Technology in Society 74 (2023) 102325

Contents lists available at ScienceDirect

Technology in Society

journal homepage: www.elsevier.com/locate/techsoc

From speculation to reality: Enhancing anticipatory ethics for emerging technologies (ATE) in practice

Steven Umbrello [a,f,*], Michael J. Bernstein [b], Pieter E. Vermaas [a], Anaïs Resseguier [c], Gustavo Gonzalez [d], Andrea Porcari [d], Alexei Grinbaum [e], Laurynas Adomaitis [e]

[a] Department of Values, Technology, & Innovation, School of Technology, Policy & Management, Technical University Delft, Delft, the Netherlands
[b] Center for Innovation Systems & Policy, AIT Austrian Institute of Technology GmbH, Vienna, Austria
[c] Trilateral Research, Waterford, Ireland
[d] Airi - Associazione Italiana per la Ricerca Industriale, Roma, Italy
[e] CEA-Saclay/Larsim, Gif-sur-Yvette, France
[f] Center for Religious Studies, Bruno Kessler Foundation, Trento, Italy

ARTICLE INFO

Keywords:
Anticipatory technology ethics
Emerging technologies
Uncertainty
Futures studies
Forecasting
Technology assessment

ABSTRACT

Various approaches have emerged over the last several decades to meet the challenges and complexities of anticipating and responding to the potential impacts of emerging technologies. Although many of the existing approaches share similarities, they each have shortfalls. This paper takes as the object of its study *Anticipatory Ethics for Emerging Technologies* (ATE) to technology assessment, given that it was formatted to address many of the privations characterising parallel approaches. The ATE approach, also in practice, presents certain areas for retooling, such as how it characterises levels and objects of analysis. This paper results from the work done with the TechEthos Horizon 2020 project in evaluating the ethical, legal, and social impacts of climate engineering, digital extended reality, and neurotechnologies. To meet the challenges these technology families present, this paper aims to enhance the ATE framework to encompass the variety of human processes and material forms, functions, and applications that comprise the socio-technical systems in which these technologies are embedded.

1. Introduction

Different technologies can aptly be described as being at various stages of their research and development, as well as diffusion stages in their lifecycles. Consequently, it becomes difficult to evaluate the social, ethical, environmental, and economic impacts across various sectors, given this incongruency and asymmetry. This challenge is made even more complex given the convergence of these technologies, blurring the boundaries of where one technology may end and another begin—to say, nothing of the social worlds these technologies shape and are shaped by. This issue has been the core of technology assessment (TA) initiatives over at least the past five decades (c.f. [1]) and, in 2012, was taken up by Philip Brey in his paper *Anticipatory Ethics for Emerging Technologies* [2].

To tackle these issues, Brey evaluated the benefits and pitfalls of widely diffused approaches to assess the impacts of transformative technologies. In particular, he focused on ethical technology assessment (e.g. Refs. [3,4]), the techno-ethical scenarios approach (e.g. Ref. [5]), and the ETICA approach (e.g., Refs. [6,7]). He identified several lacunae accompanying these approaches and, consequently, proposed an alternative framework to address them. Brey offered what he considered to be a more effective framework: *anticipatory technology ethics* (ATE).

The TechEthos Horizon 2020 project adopted the ATE approach as the starting point for evaluating the ethical, legal, and social impacts of climate engineering, digital extended reality, and neurotechnologies [8]. This paper is the result of work done with the TechEthos project's attempts to use ATE in practice. Explorations of the technologies selected by the project highlighted various ways the approach could be augmented to meet challenges faced in its original formulation, as well as subsequent attempts to build on it (i.e., [9,10]). In particular, this paper amends and expands the ATE framework given various conceptual privations of the ATE approach in encompassing the variety of human processes and material forms, functions, and applications that comprise the socio-technical systems in which these technologies are embedded.

* Corresponding author. Department of Values, Technology, & Innovation, School of Technology, Policy & Management, Technical University Delft, Delft, the Netherlands.
E-mail address: s.umbrello@tudelft.nl (S. Umbrello).

https://doi.org/10.1016/j.techsoc.2023.102325
Received 1 May 2023; Received in revised form 14 July 2023; Accepted 16 July 2023
Available online 20 July 2023

Enhancements are proposed to fill these lacunae. Firstly, we incorporate narrative approaches, including lay and cultural narratives. This technique facilitates a more comprehensive understanding of the ethical landscape, as it engages diverse perspectives and narratives that are rooted in varying cultural and social contexts. Secondly, we prioritize the incorporation of uncertainty over likelihood. By doing so, we open the possibility for a more nuanced exploration of potential values and value conflicts. This encourages deeper reflections and discussions on the ethical aspects of emerging technologies, fostering broader and more inclusive dialogues. Thirdly, we propose the acceptance of some degree of ethical opacity. By employing narrative analysis, we are able to reveal and interpret the subtler, less transparent ethical implications that may otherwise be overlooked in more conventional methods. Finally, our enhanced ATE approach is intended to include socially beneficial impacts. This inclusion underscores our commitment to technology development that is not just innovative, but also carries the potential for positive social transformation. These enhancements aim to create a more holistic and inclusive ATE approach, equipping it better to navigate the complex ethical landscape of emerging technologies.

Our work on enhancing the ATE approach represents a contribution to strengthening "ethics by design." Ethical foresight analysis frameworks like the ATE approach have been increasingly adopted by technology developers and firms in order to more effectively determine the potential ethical risks that may emerge as a function of their design and deployment [11]. Ethical foresight can help design teams to anticipate and attempt to avoid these risks, and thus design their systems *for* human values rather than at their expense [12] using ethics-by-design approaches, like value sensitive design, to research and development of novel technologies [13].

In order to realize the enhancements proposed, the paper begins by describing the ATE approach in greater detail. The following section describes some of the lacunae in ATE as well as some of the requirements of the TechEthos project that necessitated enhancing ATE. This is followed by a section that describes a more detailed classification to better capture the nuances the TechEthos project surfaced, and a discussion concerning how the new approach meets the TechEthos requirements. The final section considers potential limitations of this enhanced ATE approach and fruitful avenues for future research.

2. Anticipatory technology ethics (ATE)

Brey, prior to presenting his own ATE framework, describes the benefits and pitfalls of three other approaches: (1) ethical technology assessment, (2) the techno-ethical scenarios approach, and (3) the ETICA approach. He argues that each of these approaches fails to account for essential elements in engaging in the ethics of emerging technologies. As such, his ATE differs from these extant approaches on at least three dimensions:

1. Levels and Objects of Ethical Analysis
2. Foresight Methods
3. Methods of Ethical Analysis

2.1. Levels and objects of ethical analysis

Similar to the ETICA approach, which distinguishes between the various features of a technology, Brey's ATE provides three levels of analysis: (1) technology, (2) artefact, and (3) application (Fig. 1). This trio, however, is marketed as unique and more comprehensive given that ethical considerations can be undertaken at any given level in isolation from other levels. To begin with the highest level, Brey first defines *technology*, wherein individual technologies may be evaluated. Technology, according to Brey, "is a collection of techniques that are related to each other because of a common purpose, domain, or formal or functional features" ([2]; p. 7). Examples of a collection of techniques (i.e., a *technology*) are nuclear power or nanotechnology. Ethical analysis can be conducted at the technology level independent of the artefact and application levels. This, however, requires the locus of analysis to be broader, looking at the generic ethical issue that can be attributed to the "features of the technology at large, particular subclasses of it, or techniques within it" ([2]; p. 8).

One level down from the technology level is the artefact *level*. Here artefacts are defined as the "physical configurations that, when operated in the proper manner and in the proper environment, produces a desired result" ([2]; p. 8). Examples of such artefacts following our examples of the higher technology level (i.e., nuclear power and nanotechnology) would be nuclear reactors or nuclear weapons and nanopharmaceutical, respectively. *Procedures* are also crucial at this level, given that it is argued that technologies produce artefacts and procedures toward useful, practical ends. Here a procedureis understood as, "a sequence of actions that, when performed in the proper manner in the proper environment using the proper tools, produces a desired result" ([2]; p. 8). Ethical analysis at this level looks at the specific features of both the artefacts and procedures or those features most likely to emerge.

