TECHNOLOGY ASSESSMENT: CONCEPTS AND METHODS

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1 INTRODUCTION

Technology Assessment (TA) constitutes a scientific and societal response to problems at the interface between technology and society. It has emerged against the background of various experiences pertaining to the unintended and often undesirable side effects of science, technology and technicisation which, in modern times, can sometimes assume extreme proportions. The types of challenges that have evolved for TA are these: that of integrating at an early stage in decision-making processes any available knowledge on the side effects, that of supporting the evaluation of the value of technologies and their impact, that of elaborating strategies to deal with the knowledge uncertainties that inevitably arise, and that of contributing to the constructive solving of societal conflicts on technology and problems concerning technological legitimisation. What characterises TA is its specific combination of *knowledge production* (concerning the development, consequences and conditions for implementing technology), the *evaluation* of this knowledge from a societal perspective, and the *recommendations* made to politics and society. TA is thus both interdisciplinary and transdisciplinary and in accordance with its research methods, it can be classified as a "post-normal science" [Funtowicz and Ravetz, 1993] and as one of the forms of "new production of knowledge" [Gibbons *et al.*, 1994].

All the various questions regarding TA concepts, methodology and content are linked to philosophy. In terms of all the normative questions that have a bearing on technological evaluation and technological design, there are close ethics of technology ties [Grunwald, 1999], as well as links with the respective branches of applied ethics (e.g., bioethics, medical ethics, information ethics). Questions on the *validity* of the available knowledge are relevant to the philosophy of science, especially in conjunction with scientific controversy, the ratio of knowledge to non-knowledge, and the divergent interpretations of the societal implications of scientific knowledge (as currently, for instance, exemplified in neuroscience). Normative and epistemic questions (knowledge and values) are often interwoven, like for instance, when it comes to the application and consequences of the precautionary principle [Harremoes *et al.*, 2002; Schomberg, 2005]. Many TA topics are,

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furthermore, pertinent to the philosophy of technology or are anthropologically relevant, such as questions regarding the man-machine interface, the substitutability of human beings by robots, the increasing degree to which living beings are being penetrated by technology, or the "technical enhancement" of human beings [Roco and Bainbridge, 2002; Grunwald, 2007a].

An overview of TA is first given (Section 2). TA is introduced in a problem-orientated fashion by presenting the societal needs it sets out to address. The historical background to TA is then sketched on the basis of the proposed and realized TA concepts and the spectrum of methods employed in TA. The central TA challenge lies in treating the normative dimensions of technology. An entire section (Section 3) is therefore devoted to this aspect. The final section (Section 4) gives an overview of the current TA developments and of the requirements for the foreseeable future.

2 TECHNOLOGY ASSESSMENT: AN OVERVIEW

The term "Technology Assessment" (TA) is the most common collective designation of the systematic methods used to scientifically investigate the conditions for and the consequences of technology and technicising and to denote their societal evaluation. At first sight, entirely heterogeneous activities are subsumed under this name, such as the predicting of the consequences of technology, the communicating of risk, promoting innovation, improving the legitimacy of decisions on technology through increased participation [Joss and Belucci, 2002], mediating in technological conflicts, and observing sustainability. The problem met in defining TA consists in the fact that it is not *a priori* clear what the common denominator of such heterogeneous efforts should be. No consensual, unambiguous and selective definition of TA has yet been provided. As the emergence and development of TA are closely connected with specific situations arising at the interface between technology and society, these same situations form the central background to the introducing and clarifying of TA.

2.1 The historical origins of technology assessment

TA arose from specific historical circumstances in the 1960s and 1970s. The US congressional representative Daddario is now held to be the coiner of the term and of the basic theory underlying TA [Bimber, 1996], which culminated in the creation of the Office of Technology Assessment (OTA) at Congress in 1972 [United States Senate, 1972]. The concrete background consisted in the asymmetrical access to technically and politically relevant information between the USA's legislative and executive bodies. While the executive, thanks to the official apparatus at its command, was able to draw on practically any amount of information, parliament lagged far behind. This asymmetry was deemed to endanger the — highly important — balance of power between the legislative and the executive facets of technology-related issues. From this point of view the aim of legislative TA was to restore parity [Bimber, 1996].

Parallel to this very specific development, radical changes were taking place in intellectual and historical respects, which were to prove pivotal to TA. First and foremost, the optimistic belief in scientific and technical progress, which had predominated in the post Second World War period, came under pressure. The ambivalence of technology was a central theme in both the Critical Theory of the Frankfurt School (Marcuse, Habermas) and in the Western "bourgeois" criticism of technology (Freyer, Schelsky) with its dialectical view of technological progress: "the liberating force of technology — the instrumentalisation of things — turns into a fetter of liberation; the instrumentalisation of man" [Marcuse, 1966, p. 159].

At the same time, broad segments of Western society were deeply unsettled by the "Limits of Growth" [Meadows *et al.*, 1972] which, for the first time, addressed the grave environmental problems perceived as a side effect of technology and technicisation, and by discussions on technical inventions in the military setting forecasting the possibility of a nuclear attack that would put an end to humanity. The optimistic pro-progress assumption that whatever was scientifically and technically new would definitely benefit the individual and society was questioned. As of the 1960s deepened insight into technological ambivalence led to a crisis of orientation in the way society dealt with science and technology. Without this crisis surrounding the optimistic belief in progress, TA would presumably never have developed or, more precisely, would never have extended beyond the modest confines of the above-mentioned US Congressional office.

Furthermore, the legitimization problems linked to technologically relevant decisions have been crucial to the genesis of TA. Problems with side effects, the finiteness of resources and new ethical questions have all heightened decision-making complexity and have led to societal conflicts on the legitimacy of technology. The planning and decision-making procedures developed as early as the 1950s in the spirit of planning optimism [Camhis, 1979] turned out to be clearly unsuited to solving this problem. In addition, the technocratic and expertocratic character of these procedures became an issue in a society in which the populace and the media was starting to monitor democracy and transparency more closely [van Gunsteren, 1976]. Demands for a deliberative democracy [Barber, 1984] led to a climate in which it was particularly the critical aspects of scientific and technical progress that started being debated in the public arena.

The move away from metaphysical and philosophical assumptions about technology also instigated the emergence of TA, a field that focuses on the criteria and means underscoring the concrete development of technology in concrete historical contexts, the conditions facilitating the malleability of technology in society, and the relevant constraints. In the post-metaphysical world [Habermas, 1988a], it is no longer a matter of humanity's technology-driven liberation from work constraints (Marx, Bloch) or of humanity's "salvation" thanks to engineering intervention (Dessauer), neither is it an issue of man's deplored "one-dimensionality" in a technicised world (Marcuse), of the "antiquatedness of man" in sharp contrast to the technology he has developed (Anders) or of fears of a technologically-induced end to human history [Jonas, 1979]. It is more about the impact of technology and the concrete design of specific technical innovations, for instance, in transportation, in information technology, in space flight and in medicine. TA does not concern itself with technology as such but rather with concrete technical products, processes, services, systems, and with their societal impacts and relevant general settings.[1] These developments are reflected in the philosophy of technology where more emphasis is placed on empirical research [Kroes and Meijers, 1995].

The problems mentioned at the outset about the effect that parliamentary decision-making has on technology only give the "occasion" for the initiation of legislative TA facilities, not the deeper reasons for TA formulation which are rooted in the experience of ambivalence towards technical progress, in problems surrounding technological legitimacy in a society with increasing demands for participation, and in the need to concretise and contextualise technology evaluation in complex decision-making situations. The occurrence of TA is thus one of the very specific descriptors rendering our historical situation one that may be dubbed "reflective modernity" [Beck *et al.*, 1996].

2.2 TA as a response to societal challenges

The social climate of the 1960s and 1970s led to a specific TA requirements profile, which is, to a large extent, still relevant today, though new expectations and requirements continue to emerge.

2.2.1 The mounting implications of science and technology

In the twentieth century, the importance of science and technology in almost all areas of society (touching on economic growth, health, the army, etc.) has grown dramatically. Concomitant with this increased significance, the consequences of science and technology for society and the environment have become increasingly serious. Examples are the increasing intervention in the natural environment as a result of economic activity and man's increased interference — through scientific and technical progress — in his own social and moral traditions and ultimately also in his own biological constitution [Habermas, 2001]. Technological progress alters social traditions, fixed cultural habits, collective and individual identities and concepts of the self while calling into question traditional ethical norms. Decisions concerning the pursual or abandonment of various technological paths, regulations and innovation programs, new development plans, or the phasing-out of lines of technology often have far-reaching consequences for further development. They can influence competition in relation to economies or careers, trigger or change the direction of flows of raw materials and waste, influence power supplies and long-term security, create acceptance problems, fan the flames of technological conflict, challenge value systems, create new societal "states of mind" and even change

[1]This contextualization is occasionally criticized on the grounds that TA delves too deeply into the details of technical development so losing sight of the "broader questions" relating to technology, society and the shaping of the future. In this process also the degree of critical distance needed could be lost.

human nature [Roco and Bainbridge, 2002]. New and emerging technologies are not only a means of realizing new technical functions they are also "indicators of the future" [Grunwald, 2006a], on the basis of which society arrives at an understanding of non-technical questions like those relating, for example, to changes in the conceptions of humanity or new societal orders. In this respect, there is close affinity between many TA problems and the great philosophical questions, even if the former concern themselves with the details of technical innovations.

The considerably increased influence of science and technology earns such problems more attention both in politics and from the public point of view and they become the subject of critical reflection. This directly concerns technological side effects but increasingly also the entire direction of technological progress. TA has an important function when it comes to discussing and advising, in a knowledge-based and ethically reflective manner, the possibilities and/or necessities of the *social shaping of technology* [Yoshinaka *et al.*, 2003], establishing informed democratic opinion [Fisher, 1990], creating a *knowledge policy* [Stehr, 2004], or encouraging *sustainable development* [Ludwig, 1997; Grunwald and Kopfmüller, 2006].

2.2.2 Side effects and precaution problems

Since the 1960s the adverse effects of scientific and technical innovations have been considerable and some of them were of dramatic proportions: accidents in technical facilities (Chernobyl, Bhopal), threats to the natural environment (air and water pollution, ozone holes, climate change), negative health effects as in the asbestos case, social and cultural side effects (e.g., labour market problems caused by productivity gains) and the intentional abuse of technology (the attacks on the World Trade Centre). This list illustrates why many optimistic expectations relating to future technological progress have currently been abandoned. The rising range of negative effects in time and space, reaching even a "global" technological level, emphasises the relevance of all of this. In part, even the perception of technology has been dominated by a fear of apocalyptic threats to humanity's continuity (for example, [Jonas, 1984]). Playing down the side effects by referring to them as "the price of technical progress" can cause people to really question the positive aspects of technology.

This experience with such unexpected and in some cases serious impacts of technology is central to TA's motivation. Indeed, in many cases, it would have been desirable to have been warned about the disasters in advance, either to prevent them, or to be in a position to undertake compensatory measures. This explains why the methodologically quite problematic term "early warning" with regard to technological impacts has always had a prominent place in TA discussions from the very beginning [Paschen and Petermann, 1991, p. 26].

The increasing *complexity of technical systems,* their diverse interlacing, and their connectivity with many areas of society increases the difficulties of being able to predict and consider the consequences of actions or decisions. This applies on the one hand, for example, to the infrastructure technologies, particularly in the fields of transportation, energy, and water, which are closely allied to habits, consumption patterns, and societal institutions. On the other hand, due to the vast number of interfaces that have to be taken into consideration, the new cross-sectional technologies such as nanotechnology tend to broaden the spectrum of the possible side effects that have to be included in decisions concerning these technologies thereby increasing the related uncertainty.

