# Assessing Technological Innovations: From Early Warning to the Governance of Socio-technical Transformations

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*With technology we want to secure prosperity and survival, but at the same time threaten our future to the extreme*

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**Abstract** Technology assessment (TA) is an interdisciplinary field of problem-oriented research generating knowledge primarily for decision-making processes in politics, economy, and society with regard to the opportunities, risks, and challenges of emerging technologies and socio-technical change. This chapter outlines the development of the field since its roots in the 1960s to date with a focus on Germany, the USA, and Europe. Based on a rough temporal division into three phases representing an expert-based, participatory, and pragmatic TA approach, respectively, we illustrate the field's development by highlighting concrete projects and studies, reflecting on the (ever new) development of appropriate assessment methods and pointing to relevant thematic waves ("hype cycles") of technology groups, such as energy, genetic, or information technologies. Finally, we discuss the impact and future challenges of TA given current socio-political trends and upcoming socio-technical transformations. We conclude that there is a clear need for new approaches of TA so that TA will remain a valuable instrument providing guidance in a complex and uncertain technological environment in the coming decades.

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## 1 Introduction

For a long time, until the middle of the twentieth century, technological progress was commonly equated with societal progress leading to economic growth, social wealth, and well-being. However, this technological optimism had already begun to crack as a result of the horrors of the atomic bomb in World War II and came also in civilian contexts under further pressure, for instance, with regard to the environmental and human risks of the use of pesticides in the 1960s (Carson 1962). As the awareness of the ambivalence of technologies increased in politics and public life (Daddario 1966), the strong need emerged to create robust knowledge on the unintended and potentially adverse effects of a specific technology entering markets and society and to contrast this with the technology's promises and potential benefits.

The world's first institution for such a task of "technology assessment" was launched by the US Congress in 1972. It was named *Office of Technology Assessment* (OTA) and installed as a science-based body for parliamentary policy advice (Kunkle 1995; Bimber 1996). Although the founding history of the *Fraunhofer Institute for Systems and Innovation Research* (ISI) is different (cf. Edler and Walz 2024 in this anthology), it is from a historical perspective certainly no coincidence that OTA and Fraunhofer ISI were founded in the same year (1972), given the broader societal context at that time with its increasing discomfort with new or more frequently applied technologies leading, for example, to severe environmental degradation such as intensive air and water pollution, related diseases, corrosion, fish kill, or high cost of river filtrate (Grandjean 1960; Baram 1970; Reimer 1971).

Since the foundation of OTA, technology assessment (TA) has developed, established, and diversified as an interdisciplinary field of problem-oriented research practices (Paschen et al. 1978; Grunwald 2019). This chapter aims to outline the field's development to date. In loose alignment with the work of Kuhn (1962), the Austrian sociologist Bogner (2021) distinguishes three "paradigms" of TA in its rather brief history.

In a first paradigm or phase ("politicisation"), beginning in the late 1960s, TA aimed at increasing the number of options for policy making, fighting the idea that everything is determined by the technology itself, and therefore turning technology into a political, debatable issue. Given the steering optimism of that time, the expertise of scientists was meant to help with creating a scientific knowledge base that gives orientation for political decision-making on new technologies (Coates 1974). This has been described as the expert model of "classic" TA (Grunwald 2002, pp. 123ff.).

In a second paradigm or phase ("democratisation"), which became dominant in the 1980s, TA aimed at increasing the inclusion of people and stakeholders affected by technological projects, striving to democratise (the assessment of) science and technology, a field that had long been considered as a matter for scientific experts alone. Given the large societal conflicts on technologies such as nuclear energy or genetic engineering, especially in Europe, the perspectives and (local) expertise of citizens and stakeholders were meant to widen the value (and knowledge) base for decision-making in the political and administrative institutions, increasing its social robustness, and to influence or even co-create the design of technologies. This has been described as the "participatory turn" of TA or simply as "participatory TA" (Joss and Bellucci 2002).

In a third paradigm or phase ("pragmatisation"), since the 2000s to date, TA has aimed at contributing to the responsible design, implementation, and governance of technological innovations. Given the "normative turn" (Daimer et al. 2012) in national and supranational science, technology and innovation (STI) policies towards the so-called "grand societal challenges", both technological and social innovations are increasingly seen as important means to address these challenges, be it demographic or climate change. In this context, TA has taken a rather "pragmatic" position using diverse forms of expertise and processes of knowledge production to reflect upon technologies and societal discourses on possible socio-technical futures.

Certainly, these three TA paradigms or phases are not to be understood as strictly separate from each other (Bogner 2021). Not only do they overlap temporally, but the diverse TA approaches developed in a specific phase (such as expert-based and participatory models) have also been taken and adapted to the changed context conditions in later phases. Especially the current "pragmatic" paradigm is characterised by a "peaceful coexistence" (Bogner 2021, p. 56) of diverse TA approaches that have proven to be valuable in the past. The paradigms also reflect different constellations in the relationship between TA and science in general. Wehling (2021), a sociologist of science, distinguishes four types of such constellations: a scientistic (dominant in the paradigm of "classic" TA; cf. Wynne 1975), a constructivist, a participative (both dominant in the second paradigm to date), and a normative-reflexive constellation. The latter represents a rather new and fuzzy development, since the ("classic") claim of neutrality and the question of TA's implicit or explicit normativity have recently become a central topic of self-reflexive debates within TA (Nierling and Torgersen 2020; Torgersen 2019)—with an open outcome.

In this chapter, we take the three TA paradigms as a rough temporal division and further outline the development of the field of technology assessment in a broad sense focusing on Germany, the USA, and Europe. In contrast to Bogner (2021), our aim is not to define and justify such paradigms or phases, but to illustrate the development in more detail and practice-oriented terms. We therefore focus on concrete projects and studies, on the (ever new) search for and development of appropriate assessment methods, and on the connection to the thematic waves ("hype cycles") of specific groups of technologies, such as energy, genetic, or information technologies. In addition, since Fraunhofer ISI has played an active and influential role in the field from the beginning to date, we highlight some of its activities to illustrate the field's development.

