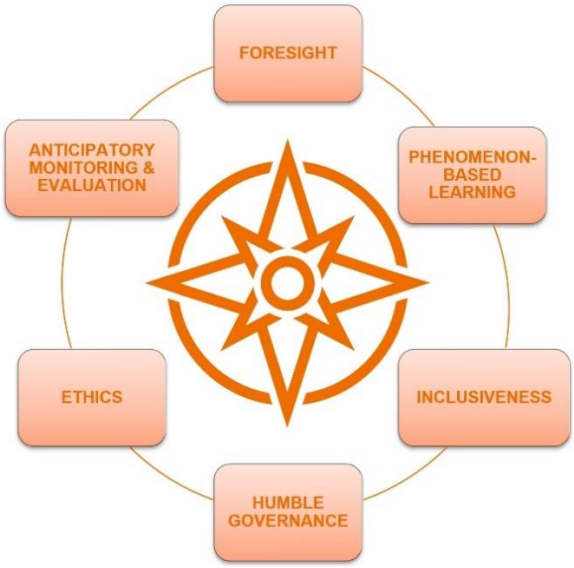


Figure 2. The AG Compass.

One of the aims of our study is to develop a practical tool, the AG Compass, for policy makers to engage more systematically in foresight and anticipatory governance (Figure 2). For such a tool to be useful, it would need to succeed in engaging policy makers, being both inspiring, engaging and useful. Ultimately, the success of AG Compass lies in its methodology, and the literature review pointed out the **key lessons for methodological development**:

- Foresight and anticipation are critical tools, which enable decision-makers to anticipate and be better prepared for future settings, contexts and scenarios. Methodologies may vary, depending on the context, strategic position and technology in question.
- Ensuring active and diverse stakeholder engagement, from policy makers to industry representatives, as well as the public at large, is needed for public legitimacy that drives the adoption of emerging technologies.
- The importance of being transparent should not be underestimated, e.g. incorporating ethical considerations and maintaining transparency throughout the development and implementation of the AG Compass itself.
- Mechanisms are needed for feedback, monitoring and evaluation to ensure that the AG compass remains relevant and effective in addressing emerging challenges and uncertainties.
- A heuristic is needed to help the user of the AG compass to determine which type of tool is most useful in the specific context (e.g. from a more risk-averse context to an open and exploratory context), along with use case examples.

In the next phase of the GOWELL project, we will conduct case studies in the areas of 1) preventive services in healthcare, 2) AI applications in medical imaging technologies and 3) simulation of new materials using quantum computing. These cases represent both challenge-driven and technology-driven opportunities, as well as technologies that are close to market vs. technologies that are still in the basic research stage. All these cases will be examined through the prism of our results thus far, including the literature review results, which will guide our further questions and explorations.

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Annex 1. Document material of the content analysis

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Annex 2. Guiding questions of the content analysis

Topic	Guiding questions
1. General framework	• What is the general framework of anticipatory governance (AG) applied in the article? • What are its key components or aspects?
2. Foresight	• What foresight/anticipation approaches and methods are systematically applied and developed? How is risk management (/precaution) taken into consideration?
3. Learning	• How is (cross-sectoral) learning or knowledge exchange addressed?
4. Inclusion	• What is said about engaging stakeholders with different perspectives?
5. Humble governance	• Are issues related to consensus-building or shared agenda creation (/shared strategic objectives) discussed?
6. Ethics	• How are ethical issues, such as transparency, fairness and accountability, dealt with? Are values (and even tensions relating to them) referred to?
7. Monitoring & evaluation	• To what extent are questions related to impact assessment or monitoring data considered?
8. Reflections & key lessons	• What are the primary challenges and tensions (explicit or implicit) associated with implementing the AG approach? • Are there any theoretical issues or practical problems within the research process itself? • How well does the research reported resonate with the AG Compass? • What implications can be identified for developing a regulative framework?

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