- Why are we faced with a fundamental insecurity?
- What are the methods to assess (emerging) technologies?

An early attempt to answer these questions, followed by a list with recommendations

Inhalt

Technology Assessment

Technology assessment (TA) can be defined as a "research practice motivated through reflexive knowledge gain for the scientific analysis of dynamic and complex socio-technical configurations with the intention of advising" (Böschen et al., 2021). There are to fundamental epistemic strategies to assess technologies (Dobroć et al., 2018):

- Ignore purposely the context of technologies (technological optimizing) -> "closing-down"; often focus on premises of efficiency and economic gain
- Account for the context of technologies (thinking in alternatives) -> "opening-up"; often focus on economical, cultural, social and political aspects, the central question is "How do we want to live now and in the future?" (and what is therefore the best alternative)

Constitutive for TA are the following characteristics (Böschen et al., 2021; Grunwald, 2010):

- orientation to consequences: how and in which context and with which cultural background will we use a technology and for which purpose
- scientific approach: distance of the (scientific) observer (relative distance and proximity); TA research is evaluated on the basis of relevant indicators such as peer-reviewed publications, external funding and promotion of young researchers
- advisory: transfer services of the science system to non-scientific recipients; demand for advisory knowledge about technology impacts and technology design in democratic structures

Uncertainty

"*[M]any new technologies are surrounded by uncertainty due to opacity, complexity, multi-agency, long-development trajectories, orientation at the future, global character, impact, and the fact that technology often shifts in application. These reasons contribute to the fact that uncertainty is an essential concept in modern, complex technology development and, consequently, it needs serious attention from those involved in ethics of technology*" (Sollie, 2007, p. 297). If undesirable consequences of technologies should be avoided it is

necessary that technologies are assessed at an early stage of development: However, at an early stage of development, technology assessment can only be based on insufficient information, so that influences and possible side-effects of the technological products on society and nature are difficult to predict yet. If technology assessment would wait until sufficient information is available and a technology is "societally entrenched", the possibilities for revision are small, for example due to economic constraints (Davis & Venkatesh, 2004; Grunwald, 2010; Hopster, 2022; Möller et al., 2021). This is called the "Collingridge dilemma" (Collingridge, 1980).

Taking a meta-perspective there are two fundamental sources of uncertainty when prospectively assessing emerging technologies (Sollie, 2007):

- **Epistemological uncertainty**: Agents (like scientists) are lacking information and the technology, which needs to be assessed, is often highly complex and many technological assessments are some kind of "wicked problems", which is a "*multifaceted concept that highlights the difficulties of comprehensively formulating a problem and of defining what constitutes a good solution*" (Keller et al., 2021, p. 98)
- **Ontological or variability uncertainty** (also called "aleatory uncertainty"): Uncertainty that is inherent to the variability of the system and which cannot be reduced; the following aspects contribute to this uncertainty:
    - Inherent randomness of natural processes, intrinsic to a stochastic process
    - Unpredictability and variability of human behavior
    - Unpredictable nature of societal processes stem from economic, social, and cultural dynamics
    - Technological surprises, like breakthroughs, unexpected consequences and side-effects

- Additional we could refer to the level of complexity how modern society are structured (e.g. Luhmann, 1987; Parsons, 1951), which leads to highly non-linear dynamics (e.g. Berlin, 1990)

- If we want to account for uncertainty this is possible in a quantitative way (uncertainty quantification), which describes risks[1] with probability distributions and in a qualitative way (uncertainty characterization), which represents uncertainties / risks through the use of scenarios (Keller et al., 2021)

Additionally, the quality of every technology assessment study, which tries to address these sources of uncertainty, can be questioned: "*[T]he definition of the problem to be dealt with; the identification of relevant questions to be addressed; the consideration of various social perspectives and interests; and the nature of policy recommendations to be made*" are all shaped by normative decisions (Hennen, 1999, p. 305). The normative claim in itself is inherently uncertain (describe what the future *will* be) and prescriptive (describe a *good* future). The future is thereby logically unknowable and the prediction must be reasonable and convincing, while the normative claim how a good future looks like should be desirable or acceptable (Mittelstadt et al., 2015).

Boundary conditions like considering only highly probable future scenarios (Kosow & Gaßner, 2008) or limiting the context by the setting boundaries of the system under consideration (Sollie, 2007) have to be made. To reflect the usefulness of the technology assessment study (interdisciplinary) research teams could reflect their theory-building approach, like emphasizing an "integrated empirical ethics" (Molewijk et al., 2004) or a "pattern of mixed judgements" (Düwell, 2009) or considering a more confirmatory or explanatory approach (Wagenmakers et al., 2012).

[1] Only for risks it is possible to define probability distributions, else in the literature we talk of uncertainty if probabilities of possible outcomes are unknown (Keller et al., 2021; Mittelstadt et al., 2015)

The impossibility to predict all possible negative (positive) side-effects of technologies has led to fundamental discussions within philosophy like „Das Prinzip Verantwortung “ (Jonas, 2020; published 1979) vs. „Das Prinzip Hoffnung“ (Bloch, 1985; published 1954 in Germany), which highly questions a (naïve) techno-optimistic perspective. Driven by powerful individuals like Elon Musk (in general “futurists”) or existing belief systems within society it could be argued that there is a positive bias for a techno-optimistic perspective: for example, expressed as a “socio-technical myth of modernity” according to Hennen (1999) there is the belief that “*there is a given, positive causal relationship between technical progress and social welfare: the former is seen as an essential requirement, and guarantee, for the latter, leading to social progress in individual freedom, welfare, justice and security*” (Hennen, 1999, p. 303).

The current crisis of democracy and ecology obligate according to Böschen et al. (2021) technological assessment institutions to foster democracy development and sustainability. This clearly shows that technological assessment is not a pure scientific endeavor, also a political one (Böschen et al., 2021; Delvenne & Parotte, 2019; Hennen, 1999). However, it is highly problematic that technological assessment often cannot meet the expectations of different stakeholder groups (such as scientific reflection on uncertainty vs. clear recommendation for action for policy makers). In the future it is assumed that the epistemic authority of science is undermined by to high expectations (of political actors or public) and the increasing digitalization and application of artificial intelligence, which leads to more and more non transparent forms of knowledge generation (?) (Böschen et al., 2021).

Methods

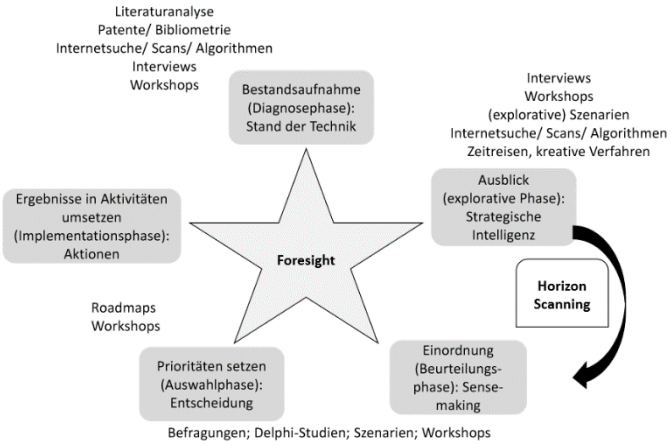
The possible set of methods can be differentiated in “ex ante, intra, ex post” (Reijers et al., 2018) according to their usefulness for a certain technological maturity (Straub, 2015; Vik et al., 2021) and the type of data being used (quantitative, qualitative, mixed). The terms “ex ante, intra, ex post” are defined as follows (Reijers et al., 2018):

- **ex ante**: methods aiming at technology assessment at an early stage of the research and innovation process; "Technology-Readiness-Level" from Straub (2015) 1-3
- **intra**: methods aiming at technology assessment during design and testing stage; "Technology-Readiness-Level" from Straub (2015) 4-8
- **ex post**: methods aiming at technology assessment when research and innovation process is already finished and concrete technologies have been developed; "Technology-Readiness-Level" from Straub (2015) 9-10

! It is important to note that the form of presentation (mock-up text at "ex ante stage" vs. live interaction at "ex post stage") has (in one study) little influence on the instrumental evaluation of a technology, but on the emotional and social evaluation. The interactivity and presentation fidelity of a technology / prototype has an effect on the evaluation (Xu et al., 2015).

Additionally, I highlight if a certain method has been used within our research group[2] and based the list of methods on different literature (Böschen et al., 2021; Markus & Mentzer, 2014; Reijers et al., 2018; Tran & Daim, 2008; Wright, 2011)[3]:

! It is also important to note that combining different methods leads to the biggest knowledge gain and increases sharply the efficiency of technological assessment studies. Two examples: (1) Beforehand writing scenario texts think about methods of brainstorming, backcasting or set up an online Delphi study to identify (ethical) key factors



[2] Possible search terms for technology assessment methods are "*Futures Research Methodology, Foresight Methods, Research and Innovation, (Ethical) Technology Assessment, Responsible Research and Innovation, Technology Foresight / Forecasting, ...*".

[3] Also considered "Futures Research Methodology — Version 3.0", see: https://www.millennium-project.org/publications-2/futures-research-methodology-version-3-0/ and "33 Foresight Methods", see: https://rafaelpopper.wordpress.com/foresight-methods/; retrieved on 10th of August 2022

driving a scenario. (2) If the aim is to understand what laypersons associate with certain terms, like sustainability, use methods of scanning or semi-automatized bibliometric analysis to extract all kinds of associations beforehand to inform your study. The combination of methods is highlighted in one possible foresight model (Böschen et al., 2021, p. 324)*:*

Table 1

Methods of prospective technological assessment according to the level of technological maturity and the type of resulting data. The column own signifies if this method was or will be applied in the Freiburg research group. The columns possible source are just single reading recommendations.

Technological maturity	Method	Aim	How	Type of Data	Own?	Possible source
ex ante	ethical issues of emerging ICT applications (ETICA) project	using a bibliometric analysis to identify potential emerging technologies	distributed discourse analysis of publications on emerging ICTs using an analytical grid (extracting specific information)	semi-quantitative	No	(Carsten Stahl, 2011)
all stages	Scanning	using big data to identify potential emerging technologies	extracting data from social networks, news outlets, … with subsequent text processing analysis (like Latent Dirichlet allocation)	semi-quantitative	No	(Kohl et al., 2018)
all stages	Patent Analysis	using a bibliometric analysis and big data to identify patent registrations	assuming that increasing or decreasing registrations would (apparently) indicate, for example, low or high potential for technology developments in a specific area	semi-quantitative	No	
ex ante / meta-method	**Sccenario approach; prerequisite for most "ex ante" methods**	construct scenario texts	construct scenarios to delineate ethical issues and/or desirable or undesirable futures resulting from emerging technologies	qualitative	Yes	(Kosow & Gaßner, 2008)

all stages	Checklist approach	setting up checklist with core issues	check-list serves as an early warning system and involves often considers issues like privacy violations, sustainability, ...	qualitative	No	(Palm & Hansson, 2006; Wright, 2011)
all stages	Delphi	systematically summarize feedbacks without any bias like "follow the leader" tendencies	repeated polling of the same individuals, feeding back (sometimes) anonymized responses from earlier rounds of polling, with the idea that this will allow for better judgements to be made without undue influence from forceful or high-status advocates	qualitative	No	(Nowack et al., 2011)
ex ante, intra	Backcasting	approach that involves working back from an imagined future, to establish what path might take us there from the present	using for example simulation modelling or scenario workshops	qualitative	No	
ex ante, intra	Brainstorming	generate new ideas around a specific area of interest	removing inhibitions and breaking out of narrow and routine discussions	qualitative	Yes (CAMs)	
all stages	Panels	typically, a mix of talks, presentations, and discussions and debates on a particular subject	include Citizen Panels, Conferences/Workshops, Expert Panels, Genius Forecasting (top leading experts)	semi-qualitative	No	

all stages	Relevance Trees and Logic Charts	creativity technique	creativity technique first accepts a problem as an existing condition, examines it for a multitude of criteria and then breaks it down into individual statements; advantage of the disassembly into individual parts is that complex problems become manageable	semi-qualitative	No	
intra	Science Fictioning	fictional narrative about possible events	narrative about possible events which have not yet materialized and elaborates on the consequences of this possible future	qualitative	No	
ex ante, intra	Roadmapping	method which outlines the future of a field of technology	generating a timeline for development of various interrelated technologies and (sometimes) including factors like regulatory and market structures (needs massive resources)	semi-quantitative	No	
all stages	Sociotechnical Transition analysis	Attempts to anticipate social discontinuities that may accompany technical developments	using future oriented analysis tools such as Delphi and scenario planning or big data approaches (needs massive resources)	semi-quantitative	No	
ex ante, intra	Simulation Gaming / Studies	form of structured role-playing; in context of military "war games"	an extensive script (model parameter) outlines the context of action and the actors involved	semi-quantitative	No	(Funke, 2001)

ex post	agent-based modelling	e.g. used to understand the effect of advertising campaigns	computational model for simulating the actions and interactions of autonomous agents; possible to set up if system under consideration is (semi-) well defined	quantitative	No	(Schröder & Wolf, 2017; Wolf et al., 2015)
all stages / meta-method	System Analysis	reflecting the system under consideration (taking into account boundaries or relations between sub-systems)	e.g. uses positive and negative feedback loops to show how expected outcomes may (not) be realized or how systems can (not) spin out of control; example "Kohlenstoffwende"	X, or quantitative	No	
ex ante, intra / meta-method	Interpretive Structural Modeling	setting up a virtual system and to understand the relations of the influential factors	computer-aided method for developing a graphical representation of system composition and structure	semi-quantitative	No	
all stages	Wild Cards & Weak Signals	identify situations/events with perceived low probability of occurrence but potentially high impact	usually carried out by small groups of highly skilled people capable of combining expertise, examining data and creative thinking (needs massive resources)	semi-quantitative	No	
all stages	Surveys	applying questionnaire	made available online, considering a large pool of respondents possible issues of technologies can be identified using correlative designs	quantitative	Yes	(Klaus et al., 2020)

all stages	Surveys with experimental designs	applying questionnaire	", additionally including a experimental / natural condition, because correlative designs are not sufficient to understand „cause-and-effect relationships“	quantitative	Yes	(Hahnel et al., 2020)
all stages	Multi-Criteria Analysis	considering multiple criteria and setting up complex matrices (like stakeholders X ethical principles)	examine the influence of each variable combination to assess the importance of various evaluative criteria or stakeholder groups	semi-quantitative	Yes	(Schroeder & Palmer, 2003)
all stages / meta-method	Risk Assessment	estimate the probability distribution of possible (identifiable) risk factors	assigning probabilities and relations to probability distribution to evaluate a technology by quantifiable risks	quantitative	No	(Keller et al., 2021)
all stages / meta-method	Life Cycle Analysis	to identify environmental concerns	methodology for assessing environmental impacts associated with all the stages of the life cycle of a technology	semi-qualitative	No	
all stages / meta-method	Cost Benefit Analysis	e.g. Technology Value Pyramid to determine the value of a technology; many other approaches	applying 33 evaluation metrics ranging from financial ratios to organizational measures to determine the value of a technology	semi-quantitative	No	(Tipping et al., 1995)

all stages / meta-method	**Procedural Approaches**	prescribe a certain method of how to trigger (ethical) responses among (public) groups; makes no substantive claims	focus on discourse principles (mainly Habermas); technologies / norms that could meet with the approval of all affected in their capacity as participants in a practical discourse	X	No	
	> possible methods	to check the quality of the procedural approach there are different ethical methods:	coherence analysis, wide reflective equilibrium, axiology, socratic approach, casuistry, …	qualitative	No	(Legault et al., 2019; Saarni et al., 2011)
ex ante	Basal attributes	evaluation of basal attributes of emerging technologies (like living materials systems)	based on expert interviews create a list of basal attributes of emerging technologies and these attributes are subsequently assessed		Yes (CAMs)	(Reuter, 2019)
ex ante	Understanding of terms	how terms like sustainability are understood by laypersons is unknown	use CAMs (big N) with subsequent aggregation to understand central associations to terms		Yes (CAMs)	

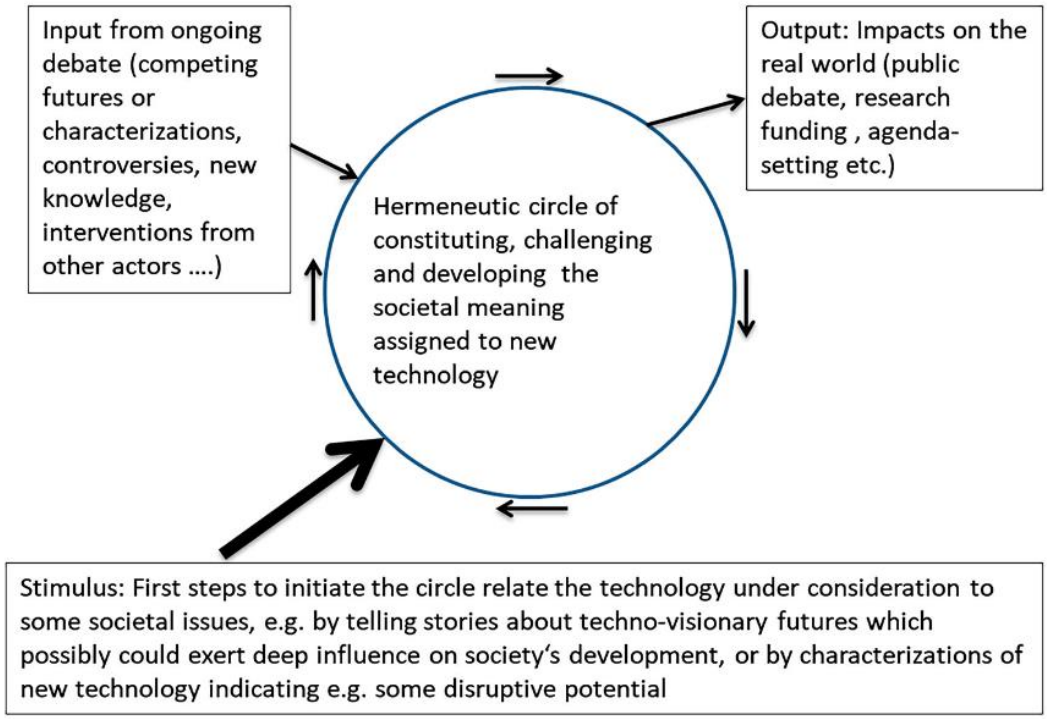
Recommendations

To assess (emerging) technologies I come up with the following recommendations:

- in the preparation phase of a study **content-wise** it is necessary to
    - conduct systematic literature reviews to develop strong theoretical models, because every technology is driven by different factors (like hedonistic vs. societal aspects are more important -> iPhone vs. nuclear power plant)
    - conduct (qualitative) pre-studies to understand how laypersons understand specific terms like sustainability
    - work within an multi- / inter- / transdisciplinary team to set up materials for a study and to understand the needs of different actors. This process should be supported by promoters and a clear strategy (Choi & Pak, 2006, 2007)
- Acceptance of emerging technologies involves a multi-dimensional, dynamic process and the involvement of different perspectives; therefore, we need **methodological**
    - high reliable measurements (of acceptance, ...)
    - complex designs (longitudinal, multi-group, ...); sophisticated experimental designs, because correlative designs are not sufficient to understand „cause-and-effect relationships“
    - combine different sources of data (data blending)
    - enough power (N) to
        - use latent modelling approaches
        - do latent class / cluster analysis
        - approaches which not assuming linearity
- **Continuously assess technologies** (at best in “real-time”), also called “tracker technology assessment” (Böschen et al., 2021; Lucivero, 2016), to

- adjust technologies as early as possible when a technology is not socially entrenched
- to avoid costs
- to get a multi-actor perspective to reduce the asymmetry of power between the "impactors" (those developing and promoting a technology) and "impactees" (those who are affected by a technology) (Delvenne & Parotte, 2019; Rip, 2018)
- to negotiate possible points of contention between different stakeholders ("Positionsarbeit") as early as possible (political system, science, public sphere, …)

The need for continuously assessing technologies can be fostered by Grunwald (2020) hermeneutic extension to include the societal meaning attached to emerging technologies, which is always a process never complete (Grunwald, 2020, p. 102):



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