## 2 The Beginnings: Expert-Based TA as Policy Advice

In the late 1960s, concerns about technological innovations and their effects became increasingly known in the USA. They came from environmentalists, doctors, and psychotherapists and were put together as complaints to the legal system. Thus, it is surprising only at first glance that the demand for systematic forecasting of new (and known) technical developments appeared very early in jurisprudential publications (Baram 1970). Green (1967), for instance, states:

> The basic question is whether our legal system is capable of imposing effective social control over new technologies before they inflict very substantial, or even irreparable injury upon society. It seems clear that we cannot rely on the courts alone to protect society against fast-moving technological developments. Judge-made rules of law always come after, and usually long after, the potential for injury has been demonstrated. (Green 1967, cited in Baram 1970, p. 569)

The technical fields addressed by lawyers and courts at that time included motorisation, aviation, genetic engineering, and nuclear power. However, the reactive nature of the courts and the limited knowledge of judges of the various fields of technical, economic, and societal impacts made it obvious that they could not serve as society's primary instrument for TA. The limits to growth report to the Club of Rome (Meadows et al. 1972) added another global and far-reaching topic (on limited natural resources) to the discussion, using new types of simulation models (such as system dynamics by Forrester 1971) and the increasing capacity of computers.

In this challenging situation, it became very clear that there had to be both interdisciplinary scientific training and corresponding research funding for the development and application of projection methods and their interdisciplinary linkage. Both were achieved through corresponding initiatives by US universities (e.g., in the Boston area; cf. Baram 1970, pp. 576–578) and the establishment of the *Research Applied to National Needs Program* (RANN) of the *National Science Foundation* (NSF). Between 1970 and 1976, the NSF supported 43 TA studies and 23 methodological studies, surveys, and conferences (Coates 1978, pp. 54–59). This support of the NSF was an essential contribution to capacity building in interdisciplinary research, facilitating also the start of work of the *Office of Technology Assessment* (OTA) in the USA in 1973 (Coates 1976).

The OTA is the first institutional format of TA and represents a first benchmark or model for an "expert-based TA", building "own" expertise for the legislative power in distinction to the US Government. OTA started with a 10 million dollar programme on issues of energy, food, oceans, health, materials, transportation, and also on methodological developments and limits (Coates 1978, pp. 63–65). Similar considerations on methods, new technical developments, and the political process were published by Hetman (1973) to inform governments of the OECD countries. In this context (Hetman 1978), a booklet on methodological guidelines for TA, co-authored by F. Hetman, J. Coates, E. Jochem, and H. Paschen, was also produced (OECD 1975). This booklet is very balanced in its assessment of the various techniques and sensible in its awareness of their strengths and limitations. It avoids the temptation of staking everything on one particular technique or quantitative method, a fault which bedevils much of the literature at that time.

In Germany, first attempts to institutionalise TA at the Federal Parliament (Bundestag) started as early as the 1970s (TAB 2022). The establishment of a parliamentary "Enquête Commission" in 1985 finally spurred the debate. While the basic decision to establish a parliamentary TA institution was taken rather quickly, the discussion about the organisational form and mode of operation of this institution included a second parliamentary "Enquête Commission" and lasted until 1989 (Petermann 1994). The *Office of Technology Assessment at the German Bundestag* (TAB) was finally established in 1990 (Paschen and Petermann 2005). It was clearly inspired by the OTA and has given policy advice to the Parliament since then.

Before being involved in both parliamentary "Enquête Commissions" that paved the way for the foundation of TAB, Fraunhofer ISI completed a study (Krupp et al. 1978) suggesting a special research programme on TA at the *German Research Foundation* (DFG) and (1) recommending pertinent areas of TA research activities in Germany, (2) addressing the difficulties and challenges involved with interdisciplinary research, and (3) proposing organisational procedures for supporting TA research. However, the proposal was not implemented by the DFG.

Nevertheless, TA research was emerging in the 1970s, both internationally and also in Germany. One important research question, for instance, addressed the limitations of the expert-based TA concept with regard to forecasting, i.e. the methodological challenge to identify unintended impacts and to produce knowledge on their causal interrelationships, which might even change in the future. Three TA studies exploring the limitations of such analyses were conducted in the 1970s and mid-1980s.

*First*, a problem-oriented partial TA study (Denton et al. 1976) focused on the intended and unintended impacts of a further possible strong oil price increase (which became reality in 1979). The self-reflecting analysis brought up obviously lacking knowledge about the impact of the reduced demand for final energies produced from crude oil. In addition, there was little information on short-term options for the substitution of oil products in case that crude oil prices double or triple. Short-term elasticities of demand and substitution of energies were unknown at that time. Therefore, assumptions on data had to be made and used in the newly designed system dynamics or simulation models. Furthermore, the input–output table of the West German economy was projected according to the changing energy flows, demand, and investments.

*Second*, in contrast to the considerable uncertainties with regard to future developments, an ex-post TA study on motorisation in the former Federal Republic of (West) Germany for the period from 1953 to 1973 (Jochem et al. 1976) showed that if a historical analogy can be used, the predictions can be very accurate and complete. This was possible because of the comparable motorisation in the USA between 1919 and 1939 which could be used as a reference (for the approach of a retrospective TA, see Coates and Finn 1979).

*Third*, an ex-ante TA study on three different applications of solar energy (decentralised thermal solar energy, photovoltaics, and satellite photovoltaic use) (Jochem et al. 1988) demonstrated the limitations of TA in various aspects such as available time and budget, empirical data, controversial opinions or assumptions within the research team, lacking methods, etc. Although the research team was large, quite interdisciplinary, and working together for more than 2 years, the limitations of realising the TA concept were manifold (see the team's critical self-evaluation presented in Table 1). Major limitations were related to:

- the available time and budget (33% of all critical notes by team members collected during the TA process referred to that). The research team often had to stop looking for empirical data or new projection models and evaluation tools.
- missing data, methods, or knowledge (34%). This limitation of the analytical steps taken was a challenge and frustrating as the quantification of intended or unintended impacts was often not possible or only with high degrees of uncertainty.

Less importance was attributed to principal limitations of prognosis (15%), using data from other sources, although the authors were not convinced of their reliability (8%), and doubts about the own assumptions and results within the team (7%).

The low number on "controversial opinions within the team" (see Table 1) was in contrast to the political debate in the 1970s and early 1980s. An example is the labelling of renewable energies as "additive energies" by the German energy providers in the 1980s arguing that solving existing energy problems by "additive energies" was actually more wishful thinking than reality (Benz 1987).