Finally, ethical analysis at the *application level* explores how artefacts and procedures are used. Here Brey understands applications as, "the concrete use of a technological artefact or procedure for a particular purpose or in a particular context, or a specific configuration of an artefact to enable it to be used in a certain way" [2]; p. 8). What is important here is the context of use since various applications of an artefact or procedure can change based on its context. A nanopharmaceutical might be used in human and nonhuman animal contexts, for healing purposes, or, perhaps more controversially, for human augmentation.

2.2. Foresight methods

Brey contends that different foresight methods are necessary depending on which level one considers a technology (Fig. 2). For example, it is argued that at the highest (technology) level, engineers are the most suited persons to help ethicists understand the specifications of the technologies, the techniques it contains, and those techniques that could be feasible in the future.

The artefact and application levels are best contended with by drawing from existing TA assessments of artefacts and applications,

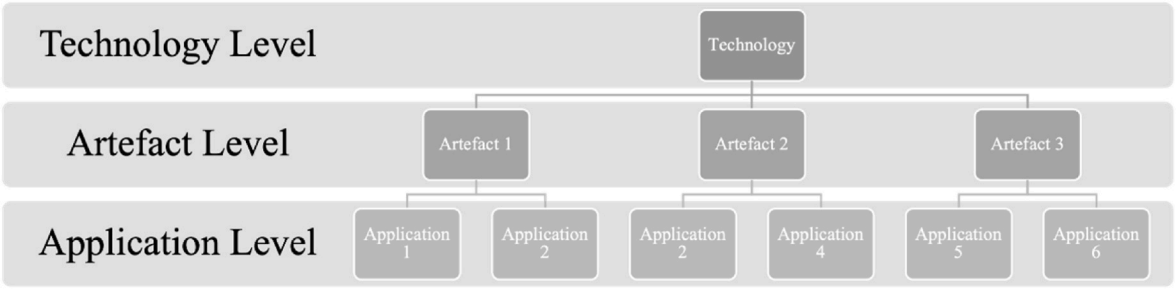


Fig. 1. Three levels of ethical analysis. Source: Brey ([2]; 7) modified.

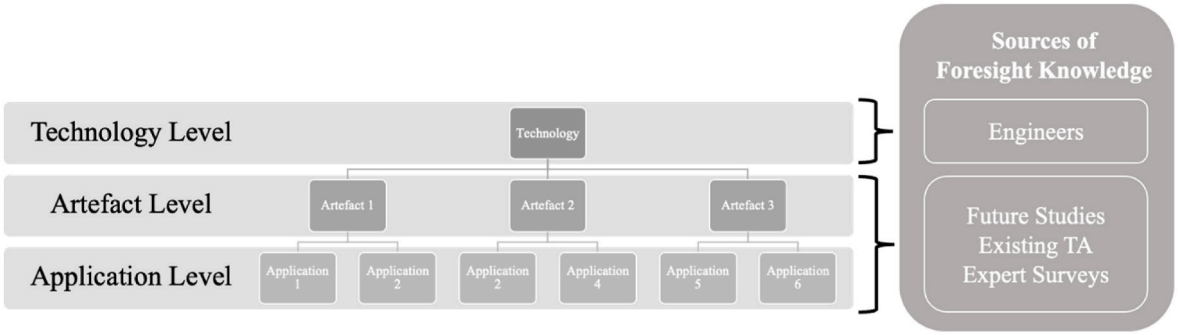


Fig. 2. Sources of knowledge for foresight at the various levels of analysis.

using future studies approaches to envision impacts, and employing empirical investigations like those of expert surveys to determine the feasibility and plausibility of forecasted scenarios. This assists in formulating sober and tempered imaginative future scenarios.

Although there is neither one nor a perfect approach to foresight (c.f. [14]), various methods may be used to better map how novel artefacts and applications might emerge from existing and novel technologies. Given that this is an imaginative process, various formulations can yield different results. Systematising the forecasting methods can narrow the results, but imaginative processes such as these are not exhaustive. Brey summarises this facet of his ATE approach by saying:

> an exhaustive futures study of a new technology would consult with engineering scientists to chart the internal features and development of the technology, and would rely on both existing futures studies and expert panels to forecast future artifacts and applications. A systematic futures study would consider how the technology may be combined with various new and emerging technologies to yield possible new capabilities and functionalities not found in current artifacts. [2]; p. 11).

2.3. Methods of ethical analysis

Brey's ATE approach is aligned with the ETICA framework, which identifies at least two stages for ethical analysis for present and future technologies following the imaginative forecasting exercises: the (1) identification stage and (2) evaluation stage. He does posit a third, albeit optional, stage in which moral responsibility can be assigned to actors in the design of the technologies. The *identification* stage is where cross-referencing a technology's description with ethical principles and values is undertaken. Through real cases or conceptual investigations of real-world conditions, the technology's operationalisation in praxis is used to determine the negative impacts of that technology.[1]

The identification stage is then followed by the *evaluation* stage, where the ethical issues identified are analysed based on their potential for realisation, their relation to one another, and, as a consequence, to what, if any, value tensions emerge between such issues (c.f. [15]), for the problem of 'moral overload'). For example, in the identification stage of the ethical issues of a nanomedicine, it may have been identified that the precision of diagnostics may implicate mental health concerns given the risk of overdiagnosis viz. the identification of even a single malignant cell [16]. This can conflict with other values, such as *human autonomy,* given that these nanomedicine systems permit individual use outside professional medical contexts, thus further risking mis- and overdiagnoses.

Ethical tensions like this can arise during the evaluation stage, and this stage can lead to a series of outputs. The output can be iterative feedback into the design of the technology that can explicitly contend with the issues and tensions.[2] The output of the evaluation stage can also amount to what Brey calls the *responsibility assignment* stage, where moral responsibility can be attributed to the relevant moral actors in the design of the technology. For example, [17] provide a comprehensive account of meaningful human control that highlights means by which we can more accurately trace and track the relevant moral actors in any given design and use chain of a system.[3] This latter stage is beneficial for policymakers and governance specialists in helping them formulate the appropriate measures concerning dealing both with the ethical issues of the system as well as those who are assigned moral responsibility concerning the use and impacts of the system.

2.4. Early adjustment

The ATE approach is not set in stone [9]. considered adjustments as part of the ethical analysis done in the SIENNA project.[4] For instance, the somewhat material term *artefact* was coupled with the term *product* to further describe the middle level of analysis. Products in this adjustment were understood as physical materials or procedures resulting from a technology development processes and intended for use by consumers, businesses, governments or future R&D activities, or otherwise. Such products might raise ethical issues independent of use (e.g., concerning ethical issues of humanoid robots), or issues in particular contexts of use (e.g., by military agencies in warfare; non-for-profit actors in healthcare; for profit actors in home care; etc.). To illustrate the latter, consider the deployment of an autonomous drone by a military agency in warfare. The drone, as a product of AI technology, carries inherent ethical considerations, including issues of accountability, transparency, and potential biases in its programming. However, when this drone is utilized within the specific context of warfare, additional ethical complexities emerge. For instance, questions of proportionality, discrimination between combatants and non-combatants, and the overall moral implications of autonomous decision-making in life-or-death situations are brought to the forefront [18]. The military's use of the drone thus surfaces a distinct set of ethical challenges that are uniquely tied to this context. Similar context-dependent ethical considerations may arise when technology is used by non-for-profit actors in healthcare or for-profit actors in home care, demonstrating the need for

[1] For an example checklist see (Table 1 of [2]; p. 12).

[2] This approach is aligned with the value sensitive design approach to iterative feedback in design, viz. conceptual, empirical, and technical investigations [57].

[3] This is an interesting design point that relates to the "tracking" and "tracing" conditions of moral responsibility for autonomous systems proposed by Santoni de Sio and van den Hoven (2018).

[4] The SIENNA project addressed ethical issues in three new and emerging technology areas: human genomics, human enhancement and human-machine interaction. These areas all come with major *socio*-economic impact. They also raise issues related to human rights. More information available at: https://www.sienna-project.eu/about-sienna/.

a nuanced understanding of ATE.

