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Eco-Efficient Fertilizers: An Environmental Innovation Organised by a Corporation and Promoted by Technology Policy

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Abbreviations

BASF	Badische Anilin und Soda Fabriken
BAuA	Bundesanstalt für Arbeitsschutz und Arbeitsmedizin (federal agency of occupational safety and industrial medicine)
BEO	Projektträger "Biologie, Energie, Umwelt" (research project management body "Biology, energy, environment"), research center Jülich
BgVV	Bundesamt für gesundheitlichen Verbraucherschutz und Veterinärmedizin (federal agency for consumer health and veterinary medicine, established separately after the dissolution of the BGA in 1994)
BMA	Bundesministerium für Arbeit und Soziales (department of labour and social affairs)
BMBF	Bundesministerium für Bildung und Forschung (department of education and research)
BMG	Bundesministerium für Gesundheit (department of health)
BML	Bundesministerium für Ernährung, Landwirtschaft und Forsten (department of food, agriculture and forestry)
BMU	Bundesministerium für Umwelt (department of the environment)
COMPO	daughter company of BASF, since 2000 subsidiary of Kali + Salz
DLR	German center for aviation and aerospace, research project management body "Environmental research and technology"
NGO	nongovernmental organisation
PTWT	Projektträger Wassertechnologie (research project management body "Water technology and sludge treatment"), research center Karlsruhe
UBA	Umweltbundesamt (federal environmental agency)
VCI	Verband der chemischen Industrie (association of German chemical industry)
VDLUFA	Verband Deutscher Landwirtschaftlicher Untersuchungs- und Forschungsanstalten (association of German agricultural research institutions)

CLMP	4 chlorine 3 methylpyrazole
DMPP	3,4 dimethylpyrazole phosphate
DCD	dicyandiamide
ENTEC	trade name of fertilizers containing DMPP
EP	environmental policy
ETP	ecology-oriented technology policy
GLP	good laboratory practice
NI	nitrification inhibitor(s)
NPK	nitrogen, phosphate, potassium
R&D	research and development

Summary

This case study investigates innovation processes and networks around the development and market introduction of a new eco-efficient fertilizer. The innovation offers a technical-fix solution to combine effective fertilizer application in modern agriculture and horticulture with environmental protection by reducing nitrogen losses with the help of ammonium stabilisators that show no significant (eco-)toxicological effects. The case study describes the period 1995 - 1999 relevant for this environmental innovation. Just those actors with the scientific competences required belonged to a loose innovation network which one could expect to participate in a cooperative R&D project with rather strict labour division, well coordinated and co-funded by BASF as its key actor. The innovation process met no serious obstacles in its technical and its social dimension, though finally some retardation in its time dimension, concerning licensing of the new fertilizer. Willingness to compromise was prevalent in case of diverging actor interests, and substantial controversy could be hardly found in the whole innovation process. Respective actors in environmental, technology, and agricultural policy cared for more or less appropriate framework conditions of the innovation project but were hardly involved themselves in the genuine innovation network. Technology policy cared for launching and co-funding the project developing eco-efficient fertilizers especially for economic reasons. Concerning the main research question of the case study, no serious attempts of substantive interpolicy coordination of environmental policy and ecology-oriented technology policy could be identified.

1 Purpose and methodology of the case study

This case study investigates innovation processes and networks around the development and market introduction of the new (eco-efficient) fertilizer type ENTEC.[1] It contains the nitrification inhibitor DMPP (3,4 dimethylpyrazol phosphate), an ammonium stabilizer strongly impeding nitrification of the ammonia nitrogen applied as fertilizer and therefore allowing to reduce the number of fertilizer dressings, improves the utilization of applied nitrogen by the plant, and thus significantly reduces nitrogen losses by translocation into soil and leaching into the groundwater as well as evaporation into the air. The case study describes the time period 1995 - 1999 relevant for this environmental innovation. Its main purpose is to study the role of environmental policy and technology policy and their mutual coordination within this innovation process (Conrad 2000).

The study is mainly based on 16 loosely structured interviews with key persons involved in this innovation process, either on a face-to-face basis (6 interviews lasting between 1 and 3 hours) or by telephone (10 interviews lasting between 15 and 45 minutes). Furthermore, some literature and documents dealing with the development of this fertilizer and its application have been studied (BASF 1999, BASF et al. 1999, BMBF/DLR 1999, BMBF/BEO 1999, COMPO 1998, 1999), facilitated by significant background knowledge of the author (Conrad 1990, 1992). Finally, the draft report of the case study has been circulated to the interviewees for critical reading and comments, which have been taken into account according to my personal assessment.

The interviews were made with representatives of the following institutions (1. figure: face-to-face interviews, 2. figure: telephone interviews): BASF (1,2), COMPO (1,0), Institute Fresenius (1,0), university Gießen, institute for applied microbiology (0,1), technical university Munich/Weihenstephan, agricultural department (0,1), Free university Berlin, chemistry department (0,1), research center Jülich, institute for radioagronomy (0,1), BMBF (0,3), BML (0,1), research project management bodies "Water technology and sludge treatment", and "Biology, energy, environment" (Karlsruhe, Jülich/Berlin) (3,0).

The details of the innovation process were successively recognised and understood during the various subsequent interviews conducted mainly in December 1999, so that critical questions about controversial issues and less openly presented intangibles could be posed on a better knowledge basis particularly in the later interviews.

From a methodological point of view, the demand to perform the (in-depth) case study within one month workload necessarily implies limited validity of its results because, first, it allows hardly any (systematic scientific) verification procedures beyond confronting individual interviewees with diverging opinions of other persons interviewed and beyond asking the interviewees for corrections of and critical comments on the

[1] It has been funded by the EU-Commission as part of the ENVINNO-project (IIUW 1998).

draft report.[2] Second, analysis of relevant contextual literature on fertilizer markets, on types and properties of fertilizers and their different environmental impacts was not possible either, so that an assessment of the adequacy of dominant cognitive frames underlying the description of the case history as an environmental innovation by the key actors could not be performed by for instance comparing them with the cognitive frames prevailing in organic farming where mineral fertilizers have to be avoided for ecological reasons. Finally, the presentation of the case study on about 25 pages does not allow to eventually discuss subtleties and different possible interpretations of the innovation processes reconstructed.

2 The physical and social setting

This section describes the physical and social setting of the environmental innovation studied by pointing out requirement, development, environmental impact, and market features and advantages of eco-efficient fertilizers and the available agro-environmental options to minimize their environmental impacts.