As TA, in its beginnings, was explicitly understood as systemic analysis and projection, the new methods of system dynamics analysis (Forrester 1971) and graph methods (Boissevain 1979) were often applied in the 1970s. In the following decades, they were more and more substituted by other methods developed and used by various scientific disciplines. However, given that the role of scientific experts in policy advice and public debates in general was increasingly criticised (Nennen and Garbe 1996), new approaches of involving stakeholders and citizens in TA processes were also developed and tested (Várkonyi 2000). Naturally, expert-based TA approaches are still in use today, but they have been complemented by methods of integrating and dealing with different types of actors and their specific expertise and perspectives, as will be shown in the following sections.

**Table 1** Critical self-evaluation during the TA process: Frequency and proportion of critical notes by members of the research team with respect to areas of limitation

| | Critical notes | |
|---|---|---|
| Areas of limitation | Frequency | Proportion (%) |
| Lack of data, methods, or knowledge | 47 | 34 |
| Time and budget limits | 45 | 33 |
| Principal limitations of prognosis | 20 | 15 |
| Taking data from others, despite critiques | 11 | 8 |
| Questioning own assumptions and results | 9 | 7 |
| Personal and institutional limitations | 3 | 2 |
| Controversial opinions within the team | 2 | 1 |
| Sum | 137 | 100 |

Source: Jochem et al. (1988, p. 353)

In other areas, such as Health Technology Assessment (HTA), the expert-based model has dominated until today. Although its origins lie in OTA activities as well, over the decades HTA has taken its own pathway of differentiation and institutionalisation (Banta 2003). Nowadays, HTA sees itself as an evidence-based instrument to support policy or management decisions within the healthcare system (e.g., whether the use of a new medical technology should be reimbursed by health insurances or not). At the forefront of the evaluation are, therefore, the efficacy and safety as well as the costs (or the cost-benefit ratio) of a new medical technology, while ethical and social aspects are dealt with rather rarely.

## 3 The Participatory Turn

Already in the 1960s and early 1970s, a wider public debate on science and technology was considered as an important element of TA. Accordingly, the critical public engagement in science and technology was seen as one of the driving forces for the institutionalisation of TA in general and also for the foundation of OTA (Joss 2002). However, the OTA actually developed mainly into an expert-driven institution. As Joss (2002) points out, a main reason for this development lies in the fact that OTA was founded to provide scientific and technological intelligence for the US Congress in order to counterbalance the respective expertise available at the White House. Since OTA was perceived as a role model for TA in political discussions worldwide, the expert-based mode of TA became prevalent in many countries in the 1970s and 1980s (Bimber and Guston 1997)—also in Germany.

A broader involvement of the public into TA emerged again on the political agenda in the 1980s when an increasing septicism and critical discussion of new technologies appeared. For example, in 1978, the human gene for insulin was first isolated and cultivated in bacteria, and in 1982, human insulin produced by genetically modified bacteria was introduced to the market (The 1989). Genetic engineering (for the production of pharmaceuticals or modification of food), plant biotechnology, reproduction medicine (e.g., in vitro fertilisation), other biomedical technologies (e.g., genetic testing), but also nuclear energy, automation in manufacturing, environmental pollution and related technologies steered public debates on risks and (to a lesser extent) chances of new technologies (for the intensive discussion on the humanisation of work, see Lerch and Jäger 2024 in this volume). Calls for stricter legislation of (perceived) risky technologies came along with these debates resulting in the first specific regulations of genetic engineering in some European countries such as Denmark where a genetic engineering act was issued in 1986 (Joss 2002).

Regulation of new technologies in general and biotechnology in particular became highly controversial issues, not only in the public domain but also in politics, industry, and science. One of the issues was to what extent legislation was hampering international competitive positions of key industries. A detailed analysis of genetic engineering regulations and their implementation in main world regions

(Europe, USA, Japan), for example, came to the conclusion that there was no systematic competitive disadvantage of European countries including Germany due to legislation compared to other world regions (Hohmeyer et al. 1994).

In the TA communities, such intensive discussions led to a renaissance of the idea of public participation in TA, democratisation of technology development and, in general, a stronger focus on affected stakeholder groups—participatory technology assessment (pTA) entered the stage.

The conceptual foundation of pTA is based on Habermas (1968) as discussed by Hennen (2012). Habermas (1968) elaborates on the relationship between scientific expertise and political decision-making and presented two ideal types of this relation: In the decisionistic model, policy makers use information from scientists, but power and interests finally shape the goals for which scientific information is employed. Here, scientific expertise could be considered as politically instrumentalised (Hennen 2012). On the other hand, in the technocratic model all political issues are reduced to factual ones assuming that decision-making issues can be resolved on the basis of science and technology. Here, political debate is replaced by expertise (Hennen 2012). Habermas (1968) realised that none of these extreme models provide an adequate description of political reality, and he proposed, as some kind of synthesis, a "pragmatist" model. In this model, normative claims in policy making have to be examined with regard to generalisability, feasibility, cost, and utility in the light of scientific and technological knowledge. At the same time, scientific and technological knowledge need to be assessed against normative and evaluative standpoints. According to Hennen (2012), this pragmatic approach forms the basis for pTA since the pragmatic discourse between science and policy making depends on an informed public debate.

The diffusion of pTA starting from the mid-1980s was fuelled by the development of an experimentation with new methods for public engagement in TA and by the further institutionalisation of TA with a specific focus on pTA. In Europe, Denmark became the forerunner of this movement. In 1985, the *Danish Board of Technology* (DBT) was set up by the Danish Parliament (Joss 2002). Main motives for its foundation were intensive political debates and public controversy about modern biotechnology and reproductive medicine (Klüver 2000). Two large Danish companies (Novo and Nordisk Gentofte) had announced their plans to produce human insulin using genetically modified bacteria. DBT developed and implemented new methods for stakeholder participation and public engagement in these controversial debates. These include in particular "consensus conferences", which became a kind of brand of the DBT, but also "voting conferences", "scenario workshops", and "future search conferences" (see, for instance, Slocum 2003).

Shortly after the setting up of the DBT, the *Netherlands Organisation for Technology Assessment* (NOTA; now *Rathenau Institute*) was created in 1986 (Joss 2002). The mission of NOTA was to broaden the basis for decision-making in science and technology by addressing social consequences and integrating different societal stakeholder into TA processes. NOTA also experimented with new participatory methods including "science shops". Other institutions and countries joined these trends, for example Switzerland and Germany. The *Swiss Science and Technology*

*Council* (now *TA-SWISS*) was founded in 1992 and, among others, developed the so-called "Publiforum" adopting experiences from the DBT. In Germany, the *Academy for Technology Assessment in Baden-Württemberg* was founded, also in 1992 (but closed in 2003), with a strong focus on exploring new methods for public participation such as the "Bürgerforum" (citizen forum) (Renn 2002).

The German TAB in contrast, although founded in 1990 (see Sect. 2), was largely rooted in the concept of "classic" TA. As an institution steered by a parliamentary committee, specific framework conditions and limitations arose. While Paschen (1999) stated that TAB has implemented many modern TA concepts, he also admitted that certain ideas were hardly feasible since, for example, many parliamentarians were critical of broad citizen participation activities because they see this as "questioning the decision-making sovereignty of MPs legitimised by elections" (Paschen 1999; own translation; see also Grunwald 2003). This was also reflected, at least in the early years of TAB, in the orientation of the studies, which mostly focused on large-scale and cutting-edge research. A distinguishing feature compared to other TA institutions of that time was the continuous monitoring of future technologies, but also of "soft" factors such as citizens' perceptions of technology (aka technology acceptance).

Another element of pTA comprises educational activities. For example, starting from the late 1990s, several such activities were initiated in Germany including the elaboration of specific curricula for debating biotechnology in classrooms or the production of movies on biotechnology for higher education and vocational training of teachers (Gaisser and Hüsing 2000). During that period, foresight approaches were increasingly integrated into TA not only focusing on future trends in science and technology but also on key societal issues (cf. Cuhls et al. 2024 in this volume).

Not only specialised institutions engaged in pTA but also "new entrants" such as museums (Joss 2002). For example, in the United Kingdom, the first consensus conference on plant biotechnology adopting the Danish model was organised and implemented at the *Science Museum* in London in 1994. In Germany, the first citizens' conference on human genetic testing was hosted by the *German Hygiene Museum* in Dresden in 2001 (Zimmer 2002). And in 2008, the *Boston Museum of Science* was partner in a consensus conference on nanotechnology in the USA (Guston 2023).

Although most pTA approaches were pursued in Europe, some more recent examples outside Europe are worth mentioning (Hahn et al. 2023): In South Korea, participative elements such as "citizen fora" are included in the parliamentary TA process; in South Africa, multi-stakeholder participatory assessments were implemented with a focus on evaluating developments in biotechnology; and Australia initiated participatory approaches on a regional level for environmental management involving experience and knowledge of indigenous communities.

The development in the USA since 1995 is most interesting considering the pioneering role of the OTA and its closure in that year (Guston 2023). In parallel to building up mainly expert-mode oriented TA capacities in the *Government Accountability Office* (GAO), pTA approaches were initiated in a less institutionalised way mainly by a group of academics called *Expert and Citizen Assessment of*

*Science and Technology* (ECAST). ECAST evolved in the aftermath of the above-mentioned consensus conference on nanotechnology conducted by the *Centre for Nanotechnology in Society at Arizona State University* (CNS-ASU). Recently, ECAST explored public perspectives of human gene editing based on CRISPR technology. As Guston (2023) points out, ECAST intensively strives for international networking and is collaborating among others with the DBT.

Along with the diffusion of pTA in the 1980s and 1990s, fundamental critique of this approach increasingly emerged in the science policy domain (Gethmann 2002). Mainly three critical points were raised (Hennen 2012): (1) lack of impact, (2) instrumentalisation, and (3) tampering of laypeople's perspectives by experts.

- Lack of impact refers to the observation that a direct influence of pTA on political decision-making is hardly detectable. However, as Hennen (2012) argues, this is not specific to pTA but can be observed for many types of scientific advice. Nevertheless, possible impact of pTA on the political decision-making process is hampered by a specific systematic feature of any TA process: TA has a systemic perspective and aims at exploring the full complexity of technical developments. Thereby, TA increases the complexity of decision-making processes at stake making it less likely that outcomes of the process are directly used by policy makers.
- Instrumentalisation is an inherent risk not only of pTA but also of many laypeople or expert-based consulting processes (Stirling 2008). A key issue to avoid or minimise instrumentalization is the institutional setting of pTA (Hennen 2012). Independent institutions with clear mission statements minimise this risk.
- Laypeople and experts can be perceived as complementary, without laypeople there are no experts. Accordingly, both play an important role in the pTA process. During the process, laypeople may change their view on a specific technological issue not least due to information provided by experts. This could be considered as tampering. On the other hand, as Hennen (2012) explains, this is also an indication of empowerment and learning in the pTA process: Minds are changing, new positions are taken.

In parallel with such critiques of pTA, evaluation activities were initiated. For example, the *European Commission* (EC) launched two large studies which analysed pTA processes in different countries and technological domains. The EUROPTA study compared 16 different pTA projects and found that mainly two factors are important for the visibility and resonance of pTA (Hennen 2002): the character and status of the public debate, and the institutional and political setting of the procedure. The ADAPTA project (Gaisser et al. 2001) explored pTA processes in several countries in three different technological domains: urban transport policy, genetically modified food, and genetic and predictive testing. The findings for the case of Germany were rather sobering as they detected only a very low impact of pTA activities on policy processes and public debate (Gaisser et al. 2001). One of the few other systematic evaluations of the impact of pTA activities concerns the above-mentioned citizens' conference on human genetic testing in the *German Hygiene Museum* in Dresden. In this case, the evaluation study was able to show

how the mentioned empowerment process of laypeople worked in practice (Zimmer 2002).

Aside from pTA, there is another prominent TA approach that has its roots in the 1980s: the concept of *Constructive Technology Assessment* (CTA) which had been developed in the Netherlands and Denmark (Rip et al. 1995). Even though the term CTA is used with different understandings, according to Schot and Rip (1997) there is a common feature of CTA, namely the modulation of ongoing technology development by all relevant stakeholders. As Schot and Rip point out, such a process can lead to new design practices of technologies which anticipate impacts and involve diverse societal groups from the beginning in a kind of societal learning. Although there is obviously some overlap with the idea of participation and inclusion in pTA, CTA has different theoretical foundations and focuses on the socially responsible design of technology ("better technology in a better society", Rip et al. 1995). It has also been taken up by more recent concepts of technology and innovation governance such as *Responsible Research and Innovation* (RRI). This plays an important role in the next ("pragmatic") phase of TA which is outlined in the following section. To begin with, the focus is on the development and discussion in Germany as it can be seen as paradigmatic for this phase.