Concerning foresight activities, ATE in the SIENNA project was coupled with various foresight methodologies such as environmental scanning, relevance trees, science and technology roadmapping, multiple perspectives, and, optionally, futures visioning. Likewise, within the same project, foresight approaches where stakeholders beyond those of engineers or domain experts were considered in order to align the approach with more general concerted efforts of Responsible Research and Innovation initiatives to include broader stakeholder communities ([10]; p. 16). However, non-expert stakeholders remained only a contingent and optional step, rather than as necessary participants in the development of technology ([10]; pp. 46–48, 50, 61–62).

This enrichment of the original ATE approach is aligned with the internal philosophical underpinnings of the methodology, which supports updating based on necessity. As such, the enhanced ATE framework described in this paper constitutes part of this tradition. Beyond these initial revisions to ATE, the TechEthos project surfaced further nuances to enrich the work done in SIENNA. The contribution that follows thus aligns with ATE's axiomatic design to be updated as novel tensions and requirements are discovered through application.

3. Lacunae observed by the TechEthos project to expand ATE

TechEthos,[5] *Ethics for Technologies with High Socio-Economic Impact* (2021–2023), is a research project funded under the Horizon 2020 Programme of the European Commission. The project focuses on three families of technologies (see Table 3) identified through project activities as having a potentially high socio-economic impact: climate engineering, digital extended reality, and neurotechnologies [8]. The project carries out a series of interdisciplinary analyses to capture these technologies' ethical, legal, and policy implications and identify public awareness and acceptance of them. Based on the findings of the analyses, it aims at contributing to their proper ethical and legal governance by increasing the likelihood that critical values and principles get taken into account from the stage of technology design through deployment and beyond. Throughout the project, the TechEthos consortium engages with a wide range of stakeholders, including academia, industry, policymakers, and the public, including members of vulnerable groups in society, in order to ensure a broad perspective on the analyses and the formulation of recommendations for enhanced governance of these technologies.

In the TechEthos project, we observed several lacunae that needed to be confronted with deploying the ATE approach, particularly putting values and principles into conversation with technology in such an *a priori* manner. More specifically, we encountered four foundational issues in the original ATE formulation which gave us pause: (1) the original formulation requires more meaningful consideration of foresight concepts and activities; such concepts and activities could benefit by becoming integral rather than optional in ATE; (2) ATE primarily focuses on the inclusion of expert stakeholders, and so could be enhanced by identifying and eliciting a broader range of stakeholders and publics; (3) ATE could be enhanced by considering how differing time horizons directly effects the types and qualities of the impacts of any given technology; (4) Finally, the ATE ethical analyses are significantly—understandably—concerned with negative impacts, yet do so at the expense of exploring also potentially significant positive impacts. Consequently, this also omits tensions related to the subjectivity of positive and negative, as well as issues of equity associated with the distributions of burdens and benefits of technology.

In general, we observed these shortcomings across: 1) levels and objects of ethical analysis; 2) approach to foresight methods; 3) methods of ethical analysis.

[5] https://www.techethos.eu.

3.1. Lacunae concerning levels and objects of ethical analysis

The ATE assessment process starts with an ontological assertion establishing "technologies" at the highest level for analysis. While this is not an issue in and of itself, it bears acknowledging how demarcations of such "technologies" might be made, and adopting mechanisms to attend to societal contexts and situations from the start. TechEthos was charged with and acknowledged a pre-selection commitment to focus on socially, ethically, and potentially economically impactful groupings of technologies (what the project came to term, "technology families"). The act of identifying and constructing technology families in this way explicitly acknowledges social contexts and societal concerns in a manner distinct from, say, from a functional perspective [19], or simply as classified by scientists and engineers (We address this, in section 4.1, by developing a glossary in which things like "goals" and "desirability" are made explicit from the start).

A degree of ambiguity related to the demarcation of levels and the language used to describe the objects of analysis at each level also made the application of the ATE framework difficult in the context of TechEthos' work. Imprecisions make it difficult to ascertain the relationship between one level and the next, and one object of analysis and the next. While overlaps in analytical levels will, of course, always occur, the analytical foci at each level vary. This issue made it difficult to conduct a standardised analysis across multiple, diverse collections of technology families and technologies – a main priority of the TechEthos project.

Finally, the original formulation of the ATE is concerned primarily with assessment of potential intended and unintended consequences. "Consequences", as used in Ref. [2]; often seem implicitly negative. Nevertheless, a focus on ethical assessment of negative consequences alone misses the chance to: a) interrogate issues of distributional justice[6] that look at burdens and benefits associated with technological developments; b) interrogate the power dynamics that may perpetuate certain inequalities associated with technology development (for example by arguing that the benefits of a particular technology outweigh the risks); c) interrogate the inherent contingency of desirability at play in either situation.

3.2. Lacunae concerning foresight methods

In the original ATE framework, analytical concerns extend to "present and future" states of technologies, artefacts, and applications. For future-oriented concerns, futures studies methods, including forecasting, technology assessment, expert survey and discussion, or scenarios, are invoked. Imagination and creativity, as well as speculation about potential combinations of technologies, are emphasised as important in this original ATE constellation.

Within these contexts, ATE focuses on "likelihood" from the perspective of expert assessment when it comes to potential unintended consequences of technology development or artefact application. The focus on "considered likelihood" in the original ATE begs the vital question of human perception (i.e., considered likely by whom? based on what evidence? in light of what motivations?). These considerations would be central to make explicit in ethical analyses—particularly ones, as in TechEthos, needing to consult broader stakeholders and publics. The 2021 enhancements to the ATE coupled it with foresight methodologies such as 'Vision in Futures,' in which scenarios are created to tease out important ethical issues. However, such exercises are

[6] 1 It should be noted that while the ATE approach indeed encompasses aspects of distributive justice, its primary representation is within the confines of ethical checklists. These checklists, though beneficial in their application, possess inherent limitations. Consequently, the depth and complexity associated with issues of distributional justice may not be fully captured by these checklists, potentially constraining the breadth of ethical engagement.

presented as optional communication tools to surface potential issues to avoid, rather than as integral to foresight activities in ATE. Such visions are explicitly negative, and presented in explicit contrast to scenarios, in order to better anticipate ethically undesirable developments ([10]; pp. 63–64), rather than surfacing positive and negative developments to consider in tension.

Of further concern, its original form, regarding future considerations, ATE does not explicitly account for uncertainty or ambiguity regarding foresight activities. Research on decision-making under conditions of uncertainty shows how context influences perceptions of uncertainty, including normative uncertainty [20]; the emotional valence of certainty appraisals [21]; as well as the way notions of delay may be (erroneously) substituted with notions of risk [22]. When employing reference to future states, ATE's focus on likelihood ignores, problematically, the nuances that accompany grappling with uncertainty, the ethical issues it raises, and the ethical issues surfaced by grappling with uncertainty head-on. For example, in constructing uncertainty as a political device [23,24]. By glossing over questions of uncertainty in favour of questions of likelihood, the original ATE left underexplored issues of governance of science and technology inherently associated with uncertainty [25] and the interesting and essential ethical dilemmas such governance surfaces.

3.3. Lacunae concerning methods of ethical analysis

In the course of our work on TechEthos, we observed that ATE shows a preferential focus on expert technical and policy perspectives to elicit possible, "social consequences that may cause harm, violate rights, affect well-being, or cause unjust distributions of goods" ([2]; p.10). This can be contrasted with the explicit mission and approach of TechEthos: to engage not only experts but also broader stakeholder groups and publics on the potential future social and ethical issues associated with the technologies studied. Opening up [26] to a greater plurality of perspectives in the anticipatory ethical analysis is a now-established way of proceeding, found in frameworks ranging from participatory technology assessment [27], real-time technology assessment [28]; anticipatory governance [29]; responsible innovation [30], and many more, with a long tradition (c.f., [31]).

Ultimately, innovation creates, "new social practices and even institutions that transform how human beings interact with the world around them" [32]. Thus, innovation as a future-creating activity cannot be detached from a careful study of the narratives it re-activates or brings to the forefront of creating meaning in society. As laypeople and experts frame innovation in stories, tell and share stories, and make judgements of technological futures based on such stories, recurrent technological-cultural narratives structure their imaginaries (e.g., see Ref. [33]). Experts and publics embrace narrative creation and thus need to be better accounted for in an enhanced ATE framework.