Fertilizers are used to stabilize and increase crop yield in agriculture and horticulture. Leaving aside the impacts of fertilizer dose, composition and chemical form on plant growth and crop yield and quality, the potential main environmental burden of fertilizing stems from their (unintended) negative impacts on the (surrounding) environment by reactions in the soil, leaching into ground and surface waters, evaporation in the air. For nitrogen (containing) fertilizers, these environmental impacts are essentially due to nitrate leaching into soil and water, and emission of ammonia and nitrogenous oxides, predominantly NO_2 into the air.

For the farmer or gardener, loss of (nitrogen) fertilizer is not in his interest, but it is unavoidable to some degree for reasons of soil and plant chemistry, on the one hand, and there is an economy-ecology trade-off involved in fertilizer application because of enhanced time requirements for fine-tuned application procedures.

The development of so-called eco-efficient fertilizers which maximize their absorption according to plant needs and minimize losses due to their physico-chemical structure should therefore contribute in practice to both less burden to the environment and more efficient utilisation of nutrients by crops, if the additional costs do not outweigh these gains, and if the use of mineral fertilizers is still considered favourable compared to organic fertilizing and natural nitrogen mineralisation in organic farming. The relative

[2] To give one example: on the flow diagram showing the various steps of product development of ENTEC presented by one interviewee, dated December 1999, substance screening of potential NI candidates was done during 1995, i.e. before the start of the joint project co-funded by the BMBF, and registration of DMPP according to the chemical act happened in 1996/97. However, according to the final report delivered in November 1999 and reconfirmed by the central actor BASF AD/E (development section of BASF fertilizer division) the main part of substance screening was done in 1996/97 within the joint project, and registration of DMPP happened in 1997/98. This difference is crucial because it implies that BASF had not yet detected the promising NI compound decisive for project success or failure when the joint project took off. Otherwise, the legitimacy of public co-funding necessary testing and monitoring experiments to introduce a new product on the fertilizer market could be questioned with good arguments.

advantage of these agro-environmental solution options may well vary with the type of agriculture pursued, the crops cultivated, and the prevailing agricultural economic and agricultural policy framework conditions.

Apart from agro-technically and environmentally advantageous fertilizer application procedures eco-efficient fertilizing can be done by adding nitrification inhibitors (NI) in an appropriate manner to nitrogen (containing) fertilizers, that chemically prevent rapid nitrification of ammonium (ammonium stabilizers), by coated fertilizers with biologically degradable coating materials, that physically protract the diffusion of nutrients out of the granulated fertilizer, or by slow release fertilizers, where the nutrients themselves because of their chemical form get only soluble by a slowly progressing process such as hydrolysis and microbial conversion.

Whereas these agro-environmental options may well serve their purpose of eco-efficient utilization of nitrogen (containing) fertilizer, the additional substances have to be environmentally compatible, too, in terms of toxicology, eco-toxicology, biological degradability, residues in crops, leaching, or evaporation into the air. This makes the development of eco-efficient fertilizers a demanding task, particularly at competitive cost levels. Fertilizers containing nitrification inhibitors (DCD, nitrapryrin (2-chlorine-6-trichlorinemethylpyridine) as well as coated fertilizers and slow release fertilizers were well available on the market since already about two decades, but at rather high costs allowing only for specialised fields of application, such as lawns and horticulture.

At this point the socio-economic conditions and changes of the fertilizer market become significant. Fertilizer use has largely stabilised in Europe during the 1980s. Following cheap imports from Arabian and East European countries and aggressive market penetration by Norsk Hydro, a Norwegian corporation mainly engaged in fertilizers, aluminium and pisci-culture, and participating in oil and gas extraction from the North Sea, which therefore disposes of cheap energy supply needed for nitrogen fertilizer production, the market has become a very competitive one with declining prices and low profit margins in the 1980s with only a few companies being able to remain in the fertilizer market. From the 1990s onward, however, particularly East European and Russian fertilizer producers equipped with cheap labour and low cost energy supply by Russian gas entered the market with very low-price products.[3] This led to excessive supply on the market about every 5 years and made fertilizer production a losing business in Western Europe, especially since 1997.

In order to follow a path of relatively integrated process management and to avoid drastic waste generation of nitrogenous chemicals - in accordance with an environmental management system of responsible care meanwhile established in the company -, BASF as the main German fertilizer producer is bound to use nitrogenous intermediates, such as ammonia or nitric acid, for production purposes because of the overall configuration of its production process, that is based to a considerable degree on

[3] On several occasions the European fertilizer industry successfully asked for EU-market protection against dumping by custom fees and import quota that were imposed on some countries for some time and partly prolongated, too.

nitrogen. Therefore, its option to go out of a loss-bringing fertilizer business is severely restricted. Under these conditions considerable though limited investments in research and development of competitive high-tech fertilizers as the more or less only available option to stay in the fertilizer business make well sense even with currently continuing business losses. Without the belief that this type of fertilizer will penetrate future markets it would have been hard to justify R&D expenses in a fertilizer business with low profit margins, which are comparable to those for much more profitable pesticide development.

Fertilizer development, production, marketing and sale was organised within the BASF group in the following way: research and development, agricultural advisory services and organising legal registration of (new) fertilizers and corresponding chemicals, as well as fertilizer production belong to the corporate division Fertilizers (BASF AD) located at Limburgerhof. Fertilizer production is done in five BASF owned plants at different sites. Production of specific ingredients such as the newly developed ammonium stabilisator DMPP, however, need not be part of this same corporate division for reasons of favourable utilisation of already existing know-how and production facilities. Marketing and sales management is divided among different BASF units: BASF AD is responsible for ordinary fertilizers mainly applied in agriculture, whereas the subsidiary COMPO cares for fertilizer specialties, mainly applied in horticulture, viniculture, fruit-culture, nurseries and public greens. With an annual turnover of 300 million Euro COMPO has been sold by BASF to Kali + Salz late in 1999, together with marketing and sales management of ordinary fertilizers for agriculture, as part of its outsourcing strategy. Thus, Kali + Salz, which belonged to BASF (with more than 70%) in the past and still with less than 25% at present, became the second largest nitrogen fertilizer supplier in Europe after Norsk Hydro. These corporate characteristics are listed here because COMPO as the main distribution and sales channel of the newly developed fertilizer type ENTEC had to fund the corresponding R&D efforts of BASF and therefore played the role of a controlling actor in the innovation network, described below.