## 4 Managing and Governing Technological Innovations

In the business world, TA used to have a notoriously bad reputation for being hostile to innovation. TA was considered to be critical of technological progress, which was not entirely unfounded in view of the failure of major large-scale research projects in the 1970s and 1980s (for example, next generation nuclear energy reactors or magnetic levitation train). For these reasons, in the USA, TA was sometimes denigrated as "technology arrestment" (Paschen and Petermann 1986, p. 22).

This does not mean, however, that there has not been a critical approach to technical progress in companies and among technicians. In Germany, the *Association of German Engineers* (VDI) had been working on a guideline on TA since 1976, which was rooted in its technology-reflecting tradition of engineering responsibility, but also took up the academic and political discussion of the time. This guideline—which was always controversial even within the association—was finally adopted in 1990 (VDI 1991). In terms of its character, it was not a "recipe book" for TA, but it had a considerable influence in industry and among engineers, mainly by raising awareness of the general TA discussion (Haberland 2016; König 2021). However, the guideline differed from other contemporary concepts of TA by its explicit orientation towards innovation processes in industrial contexts.

At the same time, some researchers in Germany noted a "crisis of the traditional TA concept" (Bröchler and Simonis 1998, p. 31). Apart from the orientation towards political and administrative decision-makers as TA's primary addressees they criticised the dominance of scientific experts and the focus on recommending options for policy making. According to these researchers, the "traditional" TA approach was based on the premises that scientific analyses can be translated into political decisions, that the state is capable of effectively steering technical development, and that this steering can be done by parliament (Bröchler and Simonis 1998, p. 34). They expressed doubts as to whether these premises were (still) valid, especially since the state technocratic approach had fallen into disrepute after the failure of many large-scale research projects. Instead, the example of Silicon Valley in the USA seemed to show that the market could produce innovations faster and more in line with demand: "TA is in danger of lagging behind the development of technology. TA is called upon to deal with this problem more intensively in conceptual and methodological terms" (Bröchler and Simonis 1998, p. 34; own translation). Moreover, social and technical developments could no longer be controlled by politics alone, but took place in networks of actors from the state, industry, science, civic associations and society. Finally, TA had to take into account the recognisable "change in consciousness [of companies] in their relationship to the social environment" and was called upon to "emphasise the non-technical factors in the process of shaping technology" (Bröchler and Simonis 1998, p. 35; own translation).

Such a turn towards TA as a "pragmatic innovation management" (Bogner 2021, pp. 51ff.; own translation) had parallels with the concept of innovation systems, which had gained popularity since the mid-1980s in the international community of innovation research and emphasised that the flow of knowledge and technology between people, companies, and institutions is the key to innovative processes (Fraunhofer ISI 2012; see also Frietsch et al. 2024 in this volume). Against this background, Meyer-Krahmer (1999, p. 214) pointed out at a conference on the occasion of "25 years of TA in Germany" that the contrast between problem-induced and technology-induced TA had to be overcome. In view of the increasing international and institutional integration of innovation actors, a development from a state-centred approach to a multi-actor-approach seemed necessary.

In order to remedy these weaknesses and to counter the perception of TA as technology-hostile and innovation-inhibiting, an innovation-oriented TA was called for, which could influence technology design through "organised innovation processes" (Tschiedel 1997, cited in Haberland 2016). Thus, in 2000, the German Government adopted central arguments for innovation-oriented TA, enriched them with considerations from social constructivist science and technology studies (STS) (Bode 2002), and finally presented a concept for an innovation and technology analysis (ITA) (Brüntink 2001). This was intended to complement and integrate existing TA measures and projects (Astor and Bovenschulte 2000), whereby "complement" meant in particular an increased addressing of businesses. According to Brüntink (2001, p. 8; own translation), the aim was "the promotion of cooperation between ITA and industry. […] Innovation processes take place in companies, innovative companies change the economy and—more and more frequently—thereby also society". The proponents of this new concept assumed that companies do not act exclusively according to profitability criteria, but also take social needs into account in the sense of a collective responsibility for the common good, and concluded that "ITA is one, if not *the* tool of choice for companies" (Baron et al. 2003, p. 34; own translation, emphasis in the original). In that sense, it had a "problem-solving potential [...] for the German economy" and was a management tool that "could draw on mature methods and be useful for the economy" (Baron et al. 2003, p. 22, 24; own translation).

From the beginning, policy makers understood ITA as a strategic attempt to bring together the different TA traditions. First, policy makers should be supported by recommendations for science, technology, and innovation (STI) policy. Second, participatory approaches should be used to involve citizens and consumers in the development process in order to increase social acceptance. And finally, it was hoped to provide companies with knowledge about technical alternatives, foreseeable obstacles, and framework conditions to be considered (Astor and Bovenschulte 2000). For the established TA community, it was not so clear whether this approach was really new or just old wine in new skins as many of its elements had already been part of TA since the 1960s (Grunwald 2001). Others considered ITA mainly as a marketing attempt to extend the target group of TA to industrial actors and suspected that it was a strategy for business development and to increase technology acceptance (Haberland 2016, pp. 83f.).