In addition to narrative analysis, virtue ethics [34] can inform the ethical motivation of the stakeholders. The personal qualities of technologists and innovators have a significant bearing on ethical judgement [32]. Under uncertainty about the future use of technology, ethical judgment is dominated by personal trust in the symbolic figures associated with this technology, called "technology evangelists". Such engineers-turned-messengers are often ambivalent figures. Whether one examines them using the archetypes of innovators, e.g., Prometheus, or in purely socio-economic terms, their impact on ethical judgment is unambiguous [35]. Analysing the families of emerging technologies in separation from the judgment on the individuals who, in the public eye, "incarnate" technologies and act as flag-bearers would thus benefit from more participatory and deliberative and inclusive processes featured above.

Based on TechEthos project requirements and this literature, we have been able to highlight several lacunae in the original ATE approach; they are summarized in Table 1 below.

Table 1
Lacunae in ATE.

Lacunae
Meaningful consideration of foresight concept/activities
Thoughtful inclusion of non-expert stakeholders and publics
Clear explanation of time horizons to consider when adopting the approach
Considering impacts beyond those that are negative

4. The TechEthos approach to ATE

The original formulation of ATE provides a robust framework for assessing the ethical implications that might emerge with new or emerging technologies. Despite the strengths of ATE, its application within the TechEthos project unveiled certain lacunae that called for further refinement. Guided by considerations of ontological precision, epistemic justice, and social justice, we propose a series of modifications to the levels and objects of ethical analysis, the methods of foresight included, and the methods of ethical analysis themselves. This triad of enhancements not only addresses the lacunae observed in the original ATE but also dovetails with the primary objectives of TechEthos, which centre around providing guidance for ethically designing technologies. In so doing, our refined ATE not only enhances the ethical assessment of technologies but also enables the subsequent development of comprehensive ethics-by-design guidelines. In doing so, we turned to extensive work in the literature of value sensitive design researchers, like Ibo van de Poel and Batya Friedman [13,36], where operationalisation proceeds by:

1. describing the object of study at the level of interest with sufficient detail on "contexts of use" (i.e., technology family, technology, technique, application, use case), as illustrated in Fig. 3.
2. identifying a moral value or principles of concern in this situated context;
3. describing real-world conditions necessary for the "realisation or frustration" of these values and concerns;
4. determining the evolving meanings of positive and negative interactions among the technologies and values in contexts, along with necessary conditions for the realisation of desirable directions of development.

In addition, we draw upon extensive work in domains of participatory technology assessment [27,31] as well as critical studies of science and technology well suited to illuminating tensions among social groups with different values [37]—and the politics associated with appeals to expertise in governance [38].

4.1. Enhancements to levels and objects of ethical analysis

During the TechEthos project, we determined that the original set of ATE terms required further nuance to describe the full range of human processes and material forms, functions, and applications that comprise the social-technical systems in which technologies are embedded. To arrive at this nuance, we first generated a revised glossary of terms to assist with a more precise demarcation of analytical levels and objects (Table 2) (see Table 4).

Next, we set out to apply these terms consistently in a coherent generalisation of the "levels" of analysis (see Fig. 4). This revision aimed to elaborate levels without reference to technology, artefact, or application so that future applications of ATE can similarly accommodate general application across a diversity of innovation contexts.

At the highest level, we propose to focus on families of technologies: collections of technologies sharing common goals, or formal or functional features. For example, a technology family bound by the term "climate engineering" might include technologies with the common goal of advancing carbon dioxide removal. At the middle, second and third

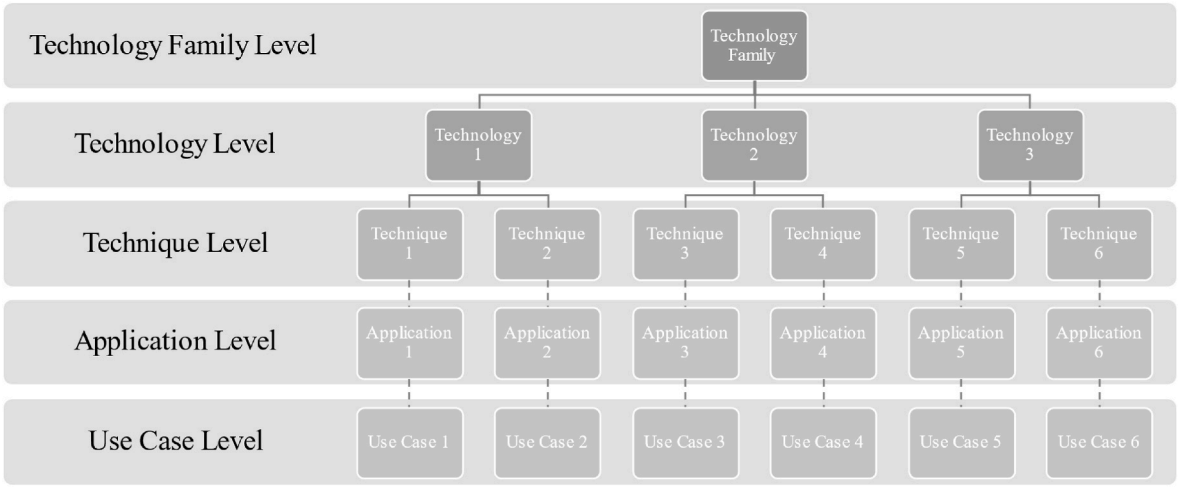


Fig. 3. TechEthos level and objects of ethical analysis. Dotted lines from the Technique Level down to the Application Level and Use Case Level signify that not all technologies will have application or use cases as a condition of their readiness level.

levels, we propose focusing on specific technologies, which may combine various techniques or domains sharing formal or functional features and goals. Continuing the example of climate engineering, "carbon capture and storage" technologies could be used to describe a collection of techniques related to fixing carbon dioxide in stable forms for long-term storage. At the lowest two levels, we propose to focus on techniques in specific applications and use cases. At these levels, material artefacts, products and actual procedures come in. Concluding the example of climate engineering, solid or liquid direct air capture techniques[7] (used in specific industrial locations) might constitute analytical focus at this lowest level. We aim to carry forward the ATE framework's postulation that these lowest levels is where the proverbial rubber meets the road. Paraphrasing [2]; as more elements of an application or use case and be specified in a chosen context, more issues of interest to an ethics analyst may arise.

Finally, we aimed to elaborate more consistently on a broad typology of ethical concerns that could be associated with each level. Drawing upon the original ATE framework, we noted a consistent thread of concerns related to the character or unintended consequences of analytical foci at each level. We combined these generalised levels of analysis and analytical concerns, using the TechEthos glossary, in a matrix to generally represent a diverse "landscape" of ethical concerns potentially covered by an enhanced ATE framework for assessment.

To augment the original landscape of ethical concerns covered by ATE, we removed reference to "likelihood" and instead focused on "desirability." Doing so allowed us, first, to give the levels and object of analyses a balance to the potentially implicitly negative/undesirable term "consequences." In addition, the terms "desirable" and "undesirable" provide a more substantial warrant for engaging the diverse public, stakeholder, and expert groups and drawing explicit analytical attention to tensions related to potentially conflicting values of different parties. Such concerns can be surfaced for intended users and non-users alike, allowing for casting an even broader analytical net. The proposed landscape of ethical concerns associated with the enhanced ATE framework is presented in the table below.

We note that the TechEthos proposal for an enhanced ATE framework is a more radically situated approach to anticipatory ethical analysis. Ultimately, this is accomplished by creating space for explicitly social, constructed aspects of technology families, technologies, and techniques at all levels (e.g., goals, desirable or undesirable effects, morally controversial developments, uncertainties and risk perceptions). Practically, this affords ATE more robust means to engage the broader array of social, and ethical issues in the process of pursuing a better grasp a) of the social realities within which these analytical objects are designed and deployed and b) the ethical issues that arise in such contexts.

4.2. Enhancements to foresight methods

For the TechEthos project, we were particularly interested in addressing the making of narratives during technology development. One tool employed was creating contrasting future scenarios, intending to elicit diverse perspectives on future social and ethical issues. Each contrasting scenario needed to adhere to considerations of plausibility, of whether the worlds created to provoke reflection sustained internal logic within the social, technical, economic, environmental, political and value dimensions of the scenarios [40]. Instead of pinpointing the most likely scenarios, this approach focused on multiple plausible futures with different ethical aspects emphasised in each. Thus, in the enhanced ATE, we suggest replacing the concern of "likely futures" with questions of "plausible futures" capable of stimulating reflection on social, ethical, environmental, economic, and other impacts.

In discussing the proposed revision to "levels of analysis," we discussed how focusing on desirability and undesirability, rather than likelihood, revealed the subjective dimensions of social and ethical issues associated with technology development. Replacing "likely futures" with "plausible futures" affords a similar enhancement to our ability to surface potential ethical problems when applying ATE. This move allows us to draw upon rich work in science and technology studies on the subjective and political dimensions of time in research and innovation [41,42]. Specifically, removing a focus on likelihood opens space for nuance in the analysis of potential ethical issues with, for example, deploying arguments about urgency as a tactic to exert power in social and technological configurations still in the making [37,43,44]. Focusing on the present and future states considered likely or unlikely begs the question of "according to whom?" (and invites participatory inquiry about said question). By instead focusing on plausible scenarios—where the internal coherence of the world rests on configurations of variables presented—we can better interrogate, as ethical problematics, claims about urgency (or likelihood) in the present and future.

We combine the focus on plausibility with the narrative method during scenario construction. The narrative method (and narratology in the ethics of technology) shows why one cannot reduce the ethical judgment to an analytic "consideration", let alone to a quantitative measure of likelihood [45]. The narratological approach takes footing

[7] https://www.iea.org/reports/direct-air-capture.

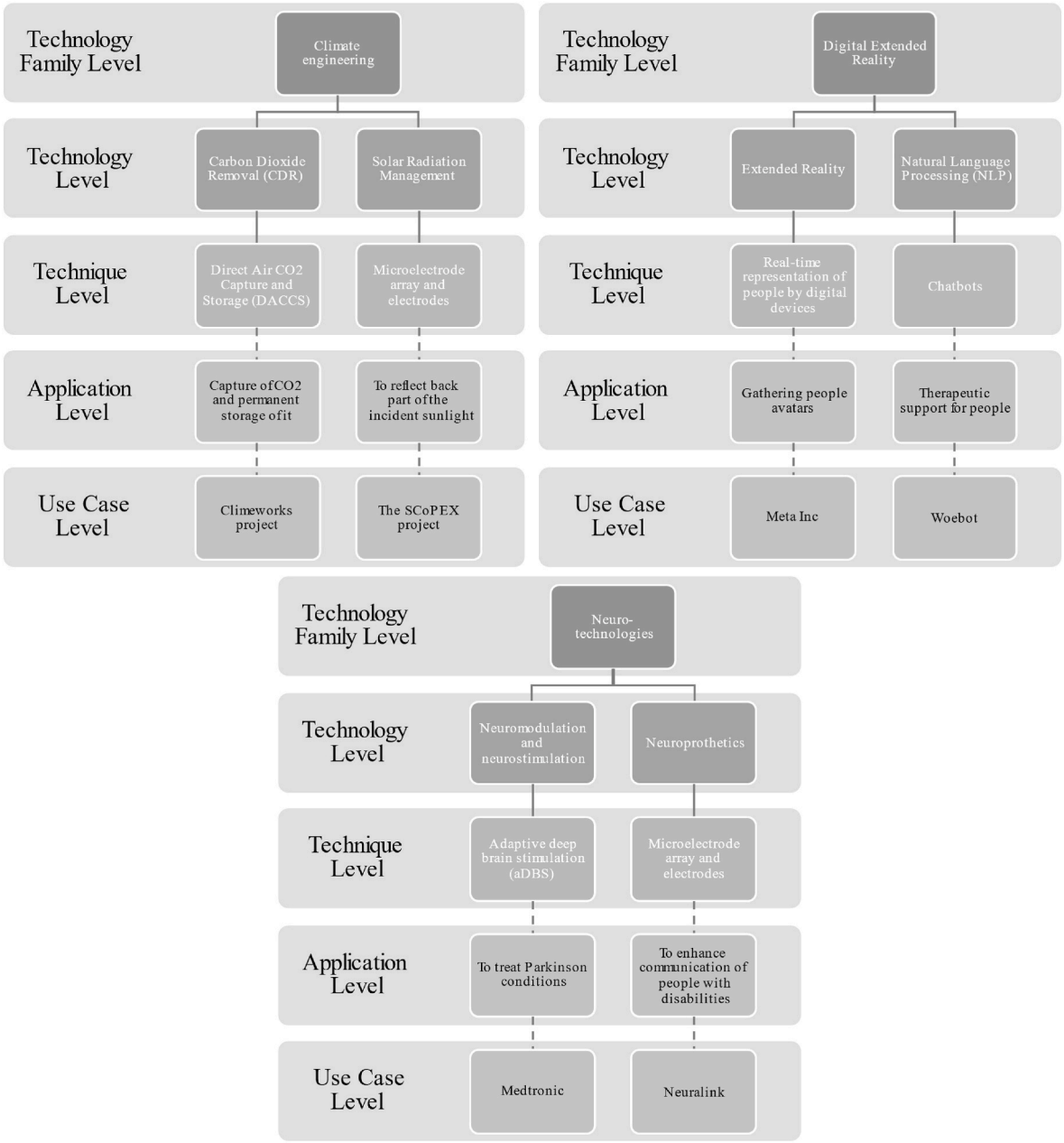


Fig. 4. TechEthos level and objects of ethical analysis applied to the technology families being analysed in the project. More details are in the TechEthos project website.

from moral opacity, which reflects that not all moral problems and considerations are always present to the moral subject transparently [46]. Williams explains, "We must reject any model of personal practical thought according to which all my projects, purposes, and needs should be made, discursively and at once, considerations for me" ([47], p. 222). An analytic framework for ATE runs here into its most fundamental limits. Framed through narratives, however, the enhanced ATE can accommodate some lack of transparency in ethical argumentation. Abstract propositional reasoning does not constitute a realistic moral judgment model, but it is also far from how stories are built and told by lay audiences. Trust and emotional projections are legitimate parts of such narratives. Adding a narratological approach to ATE allows for greater flexibility in addressing the unspeakable (tacit) components of moral reasoning.

Narrative framings have their temporality, which is not the linear time of history [48], and ethical reflection operates within a culture that connects repeating motives across their particular instantiation in technologies or objects [49]. Narrative framings help explicitly reveal how public perceptions of established and new technologies are shaped by societal debates involving claims about said technologies [50]. The technological innovation of concern to ATE thus implies more than a new set of techniques or devices: it is also concerned with the narratives that fill these new objects or practices with meanings. For example, [51] and [52] identify dominant technoscientific narratives across a range of technology involving motifs ranging from being overwhelmed (negatively) by success; tempting irreversibility and catastrophe through hubris; alienation and powerlessness; and injustice and exploitation. By focusing on plausible contrasting scenario narratives, instead of likely scenarios, the ethical tensions embedded in these and other "lay ethics" narratives can be more richly interrogated to inform the development of ethical codes, standards, guidelines, and frameworks.

Table 2
TechEthos Glossary to support the enhancement of the ATE framework.

Term	Definition	Source
Object	A material entity—physical, chemical, biological, organismal, or otherwise	TechEthos
Procedure	A sequence of actions using objects in an environment	[2] + TechEthos
Technique	Use of a procedure with a specific object to realize a specific goal	[2] + TechEthos
Approach	A collection of techniques that share a goal and sequence of actions but not necessarily the same object	TechEthos
Formal features of a technique	Describing the elements of the technique—the object, environment, actions, or goals	TechEthos
Functional features of a technique	Describing the contributions of the elements of the technique to the desired result	[39]
Domain of techniques	A collection of techniques sharing similar goals	TechEthos
Technology	A collection of techniques sharing formal or functional features and goals	[2] + TechEthos
Device	Ready-to-use technologies comprised of one or several techniques or procedures.	TechEthos
Technology family	A collection of technologies sharing common goals, or formal or functional features	TechEthos
Application	An application is the carrying out of the procedure of a technique	TechEthos
Use case	A use case is the carrying out of the procedure of a technique in a particular context	TechEthos

Table 3
Landscape of ethical concerns in the proposed enhanced ATE framework.

Ethical concerns related to …	Levels of analysis		
	High	Middle	Low
Main goals or features …	*… of technology families*	*… of technologies*	*… of technique (or application or use case, as appropriate)*
Desirable or undesirable unintended side-effects for intended users …	*… of technology families*	*… of technologies*	*… of technique (or application or use case, as appropriate)*
Potential contribution to enabling future morally controversial developments if …	*… technology families are purposed to different goals*	*… technologies are purposed to different goals*	*… techniques (or application or use case, as appropriate) are purposed to different goals or with different procedures*
Unintended side-effects for non-users (desirable or undesirable), when considering uncertainties and risk perceptions …	*… of technology families*	*… of technologies*	*… of techniques (procedures, actions, or goals) in application or use case, as appropriate)*

4.3. Enhancements to methods of ethical analysis

In the original ATE, ethical analysis depends on a "cross-reference" of ethical values and principles with "technology." In Ref. [2]; the process of "operationalisation of the value or principle" in specific "real-world conditions" of application is where ethical issues are best identified. Although it is not fully explicit in ATE's original formulation, the steps involved in this process seemed to be:

1. identifying a moral value or principle of concern;
2. describing real-world conditions necessary for the "realisation or frustration" of these values and concerns;
3. describing the object of study at the level of interest with sufficient detail on "contexts of use";
4. determining the "likelihood" of whether the object of study will have a "negative impact" on moral values or principles and necessary conditions for realisation.

Table 4
Lacunae in ATE and modes for enhancement.

Lacunae	Potential Tools/Variables for Enhancement
Meaningful consideration of foresight concept/activities	Narratives approaches, including lay narratives, cultural narratives
Thoughtful inclusion of non-expert stakeholders and publics	Incorporation of uncertainty, rather than likelihood, to better surface potential values and values conflicts; use of ethnography
Clear explanation of time horizons to consider when adopting the approach	Acceptance of some degree of ethical opacity that via narrative analysis
Consideration of potential impacts beyond negative ones	Including socially beneficial impacts

Approaching such a "cross-referencing process", ATE advocates what has since become a somewhat controversial approach to handling ethical issues by "checklist." While checklists have massive benefits in routine settings, for example, hospital administration [53], their "fitness" for settings of uncertain, ambiguous scientific and technological development is contested and may be better served in other ways [54] c.f., [55]. Specifically, attending to the ambiguities within particular contexts, as well as value conflicts by juxtaposing castings of "desirable" and "undesirable" by different groups, an enhanced ATE could advance a more nuanced set of ethical concerns to address with various interventions in policy and practice.

The evaluation of technologies via narrative analysis raises critical questions concerning transparency that had to be addressed in TechEthos. Ethical opacity does not allow for completely analytical insight into values and decisions made based on those values, especially on issues that are emerging and not fully present. For example, the motif of novelty is one of the defining features of technological innovation. It elicits a variety of reactions. An immediate impression upon the perception of novelty leads to quick rationalisation and spontaneous ethical judgment. The spectrum of such spontaneous reactions typically lies within the narratives of lay ethics. As time goes by, spontaneity yields a more seasoned, empirically grounded and reflected assessment. The motif of novelty and the associated judgment evolved in the historical time of technological development. However, they also depend on the past and future projections made by the present generation of technology developers and users: What would our ancestors say if they lived to see it? Are we breaking away from their tradition? What will future generations say, and how will they judge us?.

Also, engaging with ethnographies[8] gave the project an insight into who has the knowledge about the actions, intentions, and thoughts of the technological innovators. What kind of individuals are they? What is being disclosed and kept private? Can trust be established given the constraints of secrecy and opacity? Research in TechEthos has allowed us to establish an unambiguous connection between the judgment concerning artefacts, devices, or techniques and that concerning the manufacturers, evangelists, flag-bearers and other symbolic individual actors involved in the fabrication and use of technologies.

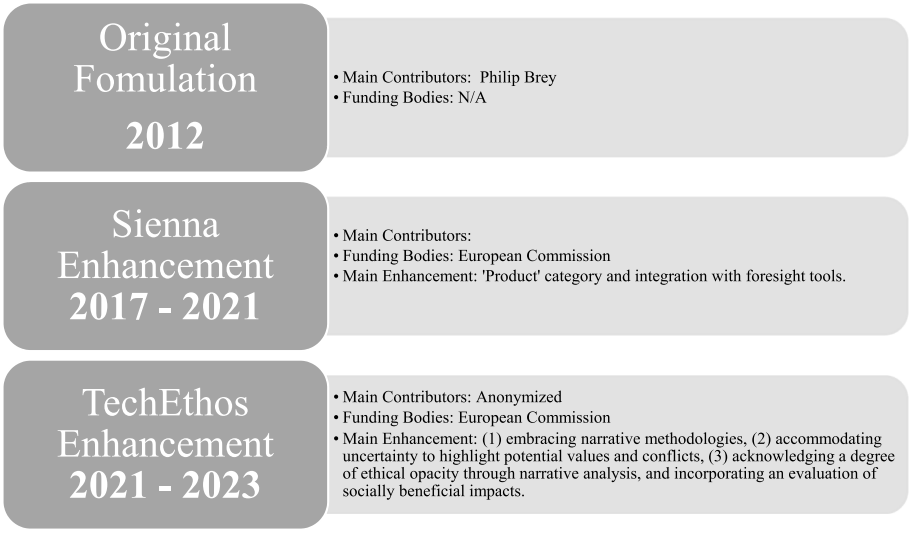
Based on our experience with TechEthos [56], we suggest, instead, the following steps, which cut through the different levels, as our proposed enhancement to the method of ethical analysis in ATE:

[8] Which were done digitally due to the covid pandemic.

1. Describe objects of interest, procedures, techniques, approaches, applications, use cases of interest, etc. (e.g., natural language processing; virtual reality; digital twins in training or health);
2. Investigate core philosophical notions and dilemmas that serve as conceptual scaffolding for the ethical issues (e.g., Is there an inherent preference for material reality over virtual reality?);
3. Identify values and principles (e.g., transparency, dignity) and return to step 2 for clarification if necessary;
4. Use narrative analysis to demarcate both transparent ethical considerations and morally opaque presuppositions in technological judgment concerning the values and principles identified in step 3 (e.g., "Be careful what you wish for", "The rich get richer, the poor get poorer");
5. Ethnographically engage with critical stakeholders associated with technologies based on narratives instead of an addition to open-ended questions.
6. Formulate a set of operationalised design questions to be asked regarding the implementation of techniques (or applications and use cases) (e.g., does the XR system take stock of the potential changes of behaviour in its users? Who profits from the changes in behaviour and how are the changes incited?).

5. Timeline of ATE enhancements

Here we provide a graphic marking development of ATE, its variants, main contributors, and the funding bodies supporting said research.



6. Conclusions

In this paper, we have proposed an advanced and expanded approach to Philip Brey's *Anticipatory Technology Ethics* (ATE), aimed at better addressing the nuanced realities of emerging technologies. We started with a comprehensive discussion of Brey's original ATE framework and highlighted areas for augmentation based on our experiences in the TechEthos project.Our exploration of ATE within TechEthos surfaced new needs for a more in-depth technology assessment - a crucial aspect of ethics-by-design. To address these needs, we proposed a more comprehensive framework of ATE that offers further nuanced ways of distinguishing levels and objects of analysis, better reflecting the ontology of emerging technology families like climate engineering and digital extended reality.

Moreover, our proposal takes a step further in addressing not only ontological but also epistemic and social justice considerations within the ethical analysis of technologies. This refined approach is not only aligned with the theoretical flexibility that Brey envisioned for ATE but also acknowledges and incorporates broader societal discourses and considerations. This enriched ATE approach aims to serve as an enhanced tool for creating ethics guidance that can inform ethics-by-design approaches. With the increasing interest in ethical foresight analysis among firms and designers, an enhanced ATE approach can assist in surfacing and evaluating potential ethical impacts and risks of novel technologies.

In conclusion, this paper positions our proposed revision of ATE within ongoing conversations about the ethics of technology, situating it in current discourses that are increasingly mindful of social justice and the necessity of bridging gaps between experts and laypeople. As a next step, we see value in empirical evaluations of this revised approach, as well as its application in practical scenarios involving diverse stakeholders, from policymakers and engineers to laypeople and citizen groups. Through this work, we aim to foster a more inclusive and nuanced dialogue on technology ethics, opening up new avenues for research and practice.

7. Positionality statement

The authors of this paper all represent diverse academic backgrounds, spanning from philosophy, sociology, law, science and technology studies (STS), and physics. This variety of expertise not only enriches our understanding of Anticipatory Technology Ethics (ATE) but also brings a multidisciplinary lens to our research and approach. Our collective experience and contributions to the TechEthos project, working across different work packages, facilitated an organic cross-pollination of ideas and perspectives. As we navigated through the project's conceptual and empirical investigations, we observed that the existing ATE approach needed further refinement and elaboration. This realisation aligned with the philosophical precedent set by Brey's advancement of ATE within the SIENNA project. In our work within TechEthos, we grappled with the nuances distinguishing different technologies. As we delved deeper, we found that the existing language used to discuss these technologies often led to confusion and miscommunication across disciplines. Therefore, this paper seeks not only to further nuance ATE but also to propose a more effective method for discussing and evaluating technology across various fields. Through this endeavor, we aim to improve the clarity of interdisciplinary communication and collaboration, a crucial component of technology ethics research.

Author statement

Steven Umbrello: Conceptualization, Writing - Original Draft, Writing - Review & Editing.

Michael J Bernstein: Conceptualization, Writing - Original Draft, Writing - Review & Editing.

Pieter E Vermaas: Conceptualization, Writing - Original Draft.

Anaïs Resseguier: Conceptualization, Writing - Review & Editing.

Gustavo Gonzalez: Writing - Review & Editing, Visualization.

Andrea Porcari: Conceptualization, Writing - Original Draft.

Alexei Grinbaum: Conceptualization, Writing - Review & Editing.

Laurynas Adomaitis: Conceptualization, Writing - Original Draft.

Data availability

No data was used for the research described in the article.

Acknowledgements

We would like to thank Philip Brey for providing substantive comments and feedback on an earlier draft of this paper. This work has been supported by the *TechEthos* project, European Commission GA-101006249. The views expressed herein are of the authors and do not necessarily reflect those of the Commission.

References

[1] B. Wynne, The rhetoric of consensus politics: a critical review of technology assessment, Res. Pol. 4 (2) (1975) 108–158, https://doi.org/10.1016/0048-7333(75)90028-1.

[2] P.A. Brey, Anticipatory ethics for emerging technologies, NanoEthics 6 (1) (2012) 1–13, https://doi.org/10.1007/s11569-012-0141-7.

[3] D. Banta, What is technology assessment? Int. J. Technol. Assess. Health Care 25 (S1) (2009) 7–9, https://doi.org/10.1017/S0266462309090333.

[4] A. Grunwald, Technology assessment: concepts and methods, in: A. Meijers (Ed.), Philosophy of Technology and Engineering Sciences, Elsevier, 2009, pp. 1103–1146, https://doi.org/10.1016/B978-0-444-51667-1.50044-6.

[5] T. Swierstra, D. Stemerding, M. Boenink, Exploring techno-moral change: the case of the ObesityPill, in: P. Sollie, M. Düwell (Eds.), Evaluating New Technologies, The International Library of Ethics, Law and Technology, vol. 3, Springer, Dordrecht, 2009, https://doi.org/10.1007/978-90-481-2229-5_9.

[6] B.C. Stahl, IT for a better future: how to integrate ethics, politics and innovation, J. Inf. Commun. Ethics Soc. 9 (3) (2011) 140–156, https://doi.org/10.1108/14779961111167630.

[7] B.C. Stahl, R. Heersmink, P. Goujon, C. Flick, J. Van Den Hoven, K. Wakunuma, M. Rader, Identifying the ethics of emerging information and communication technologies: an essay on issues, concepts and method, Int. J. Technoethics (IJT) 1 (4) (2010) 20–38, https://doi.org/10.4018/jte.2010100102.

[8] E. Buchinger, M. Kienegger, G. Zahradnik, M.J. Bernstein, A. Porcari, G. Gonzalez, D. Pimponi, G. Buceti, TechEthos Technology Portfolio: Assessment and Final Selection of Economically and Ethically High Impact Technologies, Deliverable 1.2 to the European Commission. TechEthos Project Deliverable, 2022. Available at: www.techethos.eu.

[9] P. Brey, B. Dainow, Y.J. Erden, A. Matar, P. Jansen, R. Rodrigues, P. Hoevel, SIENNA D6.3: Methods for Translating Ethical Analysis into Instruments for the Ethical Development and Deployment of Emerging Technologies. (Version V2.0), Zenodo, 2021, https://doi.org/10.5281/zenodo.5541539.

[10] P. Brey, O. King, P. Jansen, B. Dainow, Y.J. Erden, R. Rodrigues, I. van de Poel, SIENNA D6.1: Generalised Methodology for Ethical Assessment of Emerging Technologies, Zenodo, 2021, https://doi.org/10.5281/zenodo.7266894.

[11] L. Floridi, A. Strait, Ethical foresight analysis: what it is and why it is needed? Minds Mach. 30 (1) (2020) 77–97, https://doi.org/10.1007/s11023-020-09521-y.

[12] K. Shilton, "That's not an architecture problem!": techniques and challenges for practicing anticipatory technology ethics, iConference 2015 Proceedings (2015). http://hdl.handle.net/2142/73672.

[13] B. Friedman, D.G. Hendry, Value Sensitive Design: Shaping Technology with Moral Imagination, MIT Press, Cambridge, MA, 2019.

[14] P. Bishop, A. Hines, T. Collins, The current state of scenario development: an overview of techniques, Foresight 9 (1) (2007) 5–25, https://doi.org/10.1108/14636680710727516.

[15] J. Van den Hoven, G.J. Lokhorst, I. Van de Poel, Engineering and the problem of moral overload, Sci. Eng. Ethics 18 (1) (2012) 143–155, https://doi.org/10.1007/s11948-011-9277-z.

[16] J. Timmermans, Y. Zhao, J. van den Hoven, Ethics and nanopharmacy: value sensitive design of new drugs, Nanoethics 5 (3) (2011) 269–283, https://doi.org/10.1007/s11569-011-0135-x.

[17] F. Santoni de Sio, J. Van den Hoven, Meaningful human control over autonomous systems: A philosophical account, Frontiers in Robotics and AI 5 (2018) 15. https://doi.org/10.3389/frobt.2018.00015.

[18] S. Umbrello, N.G. Wood, Autonomous weapons systems and the contextual nature of hors de combat status, Information 12 (5) (2021) 216, https://doi.org/10.3390/info12050216.

[19] A. Bergek, S. Jacobsson, B. Carlsson, S. Lindmark, A. Rickne, Analyzing the functional dynamics of technological innovation systems: a scheme of analysis, Res. Pol. 37 (3) (2008) 407–429, https://doi.org/10.1016/j.respol.2007.12.003.

[20] P.D. Windschitl, E.U. Weber, The interpretation of" likely" depends on the context, but" 70%" is 70%—right? The influence of associative processes on perceived certainty, J. Exp. Psychol. Learn. Mem. Cognit. 25 (6) (1999) 1514. https://psycnet.apa.org/doi/10.1037/0278-7393.25.6.1514.

[21] L.Z. Tiedens, S. Linton, Judgment under emotional certainty and uncertainty: the effects of specific emotions on information processing, J. Personality Soc. Psychol. 81 (6) (2001) 973. https://psycnet.apa.org/doi/10.1037/0022-3514.81.6.973.

[22] B.J. Weber, G.B. Chapman, The combined effects of risk and time on choice: does uncertainty eliminate the immediacy effect? Does delay eliminate the certainty effect? Organ. Behav. Hum. Decis. Process. 96 (2) (2005) 104–118, https://doi.org/10.1016/j.obhdp.2005.01.001.

[23] N. Oreskes, Merchants of Doubt: How a Handful of Scientists Obscured the Truth on Issues from Tobacco Smoke to Global Warming, first ed., Bloomsbury Press, London, 2011.

[24] J. Stilgoe, The (co-)production of public uncertainty: UK scientific advice on mobile phone health risks, Publ. Understand. Sci. 16 (1) (2007) 45–61, https://doi.org/10.1177/0963662506059262.

[25] O. Renn, A. Klinke, M. van Asselt, Coping with complexity, uncertainty and ambiguity in risk governance: a synthesis, Ambio 40 (2) (2011) 231–246, https://doi.org/10.1007/s13280-010-0134-0.

[26] A. Stirling, "Opening up" and "closing down": power, participation, and pluralism in the social appraisal of technology, Sci. Technol. Hum. Val. 33 (2) (2008) 262–294, https://doi.org/10.1177/0162243907311265.

[27] J. Durant, Participatory technology assessment and the democratic model of the public understanding of science, Sci. Publ. Pol. 26 (5) (1999) 313–319, https://doi.org/10.3152/147154399781782329.

[28] D.H. Guston, D. Sarewitz, Real-time technology assessment, Technol. Soc. 24 (1) (2002) 93–109, https://doi.org/10.1016/S0160-791X(01)00047-1.

[29] D. Barben, E. Fisher, C. Selin, D.H. Guston, E.J. Hackett, O. Amsterdamska, M. Lynch, Anticipatory governance of nanotechnology: foresight, engagement, and integration, in: The Handbook of Science and Technology Studies, third ed., MIT Press, Cambridge, MA, 2007, pp. 979–1000.

[30] J. Stilgoe, R. Owen, P. Macnaghten, Developing a framework for responsible innovation, Res. Pol. 42 (9) (2013) 1568–1580, https://doi.org/10.1016/j.respol.2013.05.008.

[31] F.N. Laird, Participatory analysis, democracy, and technological decision making, Sci. Technol. Hum. Val. 18 (3) (1993) 341–361, 10.1177%2F016224399301800305.

[32] Grinbaum, A. and Groves, C. (2013). What Is "Responsible" about Responsible Innovation? Understanding the Ethical Issues. In Responsible Innovation (eds R. Owen, J. Bessant and M. Heintz). https://doi.org/10.1002/9781118551424.ch7.

[33] A. Grinbaum, L. Adomaitis, Moral Equivalence in the Metaverse, Nanoethics, 2022, https://doi.org/10.1007/s11569-022-00426-x.

[34] M. Steen, M. Sand, I. van de Poel, Virtue ethics for responsible innovation, Bus. Prof. Ethics J. 40 (2) (2021) 243–268, https://doi.org/10.5840/bpej2021319108.

[35] V. Politi, A. Grinbaum, The distribution of ethical labor in the scientific community, Journal of Responsible Innovation 7 (3) (2020) 263–279, https://doi.org/10.1080/23299460.2020.1724357.

[36] I. van de Poel, Translating values into design requirements, in: D. Michelfelder, N. McCarthy, D. Goldberg (Eds.), Philosophy and Engineering: Reflections on Practice, Principles and Process, Philosophy of Engineering and Technology, vol. 15, Springer, Dordrecht, 2013, https://doi.org/10.1007/978-94-007-7762-0_20.

[37] W.E. Bijker, T.P. Hughes, T.J. Pinch, The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology, MIT Press, Cambridge, MA, 1984.

[38] S. Rayner, Democracy in the age of assessment: reflections on the roles of expertise and democracy in public-sector decision making, Sci. Publ. Pol. 30 (3) (2003) 163–181, https://doi.org/10.3152/147154303781780533.

[39] W. Houkes, P.E. Vermaas, Technical Functions: on the Use and Design of Artefacts, Vol. 1 of Philosophy of Engineering and Technology, Springer, Dordrecht, 2010.

[40] S. Urueña, Understanding "plausibility": a relational approach to the anticipatory heuristics of future scenarios, Futures 111 (2019) 15–25, https://doi.org/10.1016/j.futures.2019.05.002.

[41] C. Selin, The sociology of the future: tracing stories of technology and time, Sociology Compass 2 (6) (2008) 1878–1895, https://doi.org/10.1111/j.1751-9020.2008.00147.x.

[42] U. Felt, Of timescapes and knowledgescapes: retiming research and higher education, in: P. Scott, J. Gallacher, G. Parry (Eds.), New Languages and Landscapes of Higher Education, Oxford University Press, 2016, https://doi.org/10.1093/acprof:oso/9780198787082.003.0006.

[43] J. Hassard, Introduction: the sociological study of time, in: J. Hassard (Ed.), The Sociology of Time, Palgrave Macmillan UK, London, 1990, pp. 1–18, https://doi.org/10.1007/978-1-349-20869-2_1.

[44] J. Law, Organising Modernity: Social Ordering and Social Theory, John Wiley & Sons, Hoboken, NJ, 1993.

[45] B. Wynne, May the sheep safely graze? A reflexive view of the expert-lay knowledge divide, Risk, environment and modernity: Towards a new ecology 40 (1996) 44. https://digital.casalini.it/9781848609570.
[46] A. Grinbaum, On the scientist's moral luck and wholeheartedness, Journal of Responsible Innovation 7 (2020) S12–S24, https://doi.org/10.1080/23299460.2020.1805266, sup.2.
[47] B. Williams. Ethics and the Limits of Philosophy, 1st ed., Routledge, 2011. https://doi.org/10.4324/9780203828281.
[48] J. Dupuy, A. Grinbaum, Living with uncertainty: toward the ongoing normative assessment of nanotechnology, in: J. Schummer, D. Baird (Eds.), Nanotechnology Challenges: Implications for Philosophy, Ethics and Society, World Scientific Publishing Company, 2004, pp. 287–314. Retrieved 22 September 2022, from.
[49] A. Grinbaum, Les robots et le mal, Desclée de Brouwer, Paris, 2019.
[50] T. Swierstra, A. Rip, Nano-ethics as NEST-ethics: patterns of moral argumentation about new and emerging science and technology, Nanoethics 1 (1) (2007) 3–20, https://doi.org/10.1007/s11569-007-0005-8.
[51] S.R. Davies, P. Macnaghten, Narratives of mastery and resistance: lay ethics of nanotechnology, NanoEthics 4 (2010) 141–151. https://doi.org/10.1007/s11569-010-0096-5.
[52] J. Dupuy, The narratology of lay ethics, Nanoethics 4 (2) (2010) 153–170, https://doi.org/10.1007/s11569-010-0097-4.
[53] A. Gawande, The Checklist Manifesto: How to Get Things Right, first ed., Metropolitan Books, New York, 2010.
[54] M. Akrich, The de-scription of technical objects, in: W.E. Bijker (Ed.), Shaping Technology/building Society: Studies in Sociotechnical Change, The MIT Press, Cambridge, MA, 1992. https://hdl.handle.net/2027/heb.01128.
[55] K. Shilton, Values levers: building ethics into design, Sci. Technol. Hum. Val. 38 (3) (2013) 374–397, https://doi.org/10.1177/0162243912436985.
[56] L. Adomaitis, A. Grinbaum, D. Lenzi, TechEthos D2.2: identification and specification of potential ethical issues and impacts and analysis of ethical issues of digital extended reality, neurotechnologies, and climate engineering, TechEthos Project Deliverable (2022). Available at: www.techethos.eu.
[57] B. Friedman, P.H. Kahn, A. Borning, A. Huldtgren, Value sensitive design and information systems, in: Early Engagement and New Technologies: Opening up the Laboratory, Springer, Dordrecht, 2013, pp. 55–95, https://doi.org/10.1007/978-94-007-7844-3_4.