This situation leads to a societal and political *precautionary problem*: how can a society which places its hopes and trust in innovation and progress, and must continue to do so in the future, protect itself from undesirable, possibly disastrous side effects, and how can it preventatively stockpile knowledge to cope with possible future adverse effects? Classic problems of this type are, for example, the use and release of new chemicals — the catastrophic history of asbestos use being a good example [Gee and Greenberg, 2002] —, dealing with genetically modified organisms, or the unknown consequences of the accumulation of non-degradable chemicals in the world's oceans, especially in the polar regions (for further examples, cf. Harremoes *et al.* [2002]). In order to be able to cope rationally with these situations of little or no knowledge of certain of the effects of the use of technology, prospective precautionary research and corresponding procedures for societal risk management are required, for instance by implementing the precautionary principle [Schomberg, 2005]. Precautionary problems of this type are a classic field of TA.

2.2.3 The ethical questions of technical progress

For a long time, the question of whether technology had any morally relevant content and could, therefore, be a subject of ethical reflection at all was a controversial topic. Well into the 1990s, technology was held by many, in particular scientists and engineers, to be *value free*. Since then, the value content of technology has been revealed, and the normative backgrounds of decisions on technology (both in design and in the laboratory) have been recognized in numerous case studies and made the subject of reflection (e.g., [Winner, 1980; Mitcham, 1994; van de Poel, 2001; van Gorp, 2005]). The basis for this development is to view technology less as a set of abstract objects or procedures but more as embedded in societal processes and to take it seriously. Technology is not nature; it does not emerge of its own accord but is instead produced to satisfy goals and purposes. Technology is, then, always already embedded in societal intentions, problem diagnoses and action strategies. Because of the side effects mentioned above, the entire field of ethical questions of risk acceptance and acceptability comes into play. In this sense, there is no such thing as a "pure" technology, divorced from society.

It has thus now been acknowledged that technology comprises values and is a legitimate object of responsibility in the normative sense (cf. for example, van Gorp and Grunwald [2007]). The moral criteria employed (that is to say whether something should, would, could, might or must be) clearly differ according to the group concerned, be they manufacturers, operators, users, or those affected directly or indirectly. Tasks requiring ethical reflection present themselves precisely whenever the judgement of various actors leads to diverging results and makes moral conflicts manifest [Grunwald, 2000]. A number of serious ethical questions have been raised, especially as a result of innovations in the modern life sciences, and have also become the subject of public debate. These questions relate particularly to reproductive cloning, reproductive medicine, stem cell research and the "technical enhancement of human beings" [Roco and Bainbridge, 2002]. Nowadays, there is thus hardly any doubt that TA must also inevitably concern itself with normative questions which means that in this way it becomes closely connected to ethics [Grunwald, 1999].

2.2.4 Technology conflicts and problems of legitimisation

Societal conflicts relating to science and technology are not unusual; they are inherent to any pluralistic society. Answers to questions about the desirability or acceptability of technology, about whether technological risks are acceptable or about where precisely the ethical limits of technology lie are generally controversial due to social pluralism, the differing degrees to which different groups in the modern world are affected by various technological impacts, diverging interests and people's differing moral convictions. Images of the future, desires and fears, visions and scenarios are also usually contested [Brown *et al.*, 2000]. Conflicts are characteristic of decisions in the field of technology, while consensus tends to constitute the exception. Making decisions in such conflict situations often results in *problems of legitimisation* because there will be winners (who profit from specific decisions) and losers. This is frequently the case when decisions must be made about the site of a technical facility such as a nuclear power plant, a waste disposal plant or a large chemical production plant. Depending on the selected location, people in the direct neighbourhood will have to accept more disadvantages than others. Problems of legitimisation always surface when the distribution of advantages and disadvantages is unequal.

In view of the decades of experience with a number of very serious acceptance problems and certain grave conflicts over technology it has become clear that the question of legitimisation is obviously important. Many examples can be given such as: opposition to nuclear power, the problem of expanding airports, the problem of how to dispose of radioactive waste, the release of genetically modified plants, and regional and local conflicts on waste disposal sites, waste incineration plants, or the location of chemical processing facilities. In these areas, political decisions are frequently not accepted by those affected or by the general public, even though they are the result of democratic decision-making procedures.

The differentiation of modern societies, their fragmentation into plural groups with different moral convictions, and the cultural heterogeneity increased by migration and globalization all make it difficult to achieve a general consensus on technology. As demonstrated above by the nuclear technology examples (atomic reactors, reprocessing plants, the transportation and disposal of radioactive waste), conflicts on technology and its lack of acceptance in society have led to situations which virtually lead to a societal standstill. This is precisely where the danger lies: the escalation of conflict on technology can lead to a hardening of fundamentalist positions which, in turn, can be an obstruction to finding pragmatic solutions to problems and can sometimes almost even lead to civil war. The challenge to society consists in dealing with the conflicts in such a way that the resulting decisions are acknowledged as legitimate, even if they run counter to the interests, values, and preferences of some parties. In particular it is participative TA procedures that try to provide solutions to this problem (Section 2.4.2).

The solving of problems allied to legitimisation and technology conflicts is complicated by a certain public mistrust of decisions made by experts that has been growing for decades. Frequently a situation arises in which expertise and counter-expertise conflict thus invalidating in the eyes of the public the expertise of scientific authorities. Scientists are not only — as their traditional self-understanding dictates — incorruptible advocates of objective knowledge, but they are also interested parties in their own cause, lobbyists for external interests, or committed citizens with political convictions, not all of which can always be kept clearly separated from their professional position. In addition to this the political system is perceived to be less and less of a trustee of citizens' interests, and increasingly interested in its own gain. Methods for solving problems of legitimisation therefore basically involve more frequently integrating non-experts [Fischer, 1990]. New forms of legitimisation (through participative TA, [Joss and Belucci, 2002]; cf. Section 2.4.2 of this contribution) and solutions to specific problems in the communication between experts and non-experts [Bechmann and Hronsky, 2003] therefore belong to the spectrum of TA responsibility.

2.2.5 Economic difficulties and prerequisites for innovation

From the outset, TA has been an aspect of the national innovation system. If, in the initial phase, it was primarily a question of providing an early warning on technological risks, this was not so much done to hamper new technologies as to open up opportunities to avoid or overcome such risks by detecting them early on. The early detection of risks fits into the tradition of deploying the innovation potentials of science and technology as "well" as possible. For this reason, another TA topic that emerged early on was the early detection of technological *opportunities* so that the best possible use could be made of these benefits and so that the benefits and hazards could also be rationally determined. The search for opportunities and possible innovative applications of technology is an inseparable aspect of TA [Ayres *et al.*, 1970; Smits and Leyten, 1991].

Since the 1990s, new challenges have arisen. In many national economies, serious economic problems have cropped up, which have led to mass unemployment and to the accompanying consequences for the social welfare systems. Increased innovativeness is said to play a key role in solving these problems. On the basis of this analysis, new functions have been ascribed to TA within the scope of innovation research [Smits and Den Hertog, 2007]. Its basic premise is to involve TA in the design of innovative products and processes because innovation research has shown that scientific-technical inventions do not automatically lead to societally relevant and economically profitable innovations. The "supply" from science and technology and the societal "demand" do not always correspond. This means that more attention has to be paid to more pronouncedly orienting towards society's needs within the scientific-technical system, the diffusion of innovations and the analysis of opportunities and constraints.

The theoretical question as to how economic conditions contribute to the success or failure of technical innovations demonstrates that TA takes an active interest in the relevant societal background. Cultural and social questions are also seen as relevant factors for innovations. Including users in technology design, in order to better link technical proposals and consumer demands, should also be mentioned here [Smits and Den Hertog, 2007].

2.3 General characteristics and definition of TA

The above-mentioned facets of the diagnosis of societal developments in the past decades form the problem background against which TA was formulated, and the solution to which it is supposed to contribute. Depending on the context, corresponding societal expectations present themselves in a specific form, and show considerable heterogeneity. In spite of the diversity stimulated by this situation the general characteristics of TA can nonetheless be listed:

- *Orientation on Advice and Decision-Making*: TA supports public opinion and public participation in decisions on science and technology. In this endeavour, it aims at embedding TA knowledge and orientations into the perspective of decision makers: TA knowledge is knowledge for those who are to be advised. Because decisions always affect the future, a reference to the future is always included. TA always functions *ex ante* with regard to decisions.

- *Side Effects*: In TA, it is a matter of combining "comprehensive" decision support with the widest possible contemplation of the spectrum of foreseeable or presumable effects. Beyond classical decision theory, which establishes the relationship between goals and means according to the viewpoint of efficiency, TA turns its attention to unintentional side effects as a constitutive characteristic [Bechmann *et al.*, 2007].

- *Uncertainty and Risk*: Orientation to the future and the problems posed by side effects often leads to considerable uncertainty regarding TA knowledge. TA therefore always has to do with providing decision-making support in conjunction with complex innovations under conditions of uncertainty. The impact of such decisions is difficult to predict.

- *Value-Relatedness*: The rationality of decisions not only depends on knowledge about the systems involved and of the available action-guiding knowledge, but also on the basic normative principles. The disclosure and analysis of the normative positions involved is therefore also an aspect of the TA advisory service (e.g., depending on ethical reflection or sustainability evaluations [Grunwald, 1999; Ludwig, 1997]).

- *Systemic Approach:* TA aims at achieving a comprehensive view of the fields affected. Several perspectives, e.g., from different scientific disciplines, have to be integrated into a coherent picture. Specific attention is dedicated to the systemic interrelationships between the impact of technology in different societal areas.

- *Broad Understanding of Innovation:* TA understands a broad notion linked to the term "innovation". Beyond the mere technical understanding of innovations as new products or systems, TA contemplates social, political, and institutional innovations and does, in general, also consider socio-technical innovations.

- *Thinking in Alternatives*: When working on concrete projects, TA does not confine itself to a certain technology but always operates in an open window of possible alternatives. Presumed inherent necessities are broken down so that leeway for structuring can be gained. In concrete processes, the question of whether the results desired could not also be realized in a different manner is always posed. Alternative options are thus also examined which are not based on technology, but concern the political planning measures. "Thinking in alternatives" has thus become a specific TA tradition.

- *Interdisciplinarity and Transdisciplinarity*: TA concerns itself with complex societal problems that affect technological decisions and technological side effects. It does this on scientific grounds backed up by research. As a rule, such problems are worked on in an interdisciplinary or transdisciplinary manner.

- *Time Limitation*: Deadlines for completion of the analyses and studies are also inextricably intertwined with the decision-making process. TA knowledge has to be available at certain times regardless of whether all desiderata for comprehensive and reliable knowledge can be satisfied. Without this pragmatic limit, TA's claim to provide analyses that are as comprehensive possible could lead to never-ending stories.

Now that the main characteristics have been listed we shall introduce TA in a problem-orientated fashion according to its societal responsibilities in the providing of specific knowledge and advisory services. We can draw on the existing definition of TA which states that: "Technology Assessment (TA) is a scientific, interactive, and communicative process which aims to contribute to the formation of public and political opinion on societal aspects of science and technology" [Decker and

Ladikas, 2004]. This definition stresses that TA *contributes* to problem-solving, but does not pretend to provide actual solutions. TA provides knowledge, orientation, or procedures on how to cope with certain problems at the interface between technology and society but it is neither able nor legitimized to solve these problems. Only society can do this, through its institutions and its decision-making processes. There is, therefore, a constitutive *difference between advising and deciding*.

The definition given above also includes the attribute "societal" which specifies that the public and political sphere is the place for discussing and dealing with the relevant effects of technological impact. TA is concerned with the aspects of technology that have *societal* implications. Here the focus of TA dwells in the perspective of *unintended side effects*. Accidents, environmental impact, unintended side effects on social life (e.g., in employment) and other technological consequences that were neither intended nor anticipated are some of the most important issues in modern times. TA has also been set up as a societal means to enable such situations to be dealt with constructively while making use of scientific research [Bechmann *et al.*, 2007]. Early warning, sustainable development, and the precautionary principle are relevant notions here.

An international community has been formed around the concept of TA roughly sketched above [Rader, 2002; Vig and Paschen 1999]. Part of this community works in institutions explicitly devoted to TA (e.g., to provide advice on parliamentary policy) and its organizations (cf., for instance, the European Parliamentary Technology Assessment Network EPTA, www.eptanetwork.org), part of it is organized in networks (cf., e.g., the German-language network TA, www.netzwerk-ta.net), and another part converges on the fringes of disciplinary organizations and conferences, such as in sections of professional sociological or philosophical organizations, or in the social scientific STS Community (Science and Technology Studies), e.g., under the auspices of EASST (the European Association for the Study of Science and Technology), and of many IEEE (Institute of Electrical and Electronics Engineers) activities relating to the social implications of technology.

2.4 Concepts of technology assessment

Fulfilling TA's above-mentioned responsibilities and satisfying the societal expectations behind those responsibilities requires an operable framework including different facets, typically research concepts, knowledge-dissemination models, task concepts for dedicated TA institutions, or ideas on public discourse and TA's role within that. TA concepts exist at the uppermost level of TA operationalisation since they reduce the complexity of the entire collection of requirements to the focal points determined in each case.

Throughout its history, TA has undergone a series of metamorphoses. Societal trends and research directions such as planning optimism or scepticism, positivism and value orientation, social constructivism and research into the genesis of technology, participation and civil society, loss of confidence in expert decisions, and concepts such as the Risk Society, the Network Society, and the Knowledge Society, economic globalization, the discussion on the uncertainty of knowledge, new forms of knowledge production [Gibbons *et al.*, 1994], and the guiding principle of sustainable development have all made their mark on TA. For more than 30 years some complementary, some competing, and some TA concepts that were adapted to varying requirements have been developed in this manner. The concepts of TA presented below are intended to provide the most varied impression possible of TA's conceptual diversity.

2.4.1 The "classical" concept of TA

The classical concept of TA is an ex post facto construct. It does, in fact, incorporate aspects of the way in which TA was practised during its "classical" phase in the 1970s, in the Office of Technology Assessment (OTA) at the US Congress [United States Senate, 1972; Bimber, 1996] but in many respects it is a later stylization and not an adequate historical reconstruction. Nonetheless, it is useful to recall the elements of this classical concept, particularly as delimitations and re-orientations can be more clearly described against this backdrop. The following (partially normative) six elements are deemed to be constitutive for the classical conceptualisation of TA:

Positivism: TA in the classical sense is dominated by a *positivistic understanding of science*. It designates a method of producing "exact, comprehensive, and objective information on the technology, in order to facilitate the deciders' effective societal commitment" [United States Senate, 1972]. In the foreground and elaborated for the deciders' purposes is the description of what is technologically state- of- the- art and the presumed consequences thereof. Recommendations or independent judgements remain reserved for the political sphere; they are not the domain of TA. The OTA gives "no recommendations, what should be done, but rather...information about what could be done" [Gibbons, 1991, p. 27]. The positivistic legacy of TA that "OTA never takes a stand" [Williamson, 1994, p. 212] is derived from the postulate of science being value free (Weber). The classical concept corresponds in this manner to a *decisionist* division of labour between positivistic TA and the planning preserve of politics: TA provides purportedly value-free knowledge about technology and the impact of technology while the political system evaluates this knowledge and makes decisions.

Etatism: In the classical view TA is exclusively perceived to provide *advice to politics*. This is founded on the assumption that the state has the authority to direct technology in a societally desired direction: the state can procure the necessary knowledge about impacts; it represents the public interest, as opposed to citizens' preferences and interests, and it is the central planning authority empowered to actually implement intentions and programs of societal management. This etatist interpretation of the state is characteristic of the period of planning optimism [Camhis, 1979] when TA was established. This fixation on the state in the early phase of TA has since met with harsh criticism (e.g., [van Gunsteren, 1976]) which has motivated the development of more participatory TA approaches.

Comprehensiveness: TA in the classical sense aims at *comprehensiveness* with regard to the consequences of the technology to be studied. The hope is that a complete record of the effects of a technology will help society to avoid unpleasant surprises during its introduction and in the automation of processes. In a certain respect, this assumption is the legacy of former planning optimism. According to this view there must be complete knowledge of all the data on the problem to be decided — and a complete knowledge of all the side effects — in order to eliminate uncertainties. In earlier conceptions, people tried to fulfil this demand for completeness through system analysis [Paschen *et al.*, 1978]: the side effects of technology are often the result of a systemically reticulated process with nonlinear cause-and-effect relationships and interactions which are difficult to discern.

Quantification: In this approach there were also great expectations regarding the *quantitative apprehensibility* of the effects of technology. It was expected that systems theory would, in combination with the quantification of social regularities, prepare quantitative models of causal chains and laws of societal processes and, thus, "objectivise" them. This approach also harboured the expectation that the problem of subjectivity (or of lack of inter-subjectivity) in evaluations of the effects of technology could be solved by means of quantification (see Section 3.2 for limitations on this expectation).

Prognosticism: TA in the classical interpretation was seen, above all else, as a *prognostic determination* of the impact of technology and as an early warning mechanism for technologically caused risks. In analogy to a prognosis based on natural systems, the laws of societal processes were to be discovered and used for quantitative prognoses, which should be as exact as possible. Trend extrapolations and assumptions about laws should therefore make it possible to extrapolate an empirically recorded series of relevant parameters into the future. Such prognostic knowledge should then enable the political system to react appropriately and promptly and, if the situation arose, to take countermeasures against hazards.

Orientation towards experts: The classical concept of TA is orientated towards TA *experts*. They must provide the necessary knowledge and communicate with decision-makers by offering political advice. In contrast to the various models for participative TA (see below), classical TA is deemed to be focussed on experts, hence the coining of the sometimes-used term "expertocratic".

2.4.2 Participative technology aAssessment

Since the very beginnings of TA, there has been repeated demand for participative orientation, frequently following normative ideas from the fields of deliberative democracy or discourse ethics [Barber, 1984; Habermas, 1988b; Renn and Webler, 1998]. Problems of evaluation were a driving force behind this demand since according to ideas derived from the theory of democracy (e.g. [Barber, 1984]), evaluation should not be left solely to the scientific experts (expertocracy) or to the political deciders (decisionism). It is the task of participative TA to include societal groups — lobbyists, affected citizens, non-experts, and the public in general — in the process of evaluating technology and its consequences. In this manner, participative TA procedures are deemed to improve the practical and political legitimacy of decisions on technology [Paschen *et al.*, 1978, p. 72]. Such TA is informed by science and experts and, in addition, by people and groups external to science and politics [Joss and Durant, 1995; Joss and Bellucci, 2002].

The demand that those affected participate in decisions on technology has been increasingly put into practice since the1980s, beginning in the smaller, traditionally discursive western and northern European nations, such as Denmark and the Netherlands. Participation has gained particular relevance, on the one hand, in many discussions on technological locating (e.g., airport expansion, waste disposal sites, chemical processing plants, final disposal sites for radioactive waste), in which the widespread NIMBY (Not In My Back Yard) problem leads to participation being emphatically needed [Renn and Webler, 1998]. On the other hand, participation became a constitutive feature of the so-called "Foresight" processes [Martin and Irvine, 1989] in which, for example, the agenda for research policies and for promoting technology, was set or visions for the development of certain regions were formulated [FOREN, 2001].

The participation of citizens and of those affected is believed to improve the knowledge as well as the values on which judgements are based and decisions are made. "Local knowledge", with which experts and decision-makers are often not familiar, is to be used in order to achieve the broadest possible knowledge base and to substantiate decisions. This discernibly applies especially to local and regional technological problems, in particular, to questions of location. Furthermore, in a deliberative democracy, it is necessary to take the interests and values of *all* those participating and affected into consideration in the decision-making process. Participation should make it possible for decisions on technology to be accepted by a larger spectrum of society despite divergent normative convictions. In the end, this will also improve the robustness of such decisions and enhance their legitimacy [Joss and Belucci, 2002].

The participation in TA of those affected by technology is designed to improve the legitimacy of ensuing decisions and thus prevent conflict. The expectation is that when those affected have had the opportunity to present their arguments and to weigh them against those of their opponents, they are more likely to acknowledge the resulting decisions as legitimate and accept them, even if such decisions run counter to their own interests. For many, participative TA is also supposed to counteract the political disenchantment observed in many countries and "empower" those affected. The model of representative democracy, which is threatened by emaciation, is confronted here with a civil-societally renewed democracy [Barber, 1984].

These ambitious objectives are, however, hard to realize in practice [Grunwald, 2004b]. Not only representative democracy but also participatory TA is confronted with the problem of representation: only a few people can attend such meetings but they should represent all the relevant groups. The willingness to engage in participatory TA varies according to the population group and correlates with the level of education. The relation between participatory processes and the usual democratic decision-making processes remains an unresolved issue in many countries and this endangers the relevance of participatory TA.

2.4.3 Constructive technology assessment (CTA)

The basic assumption of CTA, which was developed in the Netherlands [Schot, 1992], is that TA meets with difficult problems of implementation and effectiveness whenever it concerns itself with the impacts of a technology after the latter has been developed or is even already in use [Rip *et al.*, 1995]. According to the Collingridge dilemma [Collingridge, 1980], once the impacts are relatively well-known, the chances of influencing them will significantly decrease. It would therefore be more effective to accompany the process of the *development* of a technology constructively (similarly to the idea of a "real time" TA, cf. [Guston and Sarewitz, 2002]). The origin of technological impact is traced back to the development phase of a technology so that dealing with the consequences of technology becomes a responsibility that already starts in the technology design phase.

The theoretical background to CTA is the Social Construction of Technology (SCOT) program, which was also developed in the Netherlands and which has been elaborated in a number of case studies [Bijker *et al.*, 1987; Rip et al., 1995]. According to this approach, the development of technology should be perceived as the result of societal processes of meaning giving and negotiation. Technology is "socially constructed" during these steps. CTA has pleaded for the early and broad participation of societal actors, including key economic players and for the establishment of a learning society that experiments with technology. In the normative respect, CTA builds on a basis of deliberative democracy in which a liberal picture of the state highlights self-organising processes in the marketplace. To this end, three processes have been proposed (according to [Schot and Rip, 1997, p. 257f.]):

Technology Forcing: Influencing technological progress through the promotion of research and technology as well as through regulation is how the state can intervene in technology. The options are, however, restricted. CTA therefore also addresses other actors (banks and insurance companies, standards bodies and consumer organizations). Through their business and organizational policy, these institutions can directly intervene in certain technological innovations, for instance, by dispensing with chlorine chemistry, by investing in environmentally compatible manufacturing technology, or by developing social standards that are also valid for branches of a company located in developing nations.

Strategic Niche Management: Governmental promotion of innovations should, according to CTA, be concerned with occupying "niches" in technology's repertory. In these niches publicly sponsored technology can — if protected by subsidies — be developed, make use of processes of learning, gain acceptance, and finally —

it is hoped — maintain its own in free competition unaided by public support. This approach, in which the state directs technology close to the market, is especially relevant in fields reluctant to embark on innovation, such as infrastructure technologies. Successful implementation presupposes considerable learning processes and careful observation of developments either to avoid exposing "niche technology" to competition too early, thereby endangering its growth, or to prevent prolonged subsidies leading it to miss the moment of its marketability.

Societal Dialogue on Technology: It is necessary to create the opportunities and structures for critical and open dialogue on technology. In the process, one has to go beyond the limits of scientific discourse and expert workshops to include the economy and the populace. This applies to technology forcing as well as to niche management. "Managing Technology in Society" [Rip *et al.*, 1995] is possible only when these elements harmonise.

2.4.4 Leitbild assessment

In Germany, the concept of empirical technology shaping research developed in parallel with CTA [Dierkes *et al.*, 1992; Weyer *et al.*, 1997]. As in CTA, the paramount objective is to analyse the shaping of technology and its "enculturation" by society instead of reflecting on its impacts. The shaping and diffusion of technology are traced back to social processes of communication, networking and decision-making. TA accordingly consists of research into the social processes which contribute to technological design, analysing the "setscrews" for intervening in these processes and informing decision-makers on these findings. There is, in this concept, almost no further mention of technological impact; it is presumed that the unintended side effects could be completely or largely avoided by improving the process of technology shaping.

Leitbild assessment [Dierkes *et al.*, 1992] has made it clear that technology development often follows non-technological ideals. Leitbilder ("guiding visions", cf. Grin [2000]) are often phrased in metaphors which are shared, implicitly or explicitly, by the relevant actors (e.g., the "paperless office", "warfare without bloodshed", or the "automobile city"). Research into such ideals has investigated in detail, empirically and hermeneutically, which mechanisms dominate this development, including linguistic analysis of the use of metaphors in engineering circles [Mambrey and Tepper, 2000]. The expectation is that through societal construction of the ideals shaping it, technology can be indirectly influenced in order to prevent any negative effects.

These deliberations have led to a wealth of instructive case studies [Weyer *et al.*, 1997], but they have not really been integrated into TA practice. The reason probably lies in the fact that strong assumptions are necessary for the transfer of knowledge gained *ex post* in case studies on TA problems, which are always inevitably concerned with the future. *Leitbild* assessment is a way of explaining the course of technology development *ex post* rather than by giving indications on how to shape technology. Moreover, the sociological perspective has resulted in the neglecting of the normative dimension of technological shaping.

2.4.5 Innovation-orientated technology assessment

Embedding technology in society takes place by means of innovation. There are thus overlaps between TA and innovation research and in recent years the two fields have developed "innovation-orientated" TA concepts at their interface [Smits and Den Hertog, 2007]. Innovation research focuses on the analysis of completed and current innovation processes and is primarily interested in factors that are crucial to successful market penetration. Factors enabling and preventing innovative success are identified. The objective is to attain a better understanding of innovation processes and their influencing factors. With this knowledge, governmental research and technological policies, as well as industrial decisions on innovations can be supported.

In this respect TA first contributes, by broadening the spectrum of influencing factors, by adding social and cultural elements. TA then examines — analogous to participative TA — the role of the users in innovation processes. In innovation-orientated TA, a special role is assigned to the users whenever customer-orientated and social technology designs are at stake. In order to realize this objective, the users must be included in the early phases of technology development [Smits and Den Hertog, 2007]. The classical instruments of market research are inadequate for this purpose. Instead, users have to be integrated into deliberative and prospective processes of technology prognosis (foresight). In this respect, they can play very different roles. "Users can play a role as more or less active consumers, and modifiers, as domesticators, as designers, and, in fact, also as opponents of technological innovation. ... High quality user-producer relations as well as possibilities for learning and experimenting are prerequisites for successful innovation processes" [Smits and Den Hertog, 2007, p. 49]. To this end one important function for TA is to identify the relevant actors in a certain field, to inform them and then, most importantly, to use discursive procedures to establish the users' needs, visions, interests and values. It is then a question of integrating these findings into the process of technology development. Innovation-orientated TA should thus contribute to making the regional or national innovation systems more strongly orientated towards citizens' and consumers' needs [Smits and Den Hertog, 2007].

2.4.6 Technology assessment and engineering ethics

In the engineering sciences, the challenges with which TA is confronted have been discussed as demands on the profession of engineers. The value dimension of technology has been shown in many case studies, especially in engineering design processes ([van de Poel, 2001; van Gorp, 2005]; cf. also the chapter on values and design by Ibo van de Poel, this Handbook, Part V). Decisions on technology design involve value judgements. There is, in other words, a close relationship between professional engineering ethics and the ethics of technology [Mitcham, 1994]. By way of example, one can cite VDI guideline no. 3780 of the Association of German Engineers [VDI, 1991], which has become relatively widespread. It envisages a "Guide to Technology Assessment According to Individual and Social Ethical Aspects". For engineers and in industry, assessments are to a certain extent part of their daily work. Evaluations play a central role whenever, for instance, a line of technology is judged to be promising or to lead to a dead end; whenever the chances for future products are assessed; whenever a choice between competing materials is made; or whenever a new production method is introduced to a company. Though evaluation may be commonplace in daily engineering practice, what is essentially new in this guideline for societal technological evaluation is its scope, which also includes the societally relevant dimensions of impacts as well as technical and economic factors. Technological evaluation should be conducted in line with societally acknowledged values. Eight central values forming the VDI "Value Octagon" have been identified: functional reliability, economic efficiency, prosperity, safety, health, environmental quality, personality development and social quality [VDI, 1991]. These values are thought to influence technical action and fall under the premiss [VDI, 1991, p. 7]: "It should be the objective of all technical action ... to secure and to improve human possibilities in life." They are involved in technology development when observed by engineers in practice, that is to say, they are virtually *built into* the technology. Engineers or scientists should, on the basis of their knowledge and abilities, point the development of technology in the "right" direction by observing these values and avoiding undesirable developments. If this exceeds their authority or competence, engineers should take part in the corresponding procedures of technology evaluation.

2.5 Methods in TA

Methods assume a central function in TA to fulfil its responsibilities in research, assessment or advice. The guaranteeing of the transparency, comprehensibility, and inter-subjectivity of TA results is primarily ensured, as in the classical scientific disciplines, by the ability to follow the materialisation of the results step by step as the method proceeds. The use of methods is closely allied to TA's observance of quality standards [Decker and Ladikas, 2004]. TA requires specific methods or method sets which are tailored to the relevant assignments, backgrounds and actor constellations. In TA methods can be used to collect data, provide knowledge, organize TA-relevant communication, gain ideas on conflict management, uncover the normative structure of technology conflicts, establish scenarios on future developments or assess value structures.

In order to operationalise TA activities in specific projects, a set of methods is available in the form of a "method toolbox" (see Decker and Ladikas [2004]). A first step in designing a TA project is to select appropriate methods and clarify their integration in a coherent mix relevant to the overall project goals and the specific environment. Often the specific goals of a TA project can only be attained by combining different methods or adopting new ones. The needs and expectations of the respective beneficiaries will, of course, influence the set of methods chosen, because TA knowledge has to be "customised". The project design also takes general TA quality criteria into account such as scientific reliability or interactive fairness. The project design is influenced by the institutional setting, the mission of the institution, its tradition or history and its formal status. Careful "situation appreciation" must therefore be carried out *in advance* to identify which methods are appropriate [Bütschi *et al.*, 2004]. The methods applied in TA are research methods, interactive methods and communication methods [Decker and Ladikas, 2004].

Research methods are developed in disciplines pertaining to the sciences and humanities. They are applied to TA problems in order to collect data, to facilitate predictions, to do quantitative risk assessment, to allow for the identification of economic consequences, to investigate social values or acceptance problems and to do eco-balancing. This class of methods includes (1) modelling, systems analysis, risk analysis (cf. Section 3.3.1), material flow analysis (cf. Section 3.3.3) (to understand the sociotechnical system being investigated as well as to be able to assess the impacts of the political measures proposed); (2) trend extrapolation, simulation, scenario building (to create systematic knowledge in order to contemplate the future); (3) the Delphi method (to gather expert knowledge, especially on the assessment of future developments in science and technology); (4) expert interviews and expert discussion (to gain more insight into current situations but also to analyse scientific controversy and diverging assessment with respect to the arguments used); (5) discourse analysis, values research, ethics, and value tree analysis (for the evaluating and revealing of the argumentative landscape in normative respects).

Interactive, participatory or dialogue methods are developed to organise social interaction in such a way as to facilitate conflict management, allow for conflict resolution, bring scientific expertise and citizens together, involve stakeholders in decision-making processes and mobilise citizens to shape society's future. This class of methods includes (1) consensus conferences (to involve citizens in societal debate on science and technology in a systematic manner, according to a specific framework (cf. Sect. 3.3.5)); (2) expert hearings (to inform the public but also to confront experts with laymen's views and with diverging expert judgement); (3) focus groups (to gain coherent views on a specific topic from a set of actors and citizens); (4) citizens' juries (to assess measures and planning ideas with respect to the values and interests of stakeholders and interested parties); (5) scenario workshops and perspective workshops (to create drafts of the future in an interactive way).

Communication should be seen as a two-way process. On the one hand communication methods are used to communicate the corporate image of a TA institute, the TA approach, the TA process and the TA product to the outside world so as to increase the impact of TA. On the other hand communication is important for enabling the TA institute to keep in touch with the outside world and thus with reality. This class of methods includes (1) newsletter and focus magazines, perhaps including opinion articles (for creating awareness and pointing out critical issues); (2) science theatre and video presentations (to illustrate possible science and technology impacts on future society and everyday life); (3) websites, local questionnaires or debate forums (to facilitate or strengthen interactive communication at informal level); (4) networking and dialogue conferences (to promote mutual exchange and the distribution of the new ideas and issues to be considered).

3 NORMATIVITY AND VALUE ISSUES IN TA

It is no longer a point of controvery that technology development needs normative orientation because values and normative judgements enter into technological design (cf., for example, van de Poel [2001] and van Gorp [2005]) and technology development at many stages of the process thus determining the eventual societal implications of technology to a considerable extent. Normative judgements on technical options, technological impacts, or innovation potential with regard to societal desirability or acceptability are some of the many decisions which have to be made during technology development. Analysing such normative questions of technology and giving advice to society are some of the responsibilities of TA. However, the specific problems related to this type of advice must be carefully observed [Grunwald, 2003].

3.1 Normative judgements in TA practice

The prospective assessment of technological impacts is an important part of TA projects where normative and evaluative considerations play a role but not the only role. These considerations also accompany TA processes in the definition phase, in the implementation and in impact assessment:

Definition of the Task: TA topics do not arise "by themselves". Many questions on technology and automation could be asked in various ways, e.g., from economic or social, cultural or political, or even environmental or psychological perspectives. Stem-cell research can be addressed from the medical angle of curing Alzheimer's disease, or can be seen as a moral breach in the dike, gene therapy can be seen as a therapeutic instrument, or as a step towards a new form of eugenics, whatever the approach each uncovers completely different horizons of treatment and possible answers. The definition of the task is connected to a corresponding perception of the problem (e.g., with respect to the anticipated side effects). It is all bound up with priorities, perspectives, values, actors' interests and occasionally there might even be a desire to conceal certain questions. It is relevant to see who defines the problem, which people, groups and societal subsystems are involved, and what interests they pursue. Topic determination is the result of evaluation and it is, therefore, politically relevant. For that reason, the participation of those affected and of "stakeholders" in the definition, description, and structuring of the problem must be taken into consideration, more to the point it is even absolutely necessary in order to avoid coming up with answers which are completely irrelevant in social terms. At this point, tension occasionally arises between the scientific independence requirements of TA institutions [Grunwald, 2006b] and the topic determination dependency of clients, for example, parliaments [Vig and Paschen, 1999]. One of the responsibilities of TA is also to be critical of mainstream problem formulations and, in particular, to draw attention to aspects which have been neglected so far.

Delimitation of the System: Since it is impossible to completely investigate the entire spectrum of technological impacts or the consequences and implications of a technology, the contours of a concrete TA project must be determined in detail. Before beginning a TA study, one has to decide what is of cognitive interest and what can be left out. This concerns, on the one hand, converting the subject in hand into a series of detailed questions and, on the other hand, demarcating the limits of the system to be examined in spatial, temporal and thematic terms. Taking the example of life cycle assessment (LCA, Section 3.3.3), the significance of this delimitation can be immediately seen. Even for a simple technical product, the chain of preliminary products and processes can take on quite considerable proportions and this is even more so with complex products, such as a washing machine or an automobile. In view of the limits of temporal and financial resources, decisions have to be made as to how far one wants to retrace the manufacturing chain, and which processes or material flows can be rejected as irrelevant. When this sort of decision is made, disputes often arise concerning the matter of the extent to which these system demarcations prejudice the subsequent results. Decisions of this type are decisions on relevance and the importance of the problem in hand. In terms of method they are, therefore, evaluations. Thematic demarcations of knowledge interest have an effect on the choice of scientific disciplines, and possibly also of the societal groups that are invited to participate. This is how the areas of knowledge, ranges of values and interests taken into consideration are determined — and these, too, are normative decisions about what is relevant and what is not [Decker and Ladikas, 2004; cf. Section 2.6.1]. TA has to determine what interaction or aspects of the area of study are relevant to analysis and to finding a solution. This is done according to the normative evaluation criteria used to distinguish important aspects from unimportant aspects and is often controversial. What is important for one actor may be unimportant or even detrimental to others. There is a risk involved in making such relevance judgements: they could later turn out to be unjustified. It could transpire that despite all the care taken important aspects are “forgotten” or fail to be adequately assessed. This normative dimension in the initiating phase of TA projects and processes is precarious because it often crucially and irreversibly influences further stages.

Normative Aspects of the Methodical Approach: Certain TA project methods are not based exclusively on means-end rationality, that is to say, their likelihood of attaining the relevant aims pursued. Instead, normative considerations also come into play. By choosing quantitative methods, for example, one also accepts certain (normative) quantification rules. Although in many cases this may not be a problem, like in the quantitative recording of emissions by power plants, in other areas quantifications can be ethically questionable (Section 3.2.4). When choosing methods it is thus imperative to consider the relevant normative presuppositions. For example: are they adequate in that context, and accepted by those involved? This is analogous to scientific modelling which always involves normative preconceptions. For instance, in neoclassical economics we have the common concept of a *homo oeconomicus*, whose knowledge is comprehensive and who makes his decisions according to utility maximization. As soon as models are used in TA one therefore has to inquire into their normative assumptions, their adequacy, and their acceptability in the context in question.

Evaluation of the State of Knowledge: Comprehending and evaluating the level of knowledge on the technology in question as well as establishing its operating conditions and foreseeable consequences is an integral part of TA. This is no trivial matter involving the mere gathering of available knowledge but rather an activity with its own normative challenges. First of all, there is usually no consensus on the acknowledged "status of knowledge" regarding a certain issue. Because the knowledge required for TA is not generally textbook knowledge but rather knowledge that has to be sought at the cutting edge of research there is often no consensus within the relevant scientific communities. Instead scientific controversies tend to become the order of the day. These may consist of different estimations of the reliability of certain stocks of knowledge; they may also derive from divergent opinions on the significance of these stocks of knowledge within the context of the particular TA problem in question. The interdisciplinary nature of TA knowledge complicates these judgements. Knowledge assessment thus forms an independent step in TA processes [Pereira *et al.*, 2007]. The constituents of the "status of knowledge" which can be established as a consensus have to be determined and the scientific controversies have to be more closely investigated, both with regard to their epistemological and their normative origins. For this reason, the reflexive dimension of rationality [Decker and Grunwald, 2001] requires us, on the one hand, to reveal the uncertainties and controversies connected with the available knowledge. On the other hand, the difficulties that hinder the clear determination of the limits of knowledge in consensus have to be made transparent. TA includes, in this sense, epistemological considerations: the epistemological status of the stocks of knowledge used must be clear in order to preclude one-sided, exaggerated or arbitrary conclusions being drawn on the basis of knowledge which does not epistemologically support it.

Prospective Evaluation of the Impact of Technology: The evaluation of the possible consequences of a technology is in itself the most prominent and most often discussed point and the stage when TA problems of evaluation arise. This relates to challenges such as the assessment of risks, the appraisal of expectations concerning benefits and often the need to weigh up the facts. The following types of assessment situations are common in TA practice:

- The consequences of a technology can be judged in relation to the technologically, societally, or politically determined and legitimised *goals* pursued. Wherever there are politically determined objectives there is always a clear normative basis for evaluation (which can naturally be questioned on a different level). In numerous sustainability strategies there are, for example, political target values (e.g., with regard to CO_2 emissions) that can be used as evaluation criteria.
- The evaluation of the effects of technology can include a study of the attainment of goals from the *viewpoint of efficiency*. Are there other ways of achieving the same goals with fewer side effects, fewer risks and at lower costs, etc.?
- Such an evaluation can concern itself with the acceptance or acceptability of side effects. In this case, even the general rejection of a technology can be a topic, notwithstanding expectations surrounding possible benefits (as is often the case with genetically modified organisms). It could alternatively concern proposals for a moratorium or (as is more frequently the case) comparing the side effects that have to be accepted and the expected benefits.

In any case, TA's claim to transparency and comprehensibility makes it obligatory to disclose the respective assessment criteria (see Section 3.2.1). In that way citizens, politicians, or stakeholders can compare the premises of TA's conclusions with their own values and either accept (for well-founded reasons), modify or reject them. This increases the transparency of the public debate because positions are established and conclusions are drawn in relation to the underlying premises and values.

3.2 Methodological challenges

TA's methodological orientation aims to make it possible, even in the field of evaluations, to provide for the greatest possible amount of rationality, transparency and inter-subjectivity. The results of TA have to be protected from ideological suspicions and from being accused of being particularist or arbitrary. In this way specific methodological problems emerge, including the question of whether "objective" normative conclusions can be justified in the first place [Grunwald, 2003].

3.2.1 The origin of normative criteria

Normative criteria are required to evaluate all the fields mentioned above. These can be derived and justified in conceptually divergent ways:

- *Decisionism*: In the view governed by a strict "division of labour", the normativity needed for societally relevant decisions is created directly and immediately through the political system [Schmitt, 1934]. It is therefore superfluous to advise political bodies. Such possible advising has to limit itself to a representation of the factual situation and to the provision of descriptive knowledge. This position (cf. Section 2.4.1) will not be explored any further in the following sections because it is held to be obsolete for the reasons explained above.

- *Values Research*: With social-scientific methods, the values currently prevailing in society can be empirically investigated (for the risk case see Slovic [1993]). These empirical results can then be used by politicians or engineers as a normative basis for technologically relevant decisions to pursue technological design in accordance with citizens' values.

- *Participation*: Evaluative criteria can be negotiated directly with those affected. Through participative procedures (cf. Sections 2.4.2 and 3.3), citizens with their values, preferences and interests, can be directly involved in the constitution of the evaluation criteria [Joss and Belucci, 2002].

- *Philosophical Ethics*: Normative ethics attempts to derive the criteria for judging alternative technical options from universal principles by taking, for instance, the categorical imperative or the utility maximization rule [Ferré, 1995; Mitcham, 1994; Beauchamps, 2001].

Precisely which of these approaches to including normative considerations should be brought into play remains controversial (e.g., Grunwald [1999]). The question of where the evaluative criteria should come from and how it can be justified leads to fundamental controversy between the normative approach of philosophical ethics and the empirical approach of social scientific values research. While ethics warns against a "naturalistic fallacy" [Moore 1905] and rejects the idea that an "ought" can be derived from an empirically observed "is", values research investigates the values represented empirically in society and sets out to derive orientation from exactly those empirical observations.

In this field of tension participation can be employed in various ways: participative procedures can be "informed" by research into values and by philosophical ethics. Procedures can alternatively be understood to be the implementation of discourse ethics. Discourse ethics and deliberative democracy [Habermas, 1988b] have been taken as a model for participatory TA [Renn and Webler, 1998]. With such an approach, no substantial values about acceptable or unacceptable technologies are assumed to exist but the recourse to discourse ethics suggests the presence of normative criteria indicating how the participation procedures should be organised. It is, for example, required that the processes be fair and transparent, that the participants commit themselves to providing arguments instead of to merely trying to persuade their opponents and that they are willing to question and to modify their own positions if there are good counterarguments. In this way, discourse ethics can offer orientation on the organisation of a "good" and just participative procedure [Skorupinski and Ott, 2000].

At present, the relationship between the descriptive approaches of values research and the normative approaches of philosophical ethics are held to be predominantly complementary and cooperative by many TA practitioners as well as by many practitioners in Applied Ethics. Accordingly, there are TA problems where one can derive the evaluative criteria empirically and other TA problems where that is not possible. The question that then arises is: When, in TA, is there an explicit need for reflection and when is empirical research sufficient? The answer to this question obviously depends on one's understanding of ethics. Inasmuch as ethics is seen as a discipline that reflects on empirically existing moral conceptions and so relevant at the precise moment when conflicts arise between divergent moral conceptions [Grunwald, 2000], the decisive criterion becomes whether a moral conflict has to be dealt with or not in a given TA project. The following requirements have been proposed to operationalise this abstract criterion [Grunwald, 2005]: *pragmatic completeness* (the current normative framework has to cover all normative aspects of the decision to be made); *local consistency* (there must be a "sufficient" degree of consistency between the normative framework's elements); *non-ambiguity* (between the relevant actors there must be sufficient agreement on the interpretation of the normative framework); *acceptance* (the normative framework must be accepted by those affected as the basis for the decision); and *compliance* (the normative framework has to be complied with in practice).

If all these conditions are fulfilled there is neither moral conflict nor moral ambiguity and so there is no need for ethical reflection. The normative framework can be used by TA as a basis for normative evaluation without the need for further ethical reflection. In such situations, it is possible to carry out *virtually descriptive* TA, in which the normativity that has to be considered is not in itself an object of reflection but rather something that is gathered empirically from the prevailing political circumstances. This is especially true of standard design process situations [van Gorp, 2005]. It becomes problematic as soon as the scope of these criteria is transgressed. It is a serious challenge to TA to recognize this point at all. To do this, there must be corresponding "awareness" of and competence in making ethical judgements.

3.2.2 The possibility to generalise on evaluative judgements

In its advisory capacity to society and to politics TA operates in the public sphere and must work towards results that are valid beyond a subjective or particular level. The question is whether, to what extent, and under what circumstances assessments of technological impacts can be generalised. Can TA support judgements in a generalisable way, and in what methodologically secure manner can that be done? Can the evaluative aspects of TA just be left to societal negotiation processes and do they, therefore, depend on power differences? It is first of all indisputably true that TA cannot posit that normative postulates or societal values are valid, nor declare them to be binding. TA cannot, accordingly, substantially decide whether the development and use of a technology is acceptable, desirable or even imperative. TA can only concern itself *conditionally* with certain normative principles in order to propose methodologically secure conclusions on this basis.

It can propose "if-then" statements in the following syntax: "If one applies certain normative criteria, then this has the following consequences or implications for this technological issue ...". The "if" antecedents cannot be declared valid by TA: that is society's responsibility in its legitimized procedures and institutions, informed and orientated in a normative fashion through ethical deliberation and consultation [Grunwald, 2003].

It is this *conditionally normative* structure of evaluations that makes general and intersubjective statements on assessment problems possible. It makes it clear that evaluations are not simply a function of individual, subjective normative decisions but that there are in fact possibilities for scientific (generalised) evaluations. It is, thus, the task of TA to make this structure transparent and comprehensible. A political evaluation or decision is by no means anticipated or even obviated by this; it is still the responsibility of political or other societal opinion-forming and negotiating procedures to decide on the validity of the "if" clause. The "if-then" nexus must, however, be acknowledged as a scientific proposition that is accessible to scientific cognitive interest and to scientific method. In this manner, TA can contribute to not leaving the elaboration of the normative aspects of the evaluation basis to chance – in other words, to random constellations of actors or power relationships – but to rather improving the comprehensibility and transparency of societally relevant evaluations through systematic critical appraisal and through conditionally normative judgements [Grunwald, 2003].

3.2.3 Multidimensional integration

The choice of technical solutions usually depends on a number of criteria (cf., for example, Section 2.5.6). These criteria, such as risks, costs or environmental aspects, are generally rather heterogeneous and in part incommensurable (cf. Ibo van de Poel's chapter in this Handbook). Depending on the facts of the case, they carry varying weight when it comes to arriving at an overall evaluation and they can conflict. One particular challenge is, therefore, that of aggregating the evaluations according to specific criteria in order to provide a comprehensive evaluation that can form the basis of a decision. It is often impossible to achieve this by projecting the criteria onto a uniform quantitative scale (of, for instance, monetary values) in order to solve the problem by, for example, quantitatively maximising utility. In this way, conflicts on technology, problems of legitimisation and the inherent normative problems would merely be concealed in the underlying quantification procedures (Section 3.2.4).

TA studies on sustainability aspects are especially challenging [Ludwig, 1997]. They are carried out with the help of life cycle assessments (LCA; cf. Section 3.3.3) in all the pertinent dimensions of sustainability: ecologically, economically and socially. Over the course of a life cycle, for instance, in the extraction of raw materials, transportation, processing, use and disposal, a wealth of diverse and incommensurable aspects relevant to sustainability come into play. A sustainability assessment would have to provide a complete balance of these very heterogeneous factors. It would be an integration problem of considerable complexity. There is an extreme risk of providing arbitrary results in these multidimensional integrations, because methodologically secure integration is hardly possible in such a "jungle" of heterogeneous and possibly contradictory evaluations.

3.2.4 Limitations of quantitative methods

In many fields of science, quantification is the means chosen to make objective statements possible. Inasmuch as an acknowledged normative measurement theory and a correspondingly acknowledged quantification method exist "quantitative" can, under such conditions, be equated with "objective". In the social sciences similar hopes are to some extent founded on methods of empirical social research. In this area such expectations also lead to criticism and to allusions to the fact that only selective knowledge of societal phenomena can be gained through quantification. Reference is then made to the dimensions of meaning, communication and understanding, etc. that resist quantitative compilation.

Quantification is very popular among politicians and in public administration. These actors hope that quantification will enable the subjective questions of evaluation to be "objectivised". The availability of numerical values serving, for instance, as evaluative notches on a ranking scale not only facilitates a practical approach to problems of evaluation but it also suggests a kind of objectivity: the evaluation is reduced to a mathematical operation. Criticism arises when one queries the actual significance of these "objective" statements. These quantified evaluation procedures are only objective and adequate under the condition that the "measurement rules" and the method of calculation of the evaluative figures are acknowledged as methods by those involved.

In TA very diverse parameters are quantified. These include, on a level still very close to technology, the emissions of technical processes into various environmental areas (water, soil and air). In questions of evaluation, economic (monetary) quantifications of the expected benefits or detriment and, using the quantitative version of the risk concept, the probability of a possible adverse occurrence are some of the most frequently quantified dimensions. However, the degree of acceptance of or resistance to technologies in the population, or other representative survey results is also quantified, as are the results of Delphi-sample surveys.

There are limitations to quantitative analysis though like, for instance, when data is not available or quantifying measures are disputed. The latter is encountered particularly frequently, and not just in compilations and evaluations of the social and cultural consequences of technology. Even quantifications of the effects of technology on the natural environment, for example, in the form of monetary values for damaged natural capital are controversial because the utility of such *external effects* is not estimated by means of a market-like supply-and-demand mechanism but only through market simulations, for example by the "willingness to pay" approach. Examples of such problems are questions concerning the monetary value of a rare species of toad or of a songbird in comparison to the expected economic utility of building a road through their biotope. The value of subjective well-being or of an aesthetically pleasing landscape destroyed by the construction of an industrial park can also only be quantified with reservations, or not at all. A number of evaluation methods have been developed which, despite these problems, arrive at quantifications by using some dubious substitutive considerations. One of these is inquiry into the *willingness to pay* on the part of the persons affected. Those potentially affected are for instance asked in view of the possible loss of an aesthetically valuable landscape how much they would be willing to pay in order to preserve that landscape. On the basis of that method, the personal preferences of those concerned are transformed into monetary values.

Methods of this type are controversial when compared to the methods employed in physics or chemistry. Attributing a monetary or utilitarian value to an impact of technology (to a benefit or damage) is not free of political and ethical questions (cf. van de Poel, this Handbook). The basis of quantifications in theoretical measurements is inseparable from preferences, values, norms, and their changes over the course of time, and this is what differentiates all social domains, not only economics, from the domain of the natural sciences. In the social domain quantifications are dependent on the normative assumptions that enter into the method of quantification. This is why in the field of technological impact quantification remains controversial and does not just simply supply the expected "objective" facts of the case. This is especially drastic when, for example, in the economic modelling of the effects of climate change monetary values taken from calculations in the insurance business are assigned to human lives. A quantitative assessment of human life and of the quality of human life obviously meets with ethical objections.

These limitations do not render quantification obsolete in TA. In many cases, quantitative approaches are absolutely crucial to the development of assertions that will stand up to debate. In life cycle analysis (Section 3.3.3), quantification is conducted to assess the environmental impact of technology. This is vital to achieving an overall balance when faced with effects that to some extent compete. In appraising risk (Section 3.3.1), quantitative risk analysis is also often very helpful. Despite the problems already mentioned, the result of quantification is often beneficial but this does not mean that the results are acknowledged as objective by all parties. For example, the debate on the better environmental compatibility of non-returnable as opposed to returnable packaging cannot be decided on the basis of quantitative analysis: instead the dispute switches to how one could adequately quantify and how the limits of the system could be determined (Section 3.1.2). If the results of a quantitative evaluation in a technological conflict are not accepted by a given party, it is often not difficult to attack the quantification rules. The results of evaluations are dependent on the quantification methods chosen. For this reason, the normative aspects of quantification methods must be made transparent. Only then can the results of quantitative evaluations be interpreted appropriately and linked to qualitative content. Quantitative evaluations do not stand up "objectively" on their own. In TA they often depend on the manner of quantification. Therefore they must be integrated into a *transparent frame of interpretation and deliberation*.

3.3 Assessment methods

For reasons of inter-subjective comprehensibility and transparency, TA evaluation must be conducted in a methodologically well-substantiated way. In individual cases this can be achieved through chains of painstaking justification like, for example, with the argumentation for a certain interpretation of a system's limits under relevant conditions. However, when evaluating technological impact, there are scientific methods that have been developed for the further "objectivisation" of evaluation in the political and public spheres in which TA operates. In the following section some relevant methods are briefly presented in which the specific focus lies on the discussion of the normative aspects of these methods.

3.3.1 Risk assessment

One of the main reasons for the emergence of TA was because of the risks directly or indirectly caused by technology and its use. Any decisions made on technology are also simultaneously decisions about risks and they are, therefore, dependent on *ex ante* estimations of these risks and on a readiness to accept them. The mere fact that in the present we take decisions on future hazards and living conditions testifies to the considerable relevance of this subject while revealing its societal sensitivity. TA should and does contribute to the early signalling of risks and to how they should be dealt with (Section 2.3.2). In this respect, TA embraces elements of an "early warning" system.

Dealing with technological risks has always been a facet of the development of technology. In order to meet safety standards and, for instance, to obtain public licensing, some proof has to be submitted. Technical risk analysis and risk evaluation methods were therefore developed. When risk is interpreted as the product of the probability of damage (i.e., the probability of the occurrence of an accident) and the extent of damage (expressed as a rule in monetary units), the assumption is that risk can be quantified and thus "objectified". This procedure makes it possible to carry out risk-benefit analyses prior to decision making (cf. Hansson in this Handbook).

These traditional procedures of risk assessment have, however, two intrinsic limitations (cf. Hansson's chapter on risk in Part V of this Handbook and [Shrader-Frechette, 1991]). Firstly, for many new technology risk analyses quantitative experience is lacking which means that the extent of damage cannot be properly quantified. If quantifications are nonetheless given, it is easy to dismiss them as arbitrary, subjective or ideological. In controversial fields of technology, such as nuclear power or genetic engineering, the expected objectivisation of technological risks to be achieved on the basis of irrefutable practical knowledge have not succeeded. Secondly, especially in the discussion about the hazards of nuclear power, it has emerged that this "objective" concept of risk was useless in cases of crisis because the affected public was not very impressed by the "objective" numerical values. Although atomic energy, according to technical risk analysis criteria, did not seem to be problematic, society refused to accept it, notably because of the perceived risks. This was a reason for integrating the social-scientific and psychological approaches to risk into risk analysis while devoting attention to the phenomenon of risk communication [Slovic, 1993].

Philosophical ethics, by contrast, stresses the role of normative considerations in determining the acceptability of risks and formulated corresponding principles, such as the principle of pragmatic consistency [Gethmann and Mittelstraß, 1992]. According to this principle, the acceptability of technological risk is proportionate to the risks which someone voluntarily accepts when choosing a lifestyle (like, for example, that of engaging in risky sport). It is considered to be irrational to reject technological risks if they do not exceed the risks voluntarily accepted. This approach, however, fails on at least two grounds [Grunwald, 2005]: firstly, there is no objective and value-neutral way of comparing categorically different types of risk, for example risks of technologies that do not serve the same ends; secondly, the technologically induced risk would be additional to other risks so an extra step of agreed acceptance would be required in all cases (other philosophical approaches are analysed by Hansson in this handbook).

What is completely different is Hans Jonas' "imperative of responsibility" [1984] which advocates that the use of technology is to be avoided if it is conceivable that the perpetuation of humanity could be endangered by such technology ("priority of the negative prediction", "heuristics of fear"). In this case, the judgement does not depend on probabilities of occurrence. This type of radical judgement of technological risks and similarly radical demands for relinquishment or withdrawal has not gained general acceptance. Standpoints like Jonas' would, of necessity, lead to a complete standstill since one can, after all, imagine a catastrophe for practically every innovation. Arguments that give priority to negative prediction do not permit distinctions to be made between more and less risky undertakings.

In view of the lack of knowledge about possible risks and to avoid being confined to a "wait and see" strategy, with all the dangers of catastrophe which that brings (cf., for instance, the history of asbestos, Gee and Greenberg [2002]), the precautionary principle has been introduced to European environmental legislation. It has been incorporated in 1992 in the Treaty on the European Union. The precautionary principle establishes a rationale for political action in case of highly uncertain knowledge and it substantially lowers the (threshold) level for action of governments. The following characterisation of the precautionary principle shows – in spite of the fact that it still does not cover all relevant aspects – the complex inherent structure of the precautionary principle: "Where, following an assessment of available scientific information, there is reasonable concern for the possibility of adverse effects but scientific uncertainty persists, measures based on the precautionary principle may be adopted, pending further scientific information for a more comprehensive risk assessment, without having to wait until the reality and seriousness of those adverse effects become fully apparent" [Schomberg 2005, p.

168]. At present this discussion is particularly centred on the possible toxicity of nano particles. The implementation of the precautionary principle requires a careful evaluation of the state of scientific knowledge and of the gaps in that knowledge, as well as a political decision about the level of protection required against potential risks. TA is concerned with providing advice about political action with regard to precautionary and uncertain problems.

3.3.2 Cost-benefit analysis

The assessment of technology or of measures for dealing with the impact of technology with regard to economic efficiency is a standard TA evaluation (especially in Health Technology Assessment, HTA). This especially affects the cost-benefit ratio of major public projects or the evaluation of the efficiency of research stimulation programs. Cost-benefit analysis is a managerial evaluation procedure which is occasionally also employed in TA (cf. Ibo van de Poel's chapter in this Handbook for more detailed explanation). It attempts to quantify and balance all the pertinent decision data — the costs as well as the benefits — in monetary units. Although in this calculation, "external effects" such as risks to human health or to the environment can be taken into account, the corresponding damage must ultimately be expressed in terms of monetary units (cf. Section 3.2.4 for the problems).

Technological projects have to be appraised early on with regard to their expected economic efficiency. This not only applies to technical products such as automobiles or mobile telephones but also indirectly to questions, for example, of traffic infrastructure, building construction or to large-scale technical projects such as dam construction. Cost calculations for technological products have to be made over their entire life cycle. They consist of the *development costs* (expenditure for the planning stage, the potentially necessary research work, design, the drafting and conducting of tests and, if necessary, the construction of a prototype followed by production testing), the *manufacturing costs* (production costs in the form of expenses for materials, energy and labour or staff employment costs, construction or adaptation of production facilities, quality control, preparation of manuals), the *operating costs* (energy and material requirements at plant level, expenses for monitoring, day-to-day operational tests, maintenance, repairs) and the *waste disposal costs* (possibly also the reserves needed for specific risks, for disposal as well as for the final deposition of spent fuel rods; provision for the realisation of liabilities for the taking back of, for instance, old automobiles or electrical equipment).

3.3.3 Life cycle analysis and ecological balances

Sustainability assessment technology [Ludwig, 1997] is not restricted to the operating life of a technology but extends to include the entire life cycle, including the input chains and disposal. The sustainability effects of a technological product can only be comprehended by means of a life cycle assessment (LCA). When evaluating technological impacts on the environment, the LCA approach has long since been established. Ecological balancing indicators of the environmental compatibility of, for example, products or facilities make it possible to compare various alternatives and find optimum solutions according to environmental considerations. A process chain can highlight ecological weak points and pinpoint the priorities for necessary change. The norm DIN EN ISO 14040 "Eco-Management — Ecological Balance. Principles and General Requirements" has been formulated as a framework for carrying out eco-balances. Despite the numerous methodological difficulties, the field of environmental policy and the evaluation of environmentally relevant processes cannot be envisaged without ecological balance. A recent development is the idea of including economic and social aspects in sustainability evaluations.

An ecological balance consists of the definition of its objectives, a resource balance, an impact balance and an evaluation. The definition of objectives includes determining the scope and goals of the investigation. The resource balance includes drawing up a material use and energy balance for each of the system's individual processes, examining the processes with regard to meeting environmental standards and aggregating the resource balance for the entire product line. "Product line" should be understood to mean a representation of all the relevant processes in the life cycle from raw material depositing to waste disposal site. The inclusion of transportation processes and energy consumption details may also be important in this investigation; this is decisive in the dispute on whether non-returnable packaging materials are more environmentally compatible than returnable packaging materials. In the impact balance, the materials and energies consumed in the product line are determined in relation to environmental categories and are weighted accordingly. The result is then evaluated in relation to environmental compatibility.

Ecological balances do not make it possible to ascertain absolute environmental compatibility; they merely enable comparisons. Comparisons made using this method must relate to products with the same specific purpose. The results are presented as aggregated data, in other words, they say nothing about real environmental effects in specific places at a specific time but present instead total environmental impacts over the entire life cycle. If these results are to be accepted in decision making, the ecological balances must conform to the usual methodological requirements of comprehensibility, transparency and consistency. If results are questioned, it must be possible to trace them back to the input information, assumed functional dependencies or premises. Agreement must first be reached on these parameters — typical of methods in TA — particularly with regard to the system limits to be observed (Section 3.1.2).

3.3.4 Decision-analytical methods

Decision-analytical methods are oriented towards the problem of the multi-dimensional integration of various evaluative criteria (Section 3.2.3, cf. also Ibo van de Poel, in this handbook). They are based on the evaluation of options according to various, initially separate, evaluation criteria and on their subsequent weighting and aggregation leading to a comprehensive evaluation. First, the (socio-)technical options to be assessed have to be selected. The evaluation criteria according to which the options are to be assessed then have to be formulated. Sufficient knowledge of the characteristics and effects of the options concerned is required. These parameters include, for instance, risks, costs and the possible side effects but also the expected gain or loss of utility. These "impact dimensions" must be quantified in the form of utility values for each option according to the various evaluation criteria. Finally, weightings for the criteria chosen have to be agreed upon so that the aggregation of the respective utility values can be calculated to provide a total utility for each dimension. Assuming that all of the criteria are functionally independent of one another and not redundant the best possible option will be the one with the maximum amount of "total utility". The total utility is the sum of the separate utilities, added up for all of the n criteria. The separate utilities, in their turn, are the products of the individual utility values multiplied by the weighting for the respective criterion.

Within the scope of this *utility analysis* (or *scoring method*) there are a number of different procedures such as the *multi-criteria analysis* or the *multi-attributive analysis* with further method refinement, for instance, with regard to the compilation and processing of the data. By means of fuzzy logic, attempts are made to accentuate "soft" and differentiated evaluations. Furthermore, minimum requirements can be laid down for each evaluation criterion; failure to meet such minimum requirement would then disqualify the option concerned, even if it had done well according to other criteria. In this manner, the reciprocal substitutability of positive and negative part evaluations can be restricted. The influence of the individual contributions on utility and the influence of the weighting criteria can be tested by means of *sensitivity analyses* so that the robustness of the results can be examined.

When applying these methods, the results depend to a great extent on the original assumptions. Uncertainties and estimates necessarily replace well-founded knowledge. The results also depend to a great extent on the weightings: by varying the weighting they can be altered. The risk of ideological abuse is very high. In view of these considerations, the notion of calculating a "total utility" might be generally doubted (Ibo van de Poel, this handbook). The total utility is a highly aggregated construct which might be viewed as an artefact with almost arbitrary values depending mainly on the aggregation procedure. In view of these limitations utility analysis is not so much an approach to the algorithmic determination of an "optimum" problem solving option as an expedient for bringing about transparency in complex decision-making situations. It indicates the consequences entailed in assuming certain (positive or negative) utilities and weightings and is, therefore, of elucidatory as well as heuristic value.

3.3.5 Consensus conferences

Consensus conferences are among the best-known participative TA procedures (Section 2.4.2). They have their roots in approaches of deliberative democracy and were first employed in countries with highly developed cultures of discussion and standards of deliberation and discourse. The fundamental issue is to consider the prerequisites required by a functioning democracy in which highly specialised expert knowledge is essential especially in questions of science and technological policy: " ... prior to all decisions an open (free of domination) and informed debate by all concerned is required. This debate shall secure a possibility for all concerned to express their opinions and to be heard" [Klüver, 1995, p. 45]. To this end, "an informed debate" should be conducted "between the lay and the learned" (p. 46). This is done in the following way: "A consensus conference is a chaired public hearing with an audience from the public and with the active participation of 10 –15 lay people" [p. 47].

This type of meeting requires considerable preparation: the relevant questions are to be clarified beforehand and the experts and participants are to be chosen. Lay participants are sought through advertising in newspapers. A selection of those interested is made that roughly represents a cross-section of the population in terms of age, gender, and educational and occupational background. The sampling of the participants involves declared readiness to participate and selection according to criteria of representation. Random sampling is, to a great extent, excluded. Participants may not be experts or stakeholders. When preparing the consensus conference, great importance is attached to imparting factual and specialist knowledge to the participants.

The actual consensus conference takes three days. First there is "relay-running by the experts", then there is a "cross-examination of the experts" and finally, the "presentation of the final document" [Klüver, 1995, p. 49ff.]. The first step in the procedures serves to determine the acknowledged state of knowledge and to reveal divergences in the experts' opinions. In the second phase the aim is to reveal the reasons for these divergences through "cross-examination". At this stage, at the very latest, discussions will arise on normative presuppositions and implicit premises. This is the most important phase with regard to the guaranteeing of transparency.

In Denmark, where consensus conferences were developed, they are established by law. Consensus conferences have covered a vast number of topics like, for example, on the matter of genetically modified food products (cf. [Klüver, 1995] for an overview). Some of them have even reverberated in parliamentary decisions: in 1987, after a consensus conference on the subject, parliament decided to no longer use public funding to sponsor genetic experiments on animals. These consensus conferences acted as a model for the Swiss "PubliForum" approach, operated by TA-Swiss. Experiments with international consensus conferences have also now been carried out in a multilingual European setting. The recent and ambitious "Meeting of the Minds" project concerned itself with the challenges of neuro science (see http://www.meetingmindseurope.org/).

3.3.6 Citizens' juries and variations

In the "Citizens' Juries" method, lay people are required to judge a technological decision-making problem according to "common sense". The members of the jury act as an independent committee which pronounces a well-balanced recommendation committed to "public interest" after hearing expert witnesses, persons affected and the stakeholders. These approaches provide assessment and judgement involving independent citizens which serves as advice for decision-makers.

The "Planning Cell" can be seen as a specific type of citizens' jury. It was developed at the beginning of the 1970s and is, therefore, one of the earliest participative procedures. It is mainly employed in municipal decision-making processes, for instance, for urban and traffic planning. The basic idea is that 25 randomly chosen citizens make themselves so familiar with the problem in hand over a four-day period either collectively or in small groups that they can understand and judge the possible solutions. In order to attain a greater overview, a number of planning cells are organised to deal with the same problem. Their results are summarised in a citizens' expertise group. It is expected that in that way, socially acceptable and practicable recommendations will be acquired that are in the public interest. On the level of the individual participant, a strikingly high planning cell "event value" is acknowledged that is to say, the impression of being included in processes relevant to decision-making and of thereby being taken seriously as a citizen. On the societal level, a move towards more learning ability and towards a recapture of the role of the sovereign by the citizens is hoped for.

3.3.7 Mediation and arbitration

Mediation and arbitration are negotiation-orientated procedures designed to peacefully and consensually settle conflicts with the help of a neutral party (mediator, arbitrator). They usually derive from existing conflicts which the disagreeing parties are unable to resolve constructively without external help. The common interest of the parties in conflict is presupposed in a consensual and extrajudicial agreement. According to the "Harvard Model" [Fisher and Ury, 1988], it is assumed that the deadlocked positions can be loosened by revealing the parties' "real" interests before being transformed into "win-win" situations. Here, compensations agreed upon through negotiations play an important role.

Mediation procedures can also be employed preventively, in order to avoid matters escalating. Attempts are now frequently made to gather the potentially conflicting parties round a table in the preparatory phase of decisions on, for example, where to locate technical facilities, in order to effect understanding with the specific opponent before taking measures to de-escalate impending conflicts. In the end, it is a question of establishing a situation in which both sides have advantages or can partially realize their objectives.

The role of the mediator is to break down existing blockades in communication, initiate a process of settlement and supervise it. The conflict solution is not decided by the mediator but has to be discovered by the parties in conflict under the mediator's guidance. The requirements for a good moderator are: strict neutrality in the case in question, sufficient technical competence, a knowledge of the legal regulations and provisions, competence in dealing with groups and individuals, communicative skills and practical experience of moderating discourse, orientation to public interest and social respect. Since 1973, such procedures have been practised in different variants in the U.S. in relation to environmental issues and have to some extent become integrated into the law as an alternative to judicial conflict solutions.

In TA technological conflicts involving a limited number of actors and a precisely defined problem seem to be the appropriate fields for implementing mediation procedures. Such conflicts particularly revolve around location problems focused on the just and acceptable distribution of risks, damage, and the utility of large-scale industrial facilities such as airports, power plants, waste disposal sites, or chemical processing plants. Such NIMBY ("Not In My Back Yard") problems are, as a rule, local or regional and tend to be characterized by a specific planned event, by extreme intervention in the life and environment of the local residents or by a mixture of various interests.

3.3.8 Vision assessment

Quite often, as with the emergence of nanotechnology, visions and metaphors mark the revolutionary advance of science in general and act as an important factor in societal debates. Such visions have not yet been analysed comprehensively by TA. Preliminary analysis already has shown that futuristic visions are ambivalent: they may cause fascination as well as concern and fear. The main argument for requiring early vision assessment is the importance of visions in actual debates, that is, both in the debate on the opportunities afforded by scientific and technological progress and in ongoing risk debates. To provide for more rationality, reflexivity and transparency in these debates, vision assessment should also consider values [Grunwald, 2006a; 2007a].

Vision assessment is a new TA tool that is not directed at the assessment of technologies but at the assessment of visions which are communicated in the societal environment of technology [Grin and Grunwald, 2000]. The fields of nanotechnology and all the other converging technologies are currently being subjected to broad discussion [Grunwald, 2006a; 2007a]. Vision assessment can be analytically divided into vision *analysis* – which is itself subdivided into a *substantial* aspect (what is the content of the respective vision?) and a pragmatic aspect (how is it used in concrete communication?), vision *evaluation* (how could the content of the vision be evaluated and judged?), and vision *management* (how should the people and groups affected deal with the visions?).

Vision assessment includes normative elements, like the questions of how the cognitive aspects can be categorised, how they can be judged according to a degree of realisation or feasibility, according to plausibility and evidence [Pereira *et al.*, 2007], and what status the normative aspects have, for example, relative to established systems of values or to ethical standards. The general aim is to achieve a transparent disclosure of the relationship between knowledge and values, knowledge and the lack of it and the evaluation of these relationships and their implications. In particular, vision assessment should allow the various and, partly divergent normative aspects of visions of the future to directly confront each another. This can be achieved through ethical analysis and desk research. In addition, the stakeholders should discuss their differing judgements in workshops directly with each another in order to reveal their assumptions.

3.4 Normative backgrounds to assessment methods

The TA methods presented above differ in several respects: they are relevant at different stages in the TA processes, require different types of data, offer different types of knowledge, and (as will be discussed below) differ with respect to their normative premises.

The various TA methods (or families of methods) are usually applied in specific situations and in the context of specific TA approaches. Approaches such as participative TA or innovation-orientated TA adopt a specific view on technology, on society or on decision-making procedures:

- Cost-benefit analysis and MCDA are tied to the utilitarian decision-making calculus. They share essentials of utilitarianism like the reduction of different criteria to monetary values and the principle of maximising utility. This category also includes quantitative risk assessment aimed at minimising risk.
- Life cycle analysis (LCA) relies, in part, on ecological ideas about the environmental compatibility of industrial or other economic processes.
- Sustainability assessments bring the idea of (intergenerational and intragenerational) *justice* [Rawls, 1999] and *equity* into the arena of technological development [Grunwald and Kopfmüller 2006] .
- Types of participative TA, such as consensus conferences, usually work on the basis of normative ideas about deliberative democracy and discursive ethics [Habermas, 1988b; Renn and Webler, 1998], in which persons in positions of responsibility and interested citizens all share normative ideas, which are often very close to the ideas of civil society.
- Mediation approaches work with "checks and balances" and aim at mediating diverging interests, for example, by creating compensation strategies without giving priority to ethical principles.

Two essential points have to be recognised in each concrete TA process and in TA theory as well. First of all assessment methods are not, as has been shown, value free. Normative premises and presuppositions are usually involved in the selection of specific TA methods, whether directly or because the application of a certain method is often related to normative and conceptual assumptions. For example, there is a close relationship between cost–benefit analysis and the utilitarian decision-making calculus. In order to meet the goals of TA and to avoid biases it is, therefore, indispensable to apply a high degree of reflectivity with respect to such normative elements of TA methods and to establish a maximum degree of transparency in this regard.

Secondly, what can be learned from this analysis (and what has been supported by TA experience in the past decades) is modesty in terms of the expectation that TA should be able to reduce decisions about technologies and their societal environment to algorithm-like methodical procedures. In contrast to such expectations it has been shown that methods do involve normative aspects. By applying TA methods, various kinds of data can be collected, aggregated and evaluated for the purposes under consideration. Transparency can be strengthened and arguments can be supported by methodically guided research. But such activities cannot replace the very political and ethical nature of far-ranging technological decisions; they can only inform and orientate them. Decision-support systems — and TA may be seen as a specific kind of decision-support tool — they do not replace decisions but they rather *support* decision-making.

4 CURRENT DEVELOPMENTS AND FUTURE CHALLENGES

TA is context dependent with regard to the various topics, target groups, backgrounds, and fields of technology. Changes in context (the general societal and political setting, the roles and constellations of the relevant actors, processes of opinion formation and of decision-making) therefore have direct effects on TA's options for meeting its responsibilities. TA therefore has to observe the changes in its environment and react to them conceptually. In other words it has to actively reflect these changes in its own conceptual self-understanding. Current developments in societal, political and scientific contexts that are highly relevant to TA are:

Globalization: Until recently, TA's target group in technology, research, and innovation policies were primarily institutions within nationally or regionally orientated decision-making structures. Economic, but also political and technological globalization has changed this situation. The fact that the impacts of technology have no borders has long since been acknowledged. Globalization, however, also affects technological development, diffusion, and application. Technological design takes place today in worldwide networks. Examples are Open Source software and the Human Genome Project, or nano(bio)technology. The use and diffusion of technology is also becoming increasingly global. Electric power supply networks have long since grown beyond the political boundaries of national states. In the promotion as well as in the regulation of technology, important decisions are shifting to levels of higher aggregation, that is, from the national to the European level. The influence that regional "cultures" have on how technology is dealt with is decreasing, just as the leeway of the classical national states is shrinking. TA has to find ways of dealing – conceptually and methodically, but also strategically – with globalization and with new constellations. If it does not, it will be threatened by provincialisation and loss of importance. TA is challenged to organise itself internationally, to conduct the corresponding knowledge transfer, to contribute to the development and use of new governance structures and to set cultural and intercultural TA on the agenda. TA has to operate more actively than it has up until now on a supranational and, if required, a global level, and advise a correspondingly multilevel policy in the scope of a "global governance".

The Knowledge Society: The methods of production, the access to and the distribution of the means of utilising knowledge are affected by the development of a "knowledge society". Driven by the spread of information and communication technology, the importance of knowledge is growing in economic, social and political respects. Knowledge policy and knowledge management are becoming new societal domains [Stehr, 2004]. Actions and decisions will be increasingly substantiated and legitimised by scientific knowledge. At the same time, however, the founding of societal decisions on knowledge necessarily generates risks due to uncertainties of the knowledge, even to the potential self-endangerment of society. This exacerbates the situation of contingency in the *human condition* [Grunwald, 2007a].

Sustainable Development: The guiding principle of sustainability is that it demands a research and technology policy that fosters sustainability. For TA, this is significant in at least two respects: On the one hand much prospective knowledge on the consequences of new technological innovations for sustainability is needed, which (a) covers the entire life cycle of the technology and its components and (b) is not only ecological but also concerned with all of the dimensions of sustainability [Grunwald, 2007b]. On the other hand, this quite considerably increases the expectations placed on an "integrative" assessment of the impacts [Ludwig, 1997].

Backcasting approaches: In the last years backcasting approaches have regained importance, especially concerning sustainable development. For example, transformation management which currently is a frequently used notion, operates by defining desired futures and deriving measures and strategies which should be implemented today in order to reach the desired future states.

Foresight Exercises: there have been many (technology) foresight exercises in the past 15 years (for definitions of foresight cf. [Coates, 1985] and [Martin and Irvine 1989]). In particular the European Union has supported many such exercises, mainly in the field of regional foresight [FOREN, 2001]. Foresight activities have a lot of parallels with TA but are more explorative, emphasise the social effects (such as mobilising people in a regional or building network) and do not focus on normative assessment.

New Technologies: Changes and shifts of emphasis can be discerned in the characteristics of current scientific and technical innovations. It is no longer the traditional problems of large-scale facilities that is central but rather the development — as seen in nanotechnology and information and communication technology, all of which have culminated in the notion of "converging technologies" [Roco and Bainbridge, 2002] — leading to increasing integration and to the creation of ever more interfaces. As a result, decision-making processes are becoming increasingly complex. The future pace of technology is determined by the integration of developments from originally separated areas, rather than by individual innovations.

The Importance of Social Questions: The role of technology in society is less and less determined by the *technical* feasibility of products, processes or systems. Much that is technically feasible and that has also been realised and brought onto the market, is founded on societal embedding (as innovation research has shown), on economic aspects, on a lack of societal acceptance or on insufficient adaptation to existing technology (like with Transrapid, for example). Customer acceptance, or the lack of it, occasionally leads to unexpected turns — as, for instance, with the question of genetically modified food products in Great Britain, and currently with the question of whether and when UMTS mobile phones will be accepted on the market. Here, new interfaces between innovation research, the cultural sciences and TA are being opened up.

ELSI studies: In the last few years a new type of TA-related activity has emerged. ELSI or ELSA studies (ethical, legal and social implications/aspects) have been elaborated in some emerging fields of new technologies, mainly in the area of nanotechnology. Such activities are more selective in their scope than classical TA and they are often not directly aimed at decision makers but intend to broadly inform the interested public. In a methodological and normative sense, however, there are great similarities with established TA.

The Future of Human Nature: Converging technologies from the fields of nanotechnology, biotechnology, information technology and the cognitive sciences (NBIC, cf. Roco and Bainbridge [2002]) will enable humankind to improve human performance, at individual as well as at collective level. Emerging ethical questions [Habermas, 2001] as well as the potential for innovation and advance will be prominent topics for TA in the next years.

The history of TA can be recounted as a history of experimenting with concepts and of learning by testing or deducing from relevant conceptual debates. To date this might have been done rather sporadically and against the background of practical pressure. If that is so the time now seems to have come to take a look at the "whole" spectrum of TA and to develop a theory of TA which does not yet exist (tentative steps were taken in this direction in TATUP [2007]). A theory of TA can only be a theory of learning about TA and therefore a theory of reflection on TA *on the basis of its relationship to practice.*

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