Such a pragmatic-eclectic approach to TA was not limited to Germany, even if it was much less justified with a theoretical framework in most other countries. The ITA projects carried out in Germany since 2000 were very different in their character, but aimed, at least in terms of their claim, at a holistic assessment of technological developments and responsible innovation design. The strong role of industry, both in the conduct and in the exploitation of the studies, has admittedly not been fulfilled: ITA has primarily remained an instrument of government research planning. In many cases, the focus was on specific so-called "key technologies" such as information and communication technologies, nanotechnology, biotechnology, and genetic engineering, with studies focusing less on technology risks and more on their contribution to societal needs and global challenges. Research also included studies on the human factor in innovation, for instance on factors influencing technology perceptions and what role these perceptions play for the market success (Hüsing et al. 2002). Finally, there was an increasing number of studies focusing on foresight of scientific and technological developments and their innovative impact.[1]

The discussions about ITA also had an impact when the contract for the operation of the German TAB had to be renewed in 2001. TAB's operator, the *Institute for Technology Assessment and Systems Analysis* (ITAS), was requested to cooperate with Fraunhofer ISI and to supplement established areas of work by the so-called "future reports", "innovation reports", and "policy benchmarkings". Future reports aimed to analyse medium- and long-term fields of development. They were primarily intended to identify parliamentary need for action, while the innovation reports were meant to provide orientation knowledge about areas with high development dynamics (Cuhls et al. 2003; Petermann 2003). Although true foresight studies were not conducted as part of the TAB work programme, the new study formats gained

[1] In 2021, the German Government renamed ITA "Insight—Interdisciplinary perspectives on societal and technological change", yet without fundamentally changing the underlying concept.

much popularity, especially as they were also of interest to other parliamentary groups and committees. In particular the innovation reports addressed current and urgent issues relating to the competitiveness and innovative capability of German industry (Nusser et al. 2007; Thielmann et al. 2009; Gandenberger et al. 2012).

Internationally, with the new millennium the time of the big technology controversies was over. However, as in previous decades, some technological developments received particular attention, being often utopian visions of a technologically improved world. From 2000 onward, this was primarily nanotechnology, thus the use of materials on an atomic, molecular, and supramolecular scale for industrial purposes. Visionary publications, such as those of Drexler et al. (1991) and Joy (2000), initiated an intense debate not only about the potential but also about the risks of nanotechnology which led to a series of TA studies (Malanowski 2001; Paschen et al. 2003; Malsch et al. 2004; The Royal Society 2004). Some of these early studies were mainly concerned with the visionary aspects. These were linked to the notion that there is a convergence of Nano-Bio-Info-Cogno (NBIC) technologies, resulting in a fundamental boundary shift between the natural and the artificial, and with the goal of enhancing human (physical, sensory, and cognitive) capabilities (Roco and Bainbridge 2003; Beckert et al. 2007). Later, most TA studies on nanotechnology took a rather pragmatic approach and examined how much substance the promises of the technology visionaries actually had in specific application areas (e.g., NRM 2006; Möller et al. 2009). Starting around 2010, research focused on very specific problem areas such as nanotoxicology or product safety, with the goal of defining requirements that the new technology must meet in order to fulfil its promises. This has, for instance, resulted in a long-term activity like the "Nanotrust"[2] project which has continuously been investigating specific safety and risk-relevant aspects of nanomaterials and providing input for the regulation of innovative materials since 2007.

Another substantive strand of TA research took up the notion of a networked world (Castells 1996) that became popular with the advent of the Internet and was discussed as "ubiquitous computing", "ambient intelligence", or later "Internet of things". As in the case of nanotechnology, the first step was the analysis of certain technology visions that had a strong impact on politics. An early example was the scientific deconstruction of "ambient intelligence", a vision of the future information society where intelligent interfaces enable people and devices to interact seamlessly with each other and with the environment (Ducatel et al. 2001). Several TA studies showed how naive this idea actually was and highlighted the social and environmental risks involved (Hilty et al. 2003; Bizer et al. 2006; Wright et al. 2008). More recently, TA studies—especially those conducted on behalf of the European Parliament—have provided important input to the regulation of the connected world, from the General Data Protection Regulation (GDPR) in 2016 to the regulation of artificial intelligence (AI) at present (Boucher 2020; Christen et al. 2020; Kolleck and Orwat 2020).

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[2] See https://www.oeaw.ac.at/en/ita/nanotrust/

Apart from issues of nanotechnology and digitisation, questions of energy, the environment, and sustainability became a new urgency in the context of the predicted climate change, but also changed the way TA was dealing with them. Whereas traditional TA focused primarily on the risks of single technologies to the natural environment, the focus has moved towards systemic interrelationships between technologies, society, and the environment (see also Hillenbrand et al. 2024 in this anthology). With this change in perspective and in view of the global challenges, TA has increasingly turned its attention to questions of management and governance of innovations, also bringing non-technological innovations into the focus (Howaldt et al. 2019; Ozoliņa et al. 2009). Accordingly, more research is being conducted into how socio-technical constellations should look like if they are expected to contribute to solving global challenges. The experts' knowledge of the technology's functions, effects, and unintended side effects plays an important role in this process, as does the identification and resolution of potential societal conflicts through the participation of as many stakeholders as possible.

In this context, at the EU level, TA concepts have received strong attention since around 2010 under the term *Responsible Research and Innovation* (RRI) or just *Responsible Innovation* (RI). Starting from debates on responsible development in the area of nanotechnologies in the early 2000s, RRI quickly attracted considerable attention in the academic discourse on the governance of research and innovation (Owen et al. 2021; Rip 2014). RRI is also an eclectic approach, building upon several earlier concepts (such as CTA, see Sect. 3), partially integrating and developing them further. Apart from TA in its numerous guises, it makes use of concepts and disciplinary contributions from STS, ethics of science and technology, ELSA/ELSI research (ethical, legal, social aspects/implications), sustainable technology development, value sensitive design, responsible development, participatory and transdisciplinary research, research integrity, responsible metrics, etc. (Lindner et al. 2016; Brundage and Guston 2019).

According to the definition and framework developed by Stilgoe et al. (2013) that has gained the most attention in academia, RI (or RRI) comprises four elements that are also found in various directions of TA: anticipation, reflexivity, inclusion, and responsiveness. Anticipation is about carefully considering both the intended and potential unintended consequences of research and innovation activities, covering elements of expert TA and, to some extent, foresight. Reflexivity is about reflecting on the motivations, assumptions, and commitments underlying technological developments. At the same time, reflexivity also means questioning the normative basis of the assessment (Hennen and Nierling 2019; Kollek 2019; Nierling and Torgersen 2019). Inclusion is closely related to public participation, which is the central element of pTA. It is not limited to citizens, but seeks to involve all relevant societal stakeholders (including businesses and politics) at an early stage in order to identify potential conflict fields and to reach a consensual design. Finally, responsiveness expresses that TA must not stop at the (ex-post) analysis and assessment of technologies, but must entail decisions and practical action. These decisions can then take the desirable and undesirable impacts of technology as well as the interests of citizens into account. Ideally, they result in solutions guided by values and norms in the interest of the common good.

As a concept, RRI was strongly promoted by powerful actors in the field of STI policy (cf. Lindner et al. 2024 in this anthology), particularly by the *European Commission* (EC), culminating in the integration of RRI as a crosscutting issue in the EC's Research Framework Programme "Horizon 2020" (2014–2020) (Blok 2023).[3] This development was also conducive to the uptake of RRI-related initiatives in a number of countries and organisations, which still continues (Wittrock et al. 2021).

## 5 Conclusion and Outlook

The description of the three TA paradigms or phases (expert-based, participatory, and pragmatic) shows that the paradigms are not strictly separated from each other. Rather, each highlights a specific, temporally dominant perspective on how to do TA. They all are still relevant today and continue to coexist. Figure 1 is an attempt to summarise and further illustrate the history of TA since the 1960s by roughly locating in time some of the technologies in focus, some of the methods introduced in TA, and the foundation of some TA institutions (see Fig. 1).

What can be said on the impact of TA (cf. Decker and Ladikas 2004), given the constant changes in objectives, concepts, addressees, and stakeholders involved? The most intensive interaction has been with politics, which gave the impetus for the institutionalisation of TA and has also financed much of its research. In this arena, TA has always had to strive for its independence and neutrality. TA has made numerous important contributions to evidence-based (technology) policy but had to be careful to fairly take into account the interests of all social groups. However, it cannot be denied that TA is also an instrument of power that can be—and actually is—used to justify political decisions. This can also be seen in the fact that politicians occasionally ignore even important TA results because they are inconvenient or do not fit into the current political agenda. One example is a TAB study from 2011 on the risks of a large-scale power blackout (Petermann et al. 2011), which only recently received greater attention in the context of the war in Ukraine.

Certainly, TA processes and results also have the potential to directly influence political decision-making. For example, in Denmark some restrictions of public research funding in biotechnology were informed by related TA activities of the DBT. In addition, in some areas of Europe such as Switzerland and again Denmark, TA has become an important instrument for informing citizens about technological developments and their impacts, or even for participation of citizens in technological processes. In contrast, the function of TA as an instrument of welfare-oriented innovation management has not yet been able to establish itself broadly in industry.

[3] However, in the subsequent Research Framework Programme "Horizion Europe" (2021–2027) the significance of RRI has strongly declined.

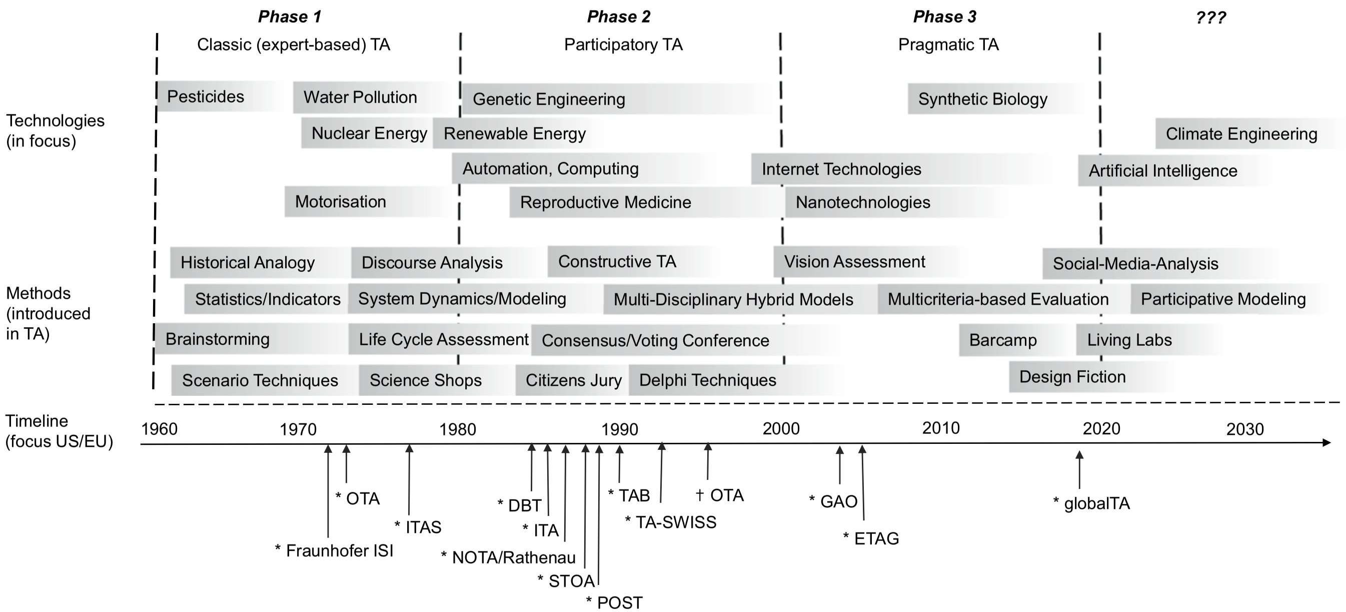


**Fig. 1** The assessment of technological innovations over time; own illustration, based on three phases by Bogner (2021). See appendix for further details and explanations regarding the TA institutions

All in all, it seems that the impact of TA is characterised by a similar diversity as TA activities themselves, ranging from almost undetectability to direct influence on political decision-making.

Looking at the future of TA, problem-orientation is needed more than ever. The problem-orientation of TA had been discussed from the very beginnings (Enzer 1974) and had been, already some time ago, expected to gain importance in the future in order to address the grand societal challenges (Decker and Fleischer 2010). Today, after the "normative turn" (Daimer et al. 2012), STI policies have to a certain extent internalised such problem-orientation, following a so-called mission-oriented approach (see also Lindner et al. 2024 in this anthology), with the goal of overcoming grand societal challenges, such as demographic or climate change. We expect TA to increasingly contribute to this goal. TA would then need to focus not only on individual technologies, but rather on socio-technical transitions and the governance of urgent system transformations, be it the transformation of the mobility, energy, healthcare, or nutrition system. Here, TA could contribute to finding appropriate system solutions as combinations of (converging) technologies, innovations, and also non-technological approaches. It would need to be embedded in knowledge and decision-making processes characterised by intense cooperation between science, industry, policy, administration, and society including NGOs, citizens, consumers, and users. The involvement of society here is at least bi- if not multi-directional, on the one hand with regard to the development of products and technical solutions and their societal (consumer/user) acceptance, and on the other hand with regard to increasingly required behavioural changes in consumption and resource use.

Of course, such an orientation comes with several challenges. One is to mediate complex impact dependencies and to decide and navigate through innovation pathways whose differences are no longer to be determined by techno-economic or socio-technical criteria alone, but rather by ethical, ecological, societal, geopolitical, and other criteria, which we might not even know yet. This requires new instruments (and indicators) for assessment and a sound factual basis.

In addition, with regard to its addressees, TA needs to communicate its (generally complex) findings in a way that reduces complexity and produces transparency through the explanation of assumptions and uncertainties. This is important because also governments, parliaments, and administrative actors in democratic societies are required to explain their (possibly TA-based) decisions in a transparent way, since they are exposed to the public discourse and to the problem that both decision criteria and scientifically derived assumptions will likely be questioned by parts of society.

This entails another challenge for TA. Given the present crisis of confidence in science and scientific policy advice, not least obvious in the dispute on COVID-19 vaccination, TA has an ambivalent position like never before between claiming neutrality, on the one hand, and representing normative perspectives, on the other (Hennen and Nierling 2019; Nierling and Torgersen 2020; Torgersen 2019). First of all, legitimate questions may be raised regarding the weighting criteria used in TA processes, especially if TA commits to contributing to specific goal-oriented socio-technical transformations. What is more, in an ever more complex, both techno-scientifically driven and democratic society, the question arises to what extent and for what reasons the various societal groups trust or distrust scientists and their research results. And if they distrust, to what extent and with what means is it possible to build up trust into TA processes and results (e.g., in terms of quality, correctness, independency) and to reach acceptance by all societal groups including those following right-wing populist views? If TA aims to contribute, for instance, to the transformation towards a more sustainable society, how can there be trust if such a goal is politically not shared? And with regard to an increasingly mission-oriented STI policy, does it not automatically make itself vulnerable to discussions in social media and fake news when apparently established certainties and common assumptions are doubted?

A further challenge is the fact that technologies are at a specific stage of development and maturity when they become the centre of public or political attention at a given time. There is not only the well-known dilemma (Collingridge 1980) that at an early point in time little is known about the impacts and unintended side effects of a technology, although the possibilities to control and shape the development are high, whereas at a later stage much more is known, but control is more difficult to achieve. In addition, technologies are subject to socially conditioned cycles of attention in research funding, in the media, and in the public and political discourse. It is therefore obvious to assume that one technology at other times, in different societal contexts, with different research efforts may be evaluated with different results leading to different decisions, selections, and design mechanisms. If so, may then the push of certain technologies at a certain time possibly hinder the development of better, alternative solutions? This opens up a field of conflict with questions about how long and intensively specific and alternative technologies (as well as non-technical innovations) should be researched and evaluated before a societal decision can be made about their significance and use.

Finally, TA increasingly needs to face the global dimension of technologies and socio-technical change including geopolitical aspects. The foundation of the *globalTA network*[4] in 2019 can only be a very first step in this regard (Hennen et al. 2023). Given the increasing importance and development of both sustainability goals (e.g., compliance with planetary boundaries, global justice, global health; cf. the UN Sustainable Development Goals, SDGs) and sustainability criteria (e.g., carbon footprint, water and energy consumption, living and health conditions), there is the need to establish local and regional structures of circular economies and value creation structures with reduced transport routes in light of current global trade. Moreover, with supply bottlenecks (e.g., of semiconductor chips and dependent products such as vehicles) in the COVID-19 pandemic and dependencies on energy (gas) and other raw materials from Russia in light of the war in Ukraine, the discussion on technology sovereignty, raw materials, and technology dependencies on other countries (including China) have attained highest actuality (Edler et al. 2020). The assessment of stability and trust in countries and regions as trading partners is becoming a new and critical parameter in decision-making processes.

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[4] See https://globalta.technology-assessment.info/.

In addition, there is the question of sufficiency in the (global) consumption of goods and mobility in today's societies. This connects to more fundamental questions of how our economies could and should work, to what extent the development towards a post-growth society could be an option for achieving the sustainability goals, and what role technological and social innovations (Sartorius et al. 2022; Heyen et al. 2024) as well as TA (Grunwald 2018) might play in this regard.

With all those challenges, TA is more than ever asked to take the "bigger picture" into account and not to focus too much on an individual technology alone. This implies questioning current hypes on the potential of new technologies, such as hydrogen or electric cars, to solve the grand societal challenges of our time. Certainly, TA will be needed for emerging technologies such as climate engineering and for the further digitisation of our societies. With such new technologies and the challenges mentioned above comes the need for new approaches of TA so that TA will remain a valuable instrument providing guidance in a complex and uncertain technological environment in the coming decades.

## Appendix

Year dates and abbreviations used in Fig. 1 (* = foundation; † = closure):

1972: * Fraunhofer ISI—Fraunhofer Institute for Systems and Innovation Research ISI (originally founded as Fraunhofer Institute for System Technology and Innovation Research, re-named in 2004)

1972/73: * OTA—Office of Technology Assessment at the US Congress; closure in 1995

1977: * ITAS—Institute for Technology Assessment and Systems Analysis, at Karlsruhe Institute of Technology KIT (foundation of predecessor institution in 1977, as ITAS since 1995)

1985: * DBT—Danish Board of Technology

1985: * ITA—Institute of Technology Assessment, at the Austrian Academy of Sciences (originally as working group of a pre-existing research institute; as ITA since 1994)

1986: * NOTA/Rathenau—Netherlands Organisation for Technology Assessment, re-named in Rathenau Institute in 1994

1987: * STOA—European Parliament Office for Scientific and Technological Option Assessment

1989: * POST—Parliamentary Office of Science and Technology, United Kingdom

1990: * TAB—Office of Technology Assessment at the German Bundestag

1992: * TA-SWISS—Foundation for Technology Assessment, at the Swiss Academies of Arts and Sciences (originally founded as Swiss Science and Technology Council)

2004: * GAO—US Government Accountability Office (originally founded in 1921, but no TA relation before the closure of OTA, re-named in 2004)

2005: * ETAG—European Technology Assessment Group (network of TA institutions)

2019: * globalTA—global Technology Assessment Network (network of TA institutions)

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