3 Case history

This section describes the history of the environmental innovation of the new fertilizer type ENTEC containing NI, referring to its development, the actors involved in related networks, and their interests and motivations. Altogether, it appears to be a successful innovation with well working cooperation of the diverse scientific research institutions involved and the willingness of the German federal ministries concerned to support this innovation process. Environmental compatibility of the new fertilizer was an important welcomed side-effect of the development process in line with legal requirements and with the justification given by the scientific referees evaluating the project proposal in 1996, but hardly, however, its main driving force.

The combination of two key concerns initiated the whole project in 1995/96. First, as already mentioned, BASF AD was under economic pressure to develop and realise a strategy to keep fertilizer sales a profitable business in the longer run. For good reasons the production and sale of fertilizer specialities with a high market potential was seen as such a strategy. Such specialities are for instance sophisticated nitrogen fertilizers of improved quality, high efficiency and limited environmental harm, at still competitive costs. Whereas coated fertilizers and slow release fertilizers tend to offer a larger profit margin, but only serve niche markets at present, NI containing fertilizers have potentially large application areas though with lower profit margins. BASF manufactures fertilizers containing NI DCD since 1989, and sells them in cooperation with the independent fertilizer company SKW Trostberg at a niche level, however, because of their high production costs and limited effectiveness.[4] Because BASF is the more or less only fertilizer manufacturer in Europe disposing of considerable corporate R&D capabilities in this respect, it has potential competitive advantage in developing an eco-efficient NI containing fertilizer at reasonable costs. Only Norsk Hydro pursues some development of sophisticated fertilizers and fertilizer application strategies in Germany, too. In times of losing business, however, available financial resources for fertilizer R&D are limited[5] so that co-funding by external institutions is likely to be welcomed despite stronger duties to disclose details of R&D results.

Second, the head of PTWT at the research center Karlsruhe saw the chance to enlarge its domain by a large project increasing its reputation and its financial means, because 5% of BMBF R&D project money is dedicated to the responsible research project management body. In line with the BMBF strategy to concentrate on lead projects, he intensely conferred with BASF, on the one hand, and with the BMBF, on the other hand. Thus, he contributed to persuade the former to invest further considerable resources, even including resources for collaborating institutions, in a R&D project implying positive ecological effects and image, which was well in line with a corporate strategy of establishing substantial environmental management systems and leaving the negative environmental image of chemical industry stemming from the late 1980s and early 1990s. And he convinced the latter to fund one of the largest BMBF R&D projects in order to keep competitiveness of an industry and accordingly employment by an environmental innovation.[6] He helped to select the cooperating R&D partners for the project though these often had already contacts and collaborated with BASF previously. In fact, essentially BASF AD/E, the R&D section of the BASF division Fertilizers, decided as the key actor of the whole innovation process which part of the project should be done by external partners, mainly for cost-saving reasons, and coordinated the whole innovation process. In addition, all specified methods and procedures developed by cooperating institutes within this R&D project, belong to BASF. Furthermore, the research project management body was involved, to some degree, in arranging the appropriate project application procedure. The project

4 The same holds true for the NI nitrapyrine of Dow Chemical in the USA, which can only be applied within liquid fertilizers.

5 The development of the Haber-Bosch process early in the 20th century, which nearly absorbed the capital stock of BASF, would be hardly funded even by a large chemical company at present.

6 It took this research project management body about one year to convince the BMBF that the project was worth funding.

proposal had to indicate its probable results and their market potential, and consisted of specified working packages of the different project partners.[7]

Concerning NI containing fertilizer development, these project participants were and still are the following ones:

- different BASF units, namely ZAG/X (central laboratory unit) supplying new molecules and AD/E for screening for active agents as possible NI candidates (about 150 different substances taken from chemical classes of pyrozoles, imidazoles, pyrimidines, triazoles, thiazoles, pyridines, terpenes, alkines and various urea derivatives),
- AD/E for further biological screening to determine the effectiveness of all NI candidates in laboratory soil experiments,
- AD/E for open-field-screening of 8 NI candidates left to examine their effectiveness under normal agricultural conditions and the concentration of the then selected NI candidates DMPP and CLMP needed in fertilizers under conditions of ordinary crop husbandry,
- AD/E for biological tests to study the influence of DMPP and partly CLMP, too, on yield and quality in agriculture and horticulture under normal field conditions,
- ZHT (central unit for human toxicology) for toxicological as well as DUU (central unit for environmental questions), together with Institute Fresenius as external contractor for eco-toxicological tests of DMPP[8] according to registration requirements of the chemical act,
- AD/E and ZET (central unit for technical research) for formulation experiments to investigate the optimal way of incorporating DMPP in different fertilizers and their respective stability during storage (shelf life),
- ZAG/X for developing and scaling up of optimal chemical production process technologies to synthesize DMPP;
- the private Institute Fresenius for developing and validating analytical methods to determine DMPP residues in crops, soil and water,
- the institute for radioagronomy, research center Jülich for applying radioactive tracing methods in lysimeter experiments to study ^{14}C-labelled DMPP and CLMP distribution in plants and soil, and in addition the whereabouts of the ammonia fertilizer during vegetation,
- the institute for plant nutrition, Technical university Munich, at Weihenstephan for studying the effects of DMPP and CLMP on different crops in dependence of the modes of fertilizer application and of soil type,
- the institute for applied microbiology, university Gießen for investigating the impacts of DMPP and CLMP on the emission of gaseous nitrogen compounds into the air, on ammonia, nitrate, nitrite, carbon and bacteria population concentrations and acidity of soils.

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7 Whereas the participating university institutes had to supply their own project proposal in separate forms, the Institute Fresenius which received about half of the resources spent outside BASF was not obliged to do so.

8 Toxicological and eco-toxicological tests required about 50% of total R&D costs!

Furthermore, COMPO participated in the (BASF-internal) steering meetings in order to be adequately informed about ongoing development efforts, because as the key future sales company of the new fertilizer it had to finance the BASF part of the project and therefore had eventual veto-power to end the project in case of failure.

For the other two R&D components of the project, coated fertilizers and slow release fertilizers, three other university institutes (chemistry department, Free university Berlin; institute for plant nutrition, university Hannover; *Fachhochschule* (graduate college) Weihenstephan) are involved. Their part has not been investigated further in this case study.

There is rather consensus that BASF as the main R&D partner and coordinator of the whole innovation project probably would have pursued at best one fertilizer option, possibly NI containing fertilizers, without additional public funding.

After agreement was reached in principle to launch the project, there was pressure by BASF to formulate, to submit and to approve the project proposal (BASF 1996) rather quickly for economic reasons. In view of the long duration and the high costs of the total project, it was split into two subsequent formally independent projects each costing more than 8,5 million Euro, 4.25 million Euro of which are contributed by the BMBF[9] amounting to formally 50% and in fact about 40% of all R&D costs. Additionally, considerable registration costs and the costs of erecting production facilities have to be covered entirely by BASF.

Because market introduction chances were considered to be more rapidly feasible for NI containing fertilizers, they were primarily developed and examined during the first project (phase) 1996 to 1999 requiring around 90% of project resources, whereas coated fertilizers and particularly slow release fertilizers are mainly developed and tested in the separate second project (phase) 1999 to 2002. The splitting into two projects was mainly due to BMBF policy orientation not to make an enormous financial commitment of 8,5 million Euro for such a long-term R&D project in favour of an industrial product.

The R&D project developing NI and the corresponding fertilizer type ENTEC was primarily coordinated and steered by AD/E (ca. 40 people), and typically organised via strong labour division for the various R&D tasks, recurrent BASF-internal project meetings (about half a day every 1 to 2 months), and general project meetings of all collaborating institutes, including the research project management body and possibly the BMBF, generously hosted by BASF (one day about each half year).

These meetings served to discuss research results and problems, to integrate these results, and to harmonise ongoing research efforts. They were important occasions of face-to-face communication, that helped to improve mutual understanding, to provide helpful differing perspectives on specific issues, and to strengthen team spirit by personal relationships. The BASF-internal project meetings served the section leader

[9] One should note that 5% of this sum are attributed to the research project management body as administrative costs and therefore not available as genuine research money.

of AD/E, who was a chemist till autumn 1999 and now is an agricultural scientist, to inform himself and to maintain control over project development. The section leader had to convince the division leader of BASF AD that the project requiring considerable investment was justified. The general project meetings helped BASF AD/E to keep control of and to coordinate project development, and to intervene in case of problems arising. The last two project meetings in 1999 served dissemination purposes by a colloquium at BASF-Limburgerhof (May 1999) and by a special morning session at the annual VDLUFA congress (September 1999) where various aspects of the project were presented (BASF 1999, VDLUFA 1999). Apart from these project meetings contact and cooperation between project partners occasionally occurred for specific technical reasons on an ad-hoc basis, mostly between just two actors.

Concerning fertilizer development, the crucial agronomical (business-relevant) tasks were done by BASF-internal working groups themselves, leading to two patent applications concerning NI, and others concerning coated fertilizers and slow release fertilizers, too, whereas mainly monitoring tasks or tasks out-sourced for cost reasons[10] or need of special expertise and equipment (lysimeter experiments by research center Jülich, developing analytical measuring methods by Institute Fresenius) were done by non-BASF collaborators, requiring about 1,5 million Euro, i.e. ca. 20% of all costs.

As illustrated by the following examples, well functioning project coordination was an important task for BASF AD/E, because it allowed well-timed start of project tasks and timely delivery of their results.

Thus, the screening of many groups of chemical substances for their potential aptness as NI involving more than 100 individual substances[11] has to proceed (eco-)toxicological examination and field tests. After these intense screening procedures two promising candidates out of the pyrazole group with strong ammonium stabilising effects remained: DMP (3,4-dimethylpyrazol) and CLMP (4-chlorine-3-methylpyrazol); whereas NI candidates of other classes of chemical substances were cancelled because of herbicidal or toxicological effects, respectively.

After CLMP was rejected because of possible chlorine-related environmental impacts, higher production costs and lower efficiency in 1997, most of the subsequent monitoring (field) experiments were then made with DMPP in the project.

Furthermore, DMPP had to be registered according to the German chemical act as a new substance. The registration procedure for the basic grade took place without any problems in 1997/98.[12] Subsequent toxicological studies and registration procedures

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[10] On average, one personyear of research amounts to about 1 million Euro in chemical industry, including all side costs (e.g. research assistants, workplace, overheads), whereas it amounts to about 100.000 Euro in private research institutes such as Institute Fresenius, and to about 60.000 Euro in university institutes, accounting separately for these also relatively lower additional costs.

[11] Typically for the development of a new pesticide 15.000 to 20.000 substances are screened resulting in one good candidate.

[12] The responsible registration office at the BAuA (Bundesanstalt für Arbeitsschutz und Arbeitsmedizin, subordinate to the federal ministry of labour BMA) receives and checks the submitted registration documents according to occupational safety, health and environmental aspects. If their is no objection

for the first grade of the chemical act, which refer to production volumes above 100 tons per year, happen in 2000, whereas the second grade must be only envisaged when production volumes above 1.000 tons per year are reached.

Finally, market introduction of ENTEC - and the planning and construction of corresponding fertilizer production plants for this purpose - required (national) registration in corresponding EU countries, such as by amendment to the fertilizer ordinance in Germany. In this case, (unintended) retardations in the amendment process led to about one year delay in market introduction in Germany, whereas the process was quicker in Spain, where ENTEC fertilizers were already successfully sold in 1999.

The various components of the R&D project could be dealt with as rather separate tasks by the different project partners, listed above, and they all led to substantial results required for successful performance of the innovation process. Without going into the details of these individual project components, the following features appear worthwhile mentioning because it was a successful project at several levels.

1. As it looks like, all scrutinizing procedures turned out to be in favour of DMPP, be it inhibiting effects, effective processing technology of DMPP synthesis, no (serious) toxicological and eco-toxicological impacts, biodegradability, little nitrate wash-out, little emission of gaseous nitrogen compounds. To have more or less only positive physical, chemical and biological effects of a new substance is rather the exception than the rule. There exist well examples where the development of new substances or processes was already far advanced and then still stopped because of toxicological findings.
2. Communication and cooperation between the various actors involved in the innovation process worked well due to mutual acquaintance, common overall R&D objective, clear distinct tasks and responsibilities for different institutions, effective coordination by BASF[13], and favourable attitudes by relevant public authorities, essentially BMBF and BML. Controversy did not play any significant role.
3. Within BASF there was a good fact-oriented working atmosphere at the level of actual R&D-related activities, and personal intrigues and power games were - apart from the dimension of (self)presentation techniques - at best relevant at higher levels of corporate hierarchy.
4. Favourable situational circumstances facilitated the rapid development and market introduction of ENTEC fertilizers. For example, (initial) production of DMPP was

within a fixed period the registered substance is approved registered without further notice to the applicant.

13 For instance, BASF AD/E helped collaborating university institutes in providing additional means for measurement equipments needed for residue analysis. Furthermore, BASF AD/E arranged cooperation of Agrostat, a private institute doing agricultural field tests, with Institute Fresenius, because Agrostat was cheaper than Institute Fresenius and possesses the GLP seal (good laboratory practice) in contrast to BASF AD. As a consequence, Agrostat carried out field trials, and the crop and soil samples were shipped to Institute Fresenius for residue analysis. Because field tests by Agrostat were not foreseen in the project proposal, this additional research was funded by shifting financial means.

possible in an already existing BASF plant for pesticide production lowering production costs. Internal reorganisation of environmental research policy in the BMBF between 1994 and 1997, implying a change of the responsible research project management body, too, did not lead to complications or delays in the innovation process itself.

5. Apart from an unintended one year delay in registration procedures in Germany, market introduction of a newly developed fertilizer after about 4 years of research and development can be judged as quite rapid. It may offer a viable option for BASF to remain an important fertilizer producer on the (European) market offering farmers and gardeners sophisticated eco-efficient fertilizer (systems) at reasonable costs.

Apart from some left-overs to be completed in the second project phase, the research project on NI containing fertilizers ended in 1999 with the presentation of its results on scientific conferences and in the final report to the research project management body (BASF et al. 1999). The amount of manpower, financial and technical resources invested varied between the different participating research groups. Typically, however, around 3 to 4 scientists, including assistants, were involved, spending between 1 and 5 personyears on the project. Prominent were all kind of field tests lasting between 1 and 3 years.[14]

Planning and erecting production plants for NI containing fertilizers at different locations (Gijon, Spain; Krefeld, Germany; probably a further one in Antwerpen, Belgium and one in Italy) started in 1997 and 1998, respectively. Similarly, preparatory efforts for market introduction began in 1997, too. Since 1999, the new fertilizer type ENTEC is sold in Spain. In Germany, Italy and France as the other large national EU markets, as well as subsequently in the Netherlands and Austria, sale started in 2000.

When a R&D project turns out to be so successful, points of suboptimal progress or failure are of special interest in order to avoid ideal-type conclusions about a real world project. Few can be mentioned, where only the first one stems from the R&D project itself:

1. As requested Institute Fresenius developed analytical methods for the determination of DMPP residues in water, soil and different crops in 1996. The residue methods were designed to allow rapid sample throughput along with maximum sensitivity and selectivity. However, the university institutes collaborating in the project did not have sufficient funds for investing in corresponding measuring instruments. Therefore, after a meeting on this problem, Institute Fresenius developed a further technique to analyse soil residues with minimal requirements in 1998 for these institutes which adapted it further for their specific purpose, supported with some additional means by BASF. However, these cheaper methods of analysis are only acceptable on the basis of cheap laboratory labour costs, and

[14] Already more than 600 field experiments testing DMPP effectiveness were performed by BASF in different countries, around half of them in Germany.

therefore not competitive on the market outside academia. This experience, frustrating for all parties, was due to missing check of available instrumentation and resources before the start of the project and can be avoided by early inventory in similar (cooperative) projects.

2. When perspectives for the new NI containing fertilizer appeared favourable, BASF asked the BML for ENTEC registration according to the fertilizer act in 1997. After registration of the active agent DMPP according to the German chemical act, a new type of fertilizer needs admission by the fertilizer ordinance. The corresponding scientific advisory board of the BML has to examine if it is not harmful to human health and the environment, and beneficial for the crop and soil as required by the fertilizer act. The advisory board, meeting twice a year, had few comments in October 1997, which were fulfilled in April 1998. Because the BML planned a more general amendment to the fertilizer ordinance within 6 months in 1998 (concerning secondary raw materials, human waste and compost), it intended to include registration of the new fertilizer type in this amendment. However, consultation and negotiation processes went on and on, and early in 1999 the BML admitted that the general amendment would be passed in 2000 at the earliest.[15,16] Meanwhile BASF, interested in quick registration, lobbied in favour for a special amendment of the fertilizer ordinance to allow registration of an environmentally friendly fertilizer. Additional pressure came from the BMBF which funded the project. In view of these circumstances the BML accepted this pathway of two separate amendments and worked rapidly in a cooperative manner to launch this special amendment. This happened in November 1999, after the BMU and BMG had been consulted, after the upper house of parliament (*Bundesrat*)had given its approval, and after the EU notification procedure of technical standards at Brussels had been passed after three months obligatory waiting time[17], all in accordance with legally required provisions.

3. Whereas for other substances, for instance pesticides, national registration often implies registration for the EU as a whole if its requirements are as strict as EU requirements, this does not hold for fertilizers.[18] There exists the option of direct registration according to EU law, too, avoiding many parallel national admission procedures. However, representatives of the various member states basically form the corresponding EU registration committee, who tend to reinsure their position by national governmental institutions and therefore to insist on examination according to national regulations, which leads to multiple similar testing and monitoring procedures in several countries. The French regulations, in particular, tend to

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[15] Due to their (naive) reliance on initial BML informations transmitted to them, these imponderable delays in registration procedures because of ongoing political bargaining processes were not correctly perceived by COMPO marketing people, in particular, keen on rapid market introduction of ENTEC fertilizers.

[16] In autumn 2000 it was clear that this amendment will be passed in 2001 at best.

[17] In case of additional inquiries, the waiting time is 6 months. In this case of DMPP containing fertilizer, however, no objections were raised.

[18] With very few fertilizer producers left in the EU, essentially BASF and Norsk Hydro, there is insufficient lobby and pressure to change these legal registration conditions.

demand repetition of all field testing already done elsewhere.[19] On average, only large corporations, having sufficient resources and informal contacts to key persons, are able to afford this expensive procedure. Therefore, it was advantageous for BASF to ask in parallel for national registration of NI containing fertilizers in several countries, namely Spain, Italy, Germany, France, Austria and Benelux, which allowed quicker market introduction on the national markets, respectively, than by the EU-wide registration procedure.

4. Lastly, German environmental policy includes some legal restrictions concerning nitrate standards (EU nitrate ordinance, nitrate threshold value of EU and national drinking water ordinance, farming restrictions in water protection zones, animal manure ordinances) and climate policy objectives to reduce emission of greenhouse gases (CO_2, NO_X, NH_3). However, it does not provide clear market incentives (e.g. a nitrogen tax), regulatory framework conditions (e.g. differentiated restrictions of fertilizer application), and up to now little suitable information material to agriculture to prefer utilization of eco-efficient fertilizers.[20]

4 Actors: their interests, perceptions, strategies and constellation

The actors involved in the case investigated can be defined at two levels: organisations and individuals. Because the various individuals in principle acted according to the rules and interests of their organisational units and because personal conflicting issues within these units had no observable impact on the case history, in general[21], it seems sufficient to analyse actor behaviour and constellation at the level of organisational units, although this does not deny the key role of certain individuals for the specific development path of the case history. Thus, organisational sub-units within a macro-organisation such as BASF, BMBF, or a university are conceived of as essential actors, where typically around 5 to 15 individuals belonging to this unit were engaged in the case investigated.

The overall actor constellation may be plausibly described as a R&D-oriented innovation network, consisting of two overlapping groups of actors within and outside BASF. The first group namely Various units of AD/E involved in laboratory experiments, agrochemical testing, and product development, and some central units of BASF and COMPO belonged to the first group, whereas the various (research) institutes listed belonged to the second group, namely Fresenius, Agrostat, the institutes at the research center Jülich and at the universities of Gießen and Weihenstephan. Further actors involved in the case outside the genuine innovation process were

[19] Apart from emphasis on national self-reliance this is due to motives of market protection of national producers.

[20] In France, for instance, manure supplemented by liquid NI can be applied for some extra weeks in winter, which should have positive environmental impacts even if only 50% of the farmers follow this regulation.

[21] For instance, the specific kind of relationship of a candidate for a doctor's degree with his supervising professor should usually have only marginal impacts on the overall R&D project.

– other BASF units, responsible for producing or marketing the new NI containing fertilizer as well as leading managers approving the project,

– the technology policy units, i.e. the responsible BMBF section and the research project management body, funding and evaluating the project,

– and the regulatory agencies of the BML, its scientific advisory board, the BMU, the BgVV, the *Bundesrat*, and the EU-Commission, all involved in the legal registration of the eco-efficient fertilizer.

Apart from the university institutes at Berlin and Hannover, and the *Fachhochschule* Weihenstephan, involved in the other two components of the eco-efficient fertilizer project, some other actors may have taken notice of the project in its later stage, such as agricultural and environmental departments at the state level, or agricultural organisations, or agro-chemical industry corporations. Furthermore, it should be noted, that neither environmental ministries (apart from registration procedures), nor environmental NGOs, nor eco-farming groups, potentially opposed to the project, were directly involved in the project. However, environmental policy (regulations) and environmental concern of the public, represented by these actors in particular, were important boundary conditions inducing this innovation effort.

Clearly, the key actor was the AD/E section of BASF who coordinated and controlled the whole R&D project and cared for registration procedures, too. No other actor had the same overall know-how and steering competence. The other research institutes received their research funds and delivered their research results, but were neither involved in the initial launching of the project nor in the registration procedures of the new fertilizer. The other political or economic actors involved had some veto-power concerning project funding (leading managers of the BASF fertilizer division, BMBF, COMPO) or NI and fertilizer registration (BAuA, BML, EU-Commission), but obviously did not belong to the genuine innovation network.

Because (parallel) competing R&D efforts did not exist, and because the actors proceeded according to their expected role and accepted existing framework conditions[22], actor interests, perceptions and strategies were rather well accommodated to and harmonised with each other so that controversial attitudes or even fundamental oppositions could be hardly observed. Rather, the respective interests and strategies were considered mutually legitimate. Genuine objectives and actual substantive strategies and activities followed by each actor were well reconciled reflecting a positive coupling of his formal and substantial interests. Because the screening process of promising NI-candidates was already well advanced at the start of the joint R&D project in 1996, all the actors (of the innovation network) were interested in successfully completing the development of an eco-efficient fertilizer so that their own R&D work could be counted as a success, too.

In more concrete terms, the AD/E section of BASF was interested in

[22] For instance, according to the contract between BASF and Institute Fresenius, the analytical methods and all results obtained belong to BASF. Institute Fresenius is not allowed to use these methods elsewhere without prior permission of BASF.

1. developing a new NI and the corresponding fertilizer,
2. receiving co-funding by public money,
3. solving the central R&D questions itself,
4. having external collaborating research teams with specific (monitoring) competences required, at probably cheaper costs than by corresponding BASF-internal testing and monitoring efforts,
5. steering the overall R&D project,
6. and managing rapid registration of the new substance DMPP and the new DMPP containing fertilizer type ENTEC in order to allow for short-term market introduction.

All these (strategic) steps can be considered necessary requirements for BASF to remain as a competitive producer in the fertilizer market.

For the different academic research institutes the joint R&D project offered the opportunity to get funds for following their genuine research orientation by doing the various monitoring experiments required for DMPP application, resulting in scientific publications and dissertations.

Institute Fresenius as a private company has to sell its competences on the market. It was paid by BASF for the development and validation of analytical methods, as well as for the analysis of DMPP residues and metabolites. Participation in the project offered it both the acquisition of contracts and the extension of its know-how in this working field.

The actors in charge of funding and supervising the project, namely both COMPO and the two subsequently responsible research project management bodies have been clearly interested in its success because failure of an innovation project usually implies loss of funds invested.

The BMBF pursues the tasks of promoting national industries and of assisting environmental technology development mainly by co-funding corresponding R&D projects. The development of eco-efficient fertilizers suited this purpose well. Thus, the BMBF agreed to appropriate the extraordinarily large sum of 8,5 million Euro for this R&D project.

The registration authorities have to check the different safety features of DMPP and of the new fertilizer according to their criteria and rules of registration, but have no interest in unnecessarily delaying permission in case of positive results of the licensing procedures.

The perceptions of the innovation process by the various actors certainly differed in terms of their respective know-how and focus of task, but not with respect to its agreed upon overall objective. Therefore, the Thomas-Theorem[23] is of no significant importance to explain different (conflicting) actor strategies. In this case its relevance just stems from a consensual perception and corresponding problem definitions that largely contribute to the relatively harmonious and conflict-free proceeding over more or less all phases of the innovation process. Without this common problem perspective this process probably would have followed another pathway.

[23] If man defines a situation as real, it will be real in all its consequences.

To sum up, the actor constellation of the case investigated can be characterised by one key actor, by a genuine innovation network of scientific actors, who followed an overall common objective, who had a similar science-oriented perspective, and who successfully cooperated under conditions of strict division of labour, and by policy-related actors with other (formal) duties and no genuine scientific interest, however with a rather favourable attitude towards the R&D project and its results. Thus, conflict between actor interests, perceptions, or strategies did not play any major role. In addition, this cooperative situation was supported by the successful results of the various R&D efforts themselves so that no critical points of potential project failure had to be mastered.

5 The innovation process and related networks

Having described actor strategies and constellation, this section inquires into the main features and network character of the environmental innovation under study.

The development of a new NI containing fertilizer can be assessed as a considerable incremental technical product innovation[24] leading to manifold (subsequent) organisational and production (re)arrangements, too. The innovation process itself followed a relatively clearly structured sequence of R&D steps: screening of substances, systematic testing of NI candidates, developing fertilizer formulae, preparing and organising fertilizer registration, production and market introduction. Thus, the innovation process is characterised by the overlap of various R&D efforts, strong labour division with separate individual research and monitoring results, integrated by joint meetings of the R&D groups and by BASF coordinating the project. Basically, the new DMPP containing fertilizer is a technical-fix solution within established agricultural systems and practices and does not require deeper changes in agricultural arrangements. It is, however, a clearly preventive solution of nitrogen-related environmental hazards independent of specific agricultural systems, as long as mineral fertilizers are considered a necessary ingredient of (modern) agriculture.

Because the crucial element of the innovation was the detection of an appropriate NI candidate in the screening process, the subsequent testing and monitoring experiments in the co-funded collaborative R&D project were of a more routine character in terms of scientific discovery, once DMPP has been selected as NI, though with still unforeseeable results. Therefore, the innovation pathway clearly followed a foreseeable technological trajectory (cf. Nelson/Winter 1982), where the actors had not to expect extraordinary new development paths, though anytime R&D results leading to a project-stop.

The (economic, political, legal, agrochemical) selection environment largely determined the steps to be taken, where it has to be considered as good luck that no substantial complications arose and all relevant selection criteria possibly terminating the project

[24] Although a new chemical substance has been found as ammonium stabilisator, it has to be judged rather an incremental than a basic innovation.

were met. Thus, various social, legal, market embedding dimensions were crucial for the innovation to become a success. Significantly, central R&D tasks remained within BASF, whereas particularly these embedding dimensions were handled by (external) partners, insofar they required R&D (monitoring) efforts. Thus, what makes the whole development of a new NI containing fertilizer an innovation, and not just a research project[25], is the coordinated integration of results in a technological trajectory leading to a market product.

One may reasonably speak of a real innovation network following a joint objective with substantial and coordinated exchange of research ideas and results, and with little conflict and competition among the network members. However, (in this case) one should not overburden the network concept: essentially, it just denominates problem-oriented cooperation with specified tasks and rules for a common goal. The innovation network consisted of several groups, which discussed R&D results and decided on future steps in regular meetings, well coordinated by BASF as central actor. These groups were typically composed of few persons. Partly, they already knew and even had some positive collaboration experience with personnel of the BASF fertilizer division.

Furthermore, separate loose networks such as the regulatory (registration) network existed, as indicated above.

Addressing the ecological dimension of this environmental innovation, environmental compatibility of the new NI containing fertilizer was an important requirement for the innovation process, which is reflected by various project tasks undertaken. However, as indicated above, environmental concern was hardly the main motivation of all actors participating in the project. Instead, the main motivation was the development of a new competitive product, the pursuit of interesting research objectives, economic competitiveness of German industries, or avoidance of political troubles due to insufficient registration procedures. It is due to the coupling of environmental tasks with these various social concerns and respective motivations that environmental compatibility strongly mattered in this R&D project.

Lastly, one may ask about the significance of contextual framework conditions favourable for successful environmental innovation, i.e. in particular sociostructural anchorage of both environmental management and innovative orientation of the actors involved. At least since the 1990s, BASF follows the responsible care strategy promoted by the association of German chemical industry VCI (VCI 1999) and has established an environmental management system in most of its facilities, that provides favourable corporate conditions for developing eco-efficient fertilizers within BASF. Secondly, due to the genuine (organisational) interests and objectives of the actors involved in the project, research and development are perceived as typical and main options to fulfil these concerns and therefore followed as routine device, and therefore are substantively embedded as actor orientation, without which R&D efforts would have been pushed less. Again, it is important to note that BASF is one of the few fertilizer manufacturers with significant R&D capacities.

[25] For instance, this case study of an environmental innovation is part of a research project only.

Thus, environmental management and innovation orientation tend(ed) to provide favourable contextual framework conditions to develop eco-efficient fertilizers.

6 The role of policies and interpolicy coordination

In accordance with the general objective of the ENVINNO-project (IIUW et al. 1998), the role of environmental policy (EP), ecology-oriented technology policy (ETP) and corresponding interpolicy cooperation is of special interest for the case studies of environmental innovations, which had to be completed.

It can be clearly stated that EP was only indirectly involved in the innovation process by setting structural framework conditions via environmental legislation and regulation, typically decided upon in the past, namely nitrate standards of ground and drinking water, restrictions for agricultural practices in water protection zones, climate policy objectives of reducing NO_X and NH_3 emissions, and, at the actor level, by deciding upon the registration of new chemical substances according to the chemical act (registration office of the BAuA). Thus, one may conclude that EP, by transforming environmental concerns into formally binding rules and standards, to some degree sets incentives in favour of eco-efficient fertilizers, and judges their environmental compatibility, too.

However, essentially severe competition on the fertilizer market and the perspective of a new cost-effective fertilizer because of reduced nitrogen losses and lower number of fertilizer applications needed, and hardly environmental regulation were the main reasons why BASF invested in a corresponding joint R&D project instead of relying further on the market niche with already existing DCD containing fertilizers.

ETP was more directly involved in the innovation process than EP by launching and extending the project via extensive co-funding, and by offering some help in finding cooperation partners. However, substantive coordination of the project itself rests with BASF, whereas BMBF and particularly its subordinate research project management body (BEO since 1998) survey and evaluate project progress and results, and still could eventually stop it, after the basic decision to fund it had been taken. Thus, successful results of the first project (1996-99) certainly helped to decide in favour of funding the second project phase (1999-2002) as well.

Under these conditions EP/ETP interpolicy cooperation cannot be expected at the actor level, except for mutual regard of relevant policies, i.e. ETP being aware of environmental standards and EP taking notice of ETP efforts towards developing eco-efficient fertilizers.

In addition, interpolicy coordination played some role at the structural and actor level by BML involvement, issuing a new fertilizer ordinance amendment. Here the BML had to evaluate agro-environmental criteria of the new fertilizer, and the BMBF made additional pressure in favour of a separate quick amendment, because it was interested in an economic success of its project, which is also time dependent.

As concerns EP/ETP coordination, in view of the clear project objective it is justified to ask what advantage additional EP-involvement and EP/ETP coordination could have brought. As long as environmental regulation was clearly given and as long as the relevant policy decision was mainly one of project funding, such advantages seem implausible, combined with typical disadvantages of additional bureaucratic coordination efforts.

If for situational reasons, UBA - as research project management body subordinate to the BMU - would have funded the project, what is unlikely because of the amount of funding required, this would have implied another funding institution, but hardly a significant structural change concerning EP/ETP coordination. In view of the regulatory obligations of EP, the BMBF as the ministry mainly responsible for ETP tends to have a better recognition as neutral sponsor for industry than the BMU as the ministry setting environmental standards.

However, to state unnecessary EP/ETP cooperation at the level of well specified R&D projects does not imply to see no options for improving EP/ETP coordination at the level of relevant framework conditions, for instance via environmental taxes or rules for water protection zones. Here, better interpolicy coordination would be well feasible, as stated by some interviewees. For instance, a nitrogen tax on fertilizers, that would support the use of eco-efficient fertilizers, has been discussed since the 1980s (cf. Conrad 1990) and has also been introduced in some EU-countries. Partly, the reason for this deficit of German EP lies in the limited power and the (past) deregulation orientation of the BMU in the former conservative government.

7 Interpretation perspectives

Looking at the interaction dynamics of structural, institutional, actor, situational, problem perspective and strategic capability factors, which ultimately determine the innovation process, these factors can be summarized as follows:

Structural framework conditions refer to the manifold (contextual) settings that influence the direction and evolution of social processes independent of actors' (current) articulation of interests and modes of procedure. Concerning the environmental innovation of competitive, NI containing, fertilizers, these structural framework conditions relate in particular to the domains of ecology and health, economics, corporate organisation and culture, law, politics and administration, general sociocultural conditions, and the (national) innovation system. Without going into their in principle endless description, I summarise key contextual settings already described in previous sections.

Environmental and health problems and corresponding sociopolitical concerns do matter in two respects: as a background concern for reducing emission of nitrogen compounds into air, soil, water and as strict (eco-) toxicological criteria deciding upon admission or rejection of a (new) chemical substance/product.

The situation and future perspectives of the fertilizer market in combination with the nitrogen based pattern of BASF's production process are key (economic) determinants of BASF strategy to develop NI containing fertilizers.

For corporate organisation and culture of BASF an established regard of environmental management and responsible care, a still comparatively long-term time horizon of company strategy and expected returns on investment, and considerable R&D capacities, including agricultural research and services at Limburgerhof, tend to act in favour of developing eco-efficient fertilizers, too.

The relevant legal, political and administrative conditions have been described above: in particular they concern registration procedures, promotion of environmental technology development supporting competitiveness of German industries, and the willingness to delegate management of publicly co-funded R&D projects to participating corporations.

General sociocultural conditions[26] typically tend to play the role of background variables which may have favoured, for instance by environmental awareness and by a pragmatic combination of participatory orientation and leadership acceptance of the main actors involved, but hardly directly influenced the innovation process.

The German landscape of R&D institutions and technology policy arrangements offered in this case relatively appropriate preconditions for a cooperative R&D project of corporate and academic institutions funded jointly by BASF and the BMBF. This institutional setting might well have been confronted with more organisational and ideological problems some decades ago. The research capacities required were available, though often only once in this case, and with some deficits of university institutes in their equipment with modern instrumentation.

At the level of an institutional eigendynamic[27], the overall environmental innovation process can be reconstructed to a considerable degree as the relatively conflict-free combination or juxtaposition of institutionally impregnated development paths. This (independent) institutional eigendynamic stems from (central) underlying (formal) organisational interests and should therefore be seen as main driving force of the innovation process. These organisational interests can be listed as the following continuous scientific, as well as economic and political concerns:

– eigendynamic induced by the common project goal to develop an environmentally sound and efficient NI containing fertilizer

[26] One may list here the modernization capacity of a society, the importance of the state and public policy, the importance of public debate and the equivalent strength of civil society, the extent of division into different social classes or strata, the degree of public participation and socio-structurally entrenched substantive democracy, the significance of self-responsibility and liability of social actors, the degree of legalism, decentralized versus centralized (political) culture and decision-making procedures, the importance of postmaterialistic value orientations, environmental awareness of, and behaviour by, main actors and the population in general, and the significance and social influence of environmental NGOs.

[27] This term means to the (social) dynamics induced by the vested interests, sunk costs, and inertia of a system, institution, or group, once it has become firmly established and developed its own momentum.

– continuation and expansion of the existing agricultural research program of Weihenstephan
– continuation and expansion of the microbiologically oriented agricultural research program at Gießen university
– further development and application of radioactive tracing methods in combination with stable isotope techniques of the research center Jülich
– development of further analytical measuring methods by Institute Fresenius
– regaining a competitive edge in the fertilizer market by BASF
– promoting competitiveness of German industries by technology policy via co-funding promising R&D projects
– reorganisation of ETP-related units in the BMBF
– self-interest of research project management bodies to keep and to expand the scope of their funding domains
– eigendynamic of the registration procedures due to the interests of political actors to keep their competences and veto-powers: BML, federal states, EU-Commission, other national registration authorities.

Furthermore mention should be made of the eigendynamic induced by nitrate standards for surface, ground and drinking waters and growing restrictions on the emission of gaseous nitrogen compounds into the air as increasingly important environmental background requirements, and, at the same time, by agricultural lobbying to keep favourable conditions for agriculture with respect to fertilizer costs and environmental regulations.

The actor constellation can be summarised by overlapping knowledge/research, business, and regulatory networks (see van Dijken et al. 1999) with the BASF AD/E section as central actor in all three networks, namely coordinating and partly performing itself the R&D project, being involved in preparing production and market introduction of the new fertilizer type ENTEC, and caring for its registration at national and EU levels. The various actors involved need not be listed once more. Of crucial importance was the rather conflict-free collaboration of the actors, partly due to strict labour division and lacking competition, on the one hand, and the well organised planning and management of the whole innovation process by BASF AD/E, on the other hand, avoiding unnecessary delay and research work.

Important situational factors influencing the innovation process, not attributable to predominant (structural) framework conditions, were the following ones:

1. Favourable conditions led to the initiation of the project: The former head of the PTWT perceived the project as a good opportunity to serve interests of both the BMBF and the research project management body. This coincided with the acute pressure of fertilizer market conditions on BASF to search for new fertilizer options. And this coincidence was realised by him, having manifold good contacts to industrial cooperations.
2. The non-appearance of substantive complications in the development process concerning various criteria of agricultural efficiency and environmental compatibility

of DMPP containing fertilizