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TECHNOLOGY ASSESSMENT IN ENGINEERING PRACTICE. THE CASE OF BIOLIQ® – FUEL PRODUCTION FROM BIOMASS

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Abstract:
This paper includes a brief overview of the basic motivations and objectives of TA, followed by a description of the three main operating fields of TA: providing scientific advice for decision-making in the political system, contributing to public debate, and enriching technology development and engineering practice. These issues will then be considered in more detail by referring to various approaches to the relationship between TA and technology development and by presenting a specific case study of an accompanying TA process over various development stages of the bioliq® process for converting dry biomass into fuel (Biomass to Liquid) and chemicals.
The accompanying TA work on the bioliq® process can, as a result of more than ten years of experience, be considered a successful technology assessment as it has opened up a new research field with a highly precautionary aspect on the one hand, and helped to win over technology-oriented research institutes to reorienting their research work, on the other. The results of the TA studies allowed to assess e.g. the competitiveness of the bioliq® process at a very early stage. The mutual trust built up in the course of the historical development between the parties involved has always been essential for this ongoing accompanying TA process. TA has been proven, in this way, a useful tool to uncover new chances for engineering research and development, and to accompany the research process.

Key words: *Technology Assessment, energetic use of biomass, process chain analysis*

INTRODUCTION

Technology Assessment (TA) emerged in the 1970s as a research-based policy-advising activity [12]. In its first period, technology was considered to follow its own dynamics (technology determinism) with the consequence that the main task of TA was seen in functions of early-warning against risks and early recognition of opportunities. The objective was to enable political actors to undertake measures to, for example, regulate or promote technology. Since the focus was on policy advice, technology development at the engineering level was not addressed.

This situation changed from the 1980s onwards. Following the emerging social constructivist paradigm, the slogan of "shaping technology" became popular in the TA community [3]. In particular, the approach of Constructive Technology Assessment (CTA) was developed [30]. TA as a contribution to technology development and engineering has since then been part of the overall TA portfolio [33], in particular with respect to sustainable development [1]. This portfolio covers the whole spectrum from the political, e.g. parliamentary, level far away from concrete development up to specific intervention in engineering, design and development at the level of R&D programs and concrete projects (see Sec. 3).

In this paper, we will give a brief overview of the basic motivations and objectives of TA including a description of the three main operating fields of TA (Sec. 2). These issues will then be considered in more detail by referring to various approaches to the relationship between TA and technology development (Sec. 3) and by presenting a specific case study of an accompanying TA process over various development stages of the bioliq® process for converting dry biomass into fuel (Biomass to Liquid, BtL) and chemicals (Sec. 4).

TECHNOLOGY ASSESSMENT – BRIEF INTRODUCTION

While in its first period TA was considered to solely consist of research-based policy advice, in particular to parliaments such as the U.S. congress [4] and the German Bundestag [15], new and additional motivations have entered the field of TA over the past decades, leading more and more to a shift towards "shaping technology" according to social values and ethical norms.

In the past decade, the issue of innovation has influenced also motivations and driving forces of TA, which is increasingly expected to contribute to "responsible innovation" and "responsible development" [31] by assisting and, perhaps, enabling technology development and engineering practices in order to take into account not only technical and economic but also ecological, social, cultural and ethical aspects.

Against this background, Technology Assessment consists of research on possible consequences and impacts of technology on society and the environment and is to contribute to processes of decision-making and opinion-forming on technology [12, 13].

TA is intended to have an "impact" [10] on the governance of technology by addressing different target groups at different levels, such as political decision-making, public debate, and industry and engineers (see below). Achieving this requires close cooperation with the addressees in the fields of politics (2.1), the democratic public (2.2) and the engineering practice (2.3) which is in the focus of this paper.

Technology Assessment for policy advice

The undoubted fact that technology and innovation development mainly takes place in the industry under market conditions does not exclude or diminish the relevance of political influence on technology [13]. We can distinguish between different aspects of technological products or systems: public aspects bound to political reasoning (environmental norms, safety regulations, technical standards, general statutory provisions, etc.) and aspects related to market developments and consumers behavior. Policy-advising TA only covers technology aspects which are subject to public policy-making, like safety and environmental standards, the setting of priorities in research policy, the definition of framework conditions for innovations, etc.

Policy-advising TA operates at different levels of the political system, with addressees either in the executive or in the legislative branch. Many TA studies are commissioned by ministries and authorities or, at the European level, by the European Commission. They often address issues of research policy, shaping of research and technology funding programs, regulation and foresight, and investigate the impact of scientific and technological advance on various fields of policy-making such as security, environmental protection, health and mobility.

TA as parliamentary activity was first established at the U.S. Congress at Washington DC [4]. It has now a tradition of decades with diverse forms of institutionalization [6]. Its aim is to advise parliamentary actors such as members of parliament and parliamentary committees and to contribute to parliamentary deliberation processes, e.g. by providing studies and organizing hearings.

An example is the Office of Technology Assessment at the German *Bundestag* [15, 28]. It was founded in 1990, and has become a permanent institution of the German legislature. Since 1990, it has been staffed by the Institute for Technology Assessment and Systems Analysis (ITAS) of the Karlsruhe Institute of Technology. The 20th anniversary of TAB was celebrated in 2010 in a ceremony conducted by the President of the *Bundestag*.

The subjects of the TAB's studies cover all fields of technology but are dominated by "classical" TA subjects, such as technology and the environment, energy, and bio- and genetic engineering. In particular, the German shift in energy policy (*Energiewende*) after the Fukushima disaster has renewed parliamentary interest in energy issues.

In many European countries, similar organizations have been established which carry out TA studies on behalf of parliaments. Together they form the European Parliamentary Technology Assessment (EPTA) network. The network was founded in 1990 and has now 16 members including e.g. TA institutions from France, United Kingdom, Denmark, Switzerland, Norway and Italy. The Bureau of Research at the Polish Parliament Sejm is an associate member.

Technology Assessment in public debate

A number of serious acceptance problems and conflicts about technology in the past decades have shown that the question of legitimization is obviously important. There are many examples of this, such as opposition to nuclear power, disputes about the expansion of airports and establishment of new infrastructure elements such as highways or railway connections, the problem of nuclear waste disposal, the release of genetically modified plants, as well as regional and local conflicts about waste disposal sites, waste incineration plants, and the location of chemical processing facilities. In these areas, political decisions are sometimes not accepted by those affected or by the general public, even though they are the result of democratic decision-making procedures. Conflict regulation and prevention are of highest importance and have been subject of TA since the 1980s [21].

TA has, in this context, repeatedly pointed out the need for *participative orientation*, frequently following normative ideas from the fields of deliberative democracy [2]. According to these normative ideas, assessment and evaluation of technology should be left neither to the scientific experts (expertocracy) nor to the political decision-makers (decisionism) alone but should involve a broader public debate. Participative TA is to include societal groups – stakeholders, affected citizens, non-experts, and the public in general – in deliberating and assessing technology and its consequences. In this manner, participative TA procedures are deemed to improve the practical and political legitimacy of decisions on technology [18].

The participation of citizens and of those affected is believed to improve the knowledge basis as well as the norms and values on which assessments are based. "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. Furthermore, it is necessary to take the interests and values of ideally all those participating and affected into consideration in the decision-making process. In the end, this shall improve the robustness of such assessments and decisions and enhance their legitimacy. Several approaches and methods have been developed and applied in the recent years, such as consensus conferences, citizens' juries, and focus groups [18].

Technology Assessment in technology development

The value dimension of technology has been demonstrated in many case studies, especially in engineering design processes [29]. In this respect there is a close relationship between TA on the one side and engineering ethics on the other. This observation motivated, for example, the Association of German Engineers (VDI) to engage itself in issues such as technology and society, responsibility of engineers and a code of conduct. The most prominent outcome of these activities is the VDI guideline no. 3780 (VDI 1991, also available in English) on Technology Evaluation (Technikbewertung) which has become relatively well-known in the German-speaking world. 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 assessment and evaluation is its scope. It goes beyond technical and economic criteria and also includes social and ecological dimensions of impacts. 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).

The values identified by VDI shall be involved in processes of technology development, in particular in technology design and development. They shall materialize themselves in the technology. Engineers or scientists should, on the basis of their knowledge and abilities, influence the development of technology in a direction given 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 at political or societal level. However, VDI did not put much attention on how to make this approach work. Therefore, the approach is well integrated in education of engineers at some technical universities but has not had much impact on concrete development yet.

More intensive consideration of how to make TA operable was undertaken by the "Constructive Technology Assessment" (CTA) approach. Its overall aim is to enrich technology development by looking at the development process of technologies and include social values in close cooperation with engineers. The basic assumption in CTA is that TA encounters difficult problems of implementation and effectiveness whenever it concerns itself with the impacts of a technology after the latter has been developed or even is already in use [30]. CTA aims – assuming this to be more effective – at accompanying the process of the development of a technology constructively. CTA argues for the early and broad participation of societal actors, including key economic players, users and people affected in these early stages. It has been applied to a great variety and number of different technologies so that a huge body of experience exists [30].

TECHNOLOGY ASSESSMENT IN PRACTICE

Conducting Technology Assessments (TA) during technology development is a complex process. On the one hand, the minimum requirement of this analytical tool must be adhered and, on the other, the budget and time frames set for performing such analyses are usually very tight. Technology Assessment studies – often carried out in the form of accompanying systems analysis – are therefore always a compromise between the theoretical model of the tool and the practical feasibility [24]. Questions regarding the client's interests and exertion of influence, the methodology of approach and concept, the involvement of expert knowledge up to the evaluation of results and their presentation and communication are of central importance here [10].

Whether and when engineers are interested in a new technology or subject and the corresponding results of a TA mainly depends on two aspects: on the one hand, on whether this field of technology is *principally* of interest to the engineer; on the other, on whether he or she expects his or her technology-related work to profit from the accompanying TA and its results.

The situation for integration of TA in the engineering sphere is particularly favorable when TA is able to raise the engineers' interest in new technological issues or even in a completely new field of technology. However, given constant time and financial resources, this also requires the engineers' willingness to partly or completely abandon technologies or research areas pursued before. The decision to abandon technologies and subject areas which are no longer considered viable is often driven by changing political conditions. A typical example is the politically imposed nuclear power phase-out and increased promotion of renewable energies in Germany (see Sec. 4.2). This has, among others, stimulated interest in using biomass for energy, e.g. for fuel production.

From the engineers' perspective, the main value of TA, besides identifying new fields of technology and subject areas, lies in the accompanying systems analysis. For example, already in the design of a production process, the analysis of mass and energy balances can provide hints for optimizing the layout. However, especially the systems analysis on transferring this production process to a large-scale production plant provides information about market perspectives of such process or product at an early stage. Besides techno-economic aspects, environmental and social issues also play an important role, e.g. potential contribution to reducing greenhouse gas emissions and acceptance of new technologies or products by the public or the consumer.

It is obvious that, in its early stage, accompanying systems analysis has to deal with a high degree of uncertainty. By systematically considering results from laboratories and the subsequent pilot or demonstration plants, these uncertainties can be successively reduced. This close interrelation between engineering and systems analytical work shows that a high level of cooperation is decisive for the success of TA in shaping technology. The necessary basis of trust must be established by the persons involved.

In the following section (Sec. 4), the **bioliq® process** is used as an example to describe the experience with the systems analytical work of a TA gained by ITAS in the course of the technical development and demonstration of a process for fuel production from dry biomass.

CASE STUDY: THE KIT BIOLIQ® PROCESS[1]

Against the background of political demands for expansion of the use of biomass as energy source, the Karlsruhe Institute of Technology (KIT), together with industry partners, is currently developing the bioliq® process [5]. The process is being tested in a pilot plant and is planned to be scaled up to an industrial level. It is an innovative biomass-to-liquid process which allows efficient thermochemical conversion of high-ash biomass into synthesis gas as feed for the production of synthetic fuels of the second generation or of basic chemicals. The two-step procedure is based on a combination of several regionally distributed, decentralized fast pyrolysis plants and subsequent gasification of the pyrolysis intermediate at a large centrally located gasification/synthesis plant.

Description of the bioliq® process

As illustrated in Figure 1, dry residual biomass such as cereal straw or forest residues, so far largely unused, is supplied to a decentralized pyrolysis plant.

[1] Note: The Karlsruhe Institute of Technology (KIT) was founded in October 2009 by a merger of Universität Karlsruhe and Forschungszentrum Karlsruhe. Though the development of the bioliq® process was decisively driven by Forschungszentrum Karlsruhe (now KIT, Campus North), we will in the following only speak of KIT for the sake of simplicity.

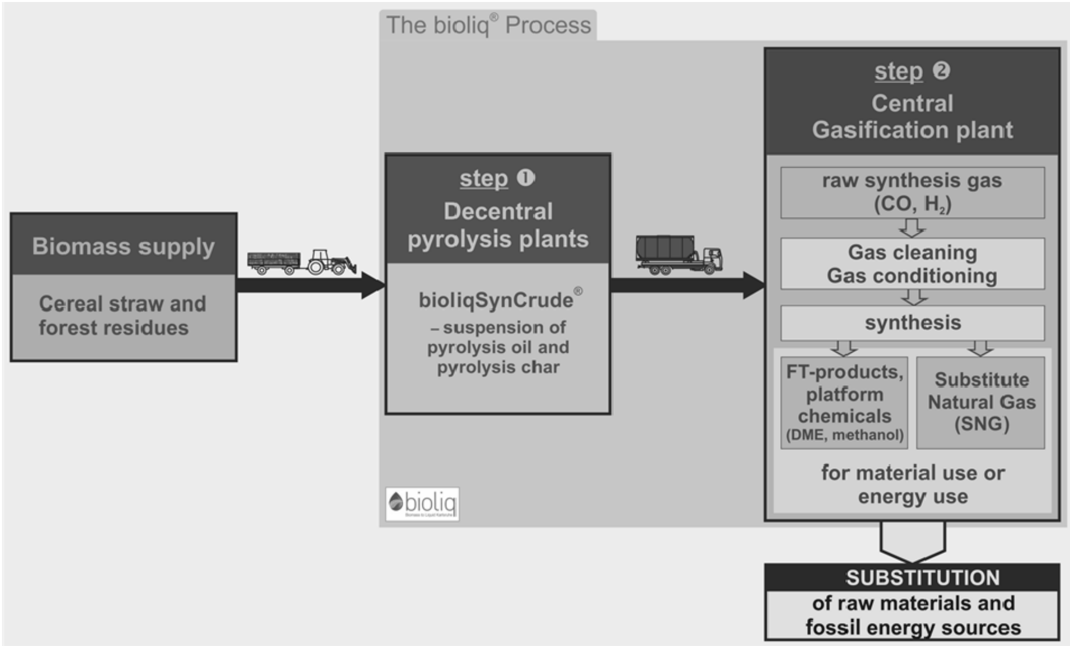

Fig. 1 Schematic diagram of the bioliq® process
Source: [5]

In the first process step (step 1) the fast pyrolysis, high-ash biomass is converted in the absence of air into a crude oil-like suspension of pyrolysis oil and pyrolysis coke, the so-called bioliqSynCrude®. Subsequently, this pumpable and storable high-energy intermediate is transported to a central gasification plant. A special logistic advantage of this procedure is that the volumetric energy density of the intermediate is increased by a factor of 10 compared with untreated biomass. In the second process step (step 2), the bioliqSynCrude® is atomized with oxygen in a high-pressure entrained flow gasifier and converted into a tar-free raw synthesis gas. After cleaning and conditioning of the raw synthesis gas, the production of fuels, basic chemicals or methane (SNG) takes place, depending on the realized synthesis route. These substances can be used as raw materials or to produce energy, with the ultimate aim of substituting fossil energy sources [22].

Historical development

An essential starting point for the development of the bioliq® process was the comprehensive study "Technikfolgenabschätzung zum Thema Nachwachsende Rohstoffe" (Technology Assessment on Renewable Raw Materials) carried out by ITAS [32]. Based on the results of this Technology Assessment, ITAS stated the need to install a test plant in order to accelerate technology development for the use of fuels derived from plants. This should focus on comparative investigations on combustion/gasification technologies under development for production of biofuels for energy, including the necessary technical infrastructure. At that time, it had already become clear that the use of biomass for energy in Germany was likely to be increasingly supported by government policy and should therefore also be included in the medium and long-term R&D strategies of KIT.

In 1995, the KIT working group "Use of Biofuels for Energy" was founded in cooperation with six institutes of the KIT, including ITAS. The aim of the working group was to conduct a market analysis on straw gasification in order to precisely define the necessary preparatory R&D work and prepare decisions on the type and size of the planned pilot plant for gasification of straw. As the majority of the technical institutes involved were in a "phase of reorientation" (cf. Sec. 4), they were very interested in the innovative topics of "gasification" and "chemistry in energy technology" as longer term research topics. Based on the results of the study "Marktanalyse zur Strohvergasung" (Market Analysis on Straw Gasification), carried out under the leadership of ITAS in 1997, the R&D Committee of the KIT recommended to deal with the topic of straw gasification in a separate project of the R&D program. However, prior to the construction of a demonstration plant for straw gasification at the KIT, the required expertise should be developed and deepened through respective qualification work.

Very helpful for the qualification work to be carried out was the approval of the externally funded project "Gas Production from Biomass" by the Federal Ministry of Agriculture of Baden-Wuerttemberg (MLR) in 2002. Its starting point was a project outline prepared by ITAS. The aim of this project was to carry out preliminary scientific work for the construction of a 1-2 MW gasification plant at KIT for the pyrolysis and gasification of residues and waste from agriculture and forestry. In the course of the project, a pilot plant (30 kW_{th}) for the pyrolysis of biomass and for feeding a high-pressure gasifier was built and key issues regarding the subsequent construction of the bioliq® pilot plant were explored. Furthermore, the gasification of bioliqSynCrude® was, for the first time, successfully demonstrated at a converted test plant in Freiberg, thus confirming the bioliq® procedure followed [16].

In 2005, construction of the first stage (= fast pyrolysis) of the bioliq® pilot plant (3 MW_{th}) started. The installation of the high-pressure entrained flow gasifier (5 MW_{th}), hot gas cleaning system and synthesis unit was completed at the end of 2011. After the functional tests, the plant was put into operation in 2012 [7]. The pilot plant has been planned, installed and operated together with for industrial partners [8, 9]. So far, a total of about EUR 60 million have been invested in the bioliq® plant at KIT/Campus North

[34], funded by the German Federal Ministry of Food, Agriculture and Consumer Protection (BMELV), Lurgi (Air Liquide) and KIT. The progress of plant construction can be followed on the bioliq® website [5].

The pilot plant is expected to supply up to 50 liters of fuel per hour in a partial flow as of mid-2013 [11]. Whether this ambitious target will actually be achieved already in 2013 is more than doubtful. The vision of this process development in pilot scale is a commercial plant with an annual production of 1 million tons of fuel.

Systems analyses performed on bioliq®

As mentioned above, the continuous technological development of individual process steps of the KIT pilot plant was accompanied by a number of systems analyses. The focus was always on TA-specific issues, e.g. availability of the required biomass, environmental impacts or cost-effectiveness of the process. The main analyses – sorted according to the individual bioliq® process steps (cf. Fig. 1) – of the accompanying research performed at ITAS in order to answer these questions from the TA perspective are listed below:

– *Systemanalytische Untersuchung zum Aufkommen und zur Bereitstellung von energetisch nutzbarem Reststroh und Waldrestholz in Baden-Württemberg* (System analysis on the volume and supply of energetically usable remnant straw und forest residues in Baden-Württemberg) [19]: The study examined the amounts of forest residues and cereal straw available in the individual municipalities in Baden-Württemberg. In addition, the costs for collecting these energy sources and providing them at selected sites for bioliq® pyrolysis plants were investigated.
– *Systemanalytische Untersuchung zur Schnellpyrolyse* (Systems analysis on fast pyrolysis) [23]: The study focused on technical and economic evaluation of fast pyrolysis – by then the least investigated process step of bioliq® on a commercial scale. The study addressed technical questions and developed learning curves and energy balances which are of particular importance for the commercial implementation of fast pyrolysis.
– *Kraftstoff, Strom und Wärme aus Stroh und Waldrestholz* (Fuel, electricity and heat from straw and forest residues) [24, 27]: This scientific report includes a detailed description of the technical state of the art of gasification, gas cleaning and Fischer-Tropsch synthesis. Furthermore, the specific advantages and disadvantages of the bioliq® concept were identified und compared to competing alternatives of heat and power generation.
– *Systemanalyse zur Gaserzeugung aus Biomasse* (Systems analysis on gas production from biomass) [25]: In this scientific report, the following selected aspects of the bioliq® process were analyzed in detail: available biomass resources and process chains of biomass supply, the process for feeding biomass to a high-pressure gasifier and comparison of processes for using synthesis gas to produce Fischer-Tropsch fuel and methanol.
– *Perspektiven für Bio-Erdgas* (Prospects for bio natural gas), Part I and II [20, 26]: Part I of these publications of BWK Das Energie-Fachmagazin examined the possibilities of bio natural gas production. Part II addressed the use of bio natural gas for heat, electricity and fuel supply. To this end, the techno-economic perspectives of producing SNG (Substitute Natural Gas) via biogas and thermochemically produced raw gas were analyzed. The latter can, in particular, also be supplied by the bioliq® process (cf. Fig. 1).
– *Techno-ökonomischer Vergleich des Einsatzes von Strom, SNG und Fischer-Tropsch-Kraftstoff aus Waldrestholz im Pkw-Bereich* (Techno-economic comparison of the use of electricity, SNG and Fischer-Tropsch fuel from forest residues in the automobile sector) [17]: This ongoing dissertation studies the economic and environmental impacts of the use of fuels from forest residues in different car propulsion systems. The considered fuels SNG and Fischer-Tropsch diesel are each supplied by the bioliq® process.

In current systems analysis, the presented methods and research topics are extended to foreign conditions. The analysis first estimates the biomass quantities and supply costs for the bioliq® process in South American countries with large potential of biomass, such as Brazil. In this context, particular focus is also on technological and economic differences arising from whether untreated biomass or preconditioned bioliqSynCrude® is transported to Germany.

Experience gained from the accompanying TA on bioliq®

The accompanying work on the bioliq® process can be considered a successful technology assessment as it has opened up a new research field with a highly precautionary aspect on the one hand, and helped to win over technology-oriented research institutes of the KIT to reorienting their research work, on the other. The results of the TA studies allowed to assess e.g. the competitiveness of the bioliq® process at a very early stage. The initial optimism among the engineers has thereby significantly faded.

The mutual trust built up in the course of the historical development (cf. Sec. 5.2) between the parties involved has always been essential for this ongoing accompanying TA process.

Of course, the results and recommendations of the accompanying research do not always meet with unanimous approval of the development engineers. An example of this was the recommendation to also consider competing technological developments in fast pyrolysis. This was hindered or even prevented already at an early stage of development with the argument that the KIT could only present itself to the outside world with one fast pyrolysis model. However, it can also be argued that an essential prerequisite for optimization approaches is to follow different and thus competing process concepts and to operate alternative test plants. Similarly, when evaluating the results of the systems analysis on the bioliq® process and drawing conclusions, the analysts were partly urged to soften or even omit critical comments that might hinder the further development of the process. However, the underlying analytical results were not questioned. From the perspective of TA, it is important to insist on addressing and assessing the negative effects of a technological development precisely at this point.

If the results of an accompanying systems analysis may not be published, or only published to a very limited extent due to agreements or even legal provisions, the question must be raised whether it is not advisable to withdraw from such research cooperation. In research projects with strong industry participation this risk is certainly particularly high.

RÉSUMÉ

Technology Assessment looks back on a history of now more than four decades. According to different and partially heterogeneous expectations of what TA should deliver, and because the expectations vary over time, TA has developed several approaches to meet different challenges and match different contexts. Besides the more policy-oriented approaches, several TA concepts deal with the challenge to support technology development in direct cooperation with engineers.

However, there are also limitations and obstacles as well as possible unintended side-effects if TA works closely with lab research. It is important to point out that the model of TA research intimately linked with technical R&D also harbors problems [14]. Its independence might be threatened, especially if the necessary distance to the technical developments and those working on them is lost. The case study (Sec. 4) is an illustrative example of this problem but also shows that it could be dealt with successfully by scientifically independent, accompanying TA.

A second critical issue is conflict and freedom of research. As soon as strong economic interests are part of the game they could lead to conflicts. If TA came up with unexpected and unfavorable results for the innovation under consideration, e.g. regarding the competitiveness or sustainability indicators (as was indeed the case in the study presented in Sec. 4), voices might come up to suppress these results. However, negative or unexpected results can often be interpreted as recommendation for change which could then improve the chances of the innovation under development at the marketplace. Anyway, simultaneously sustaining the independence of TA and its relevance to R&D in concrete research and innovation processes requires balancing the distance of an observer to the neighborhood of an involved person, which is an ambitious and delicate task.

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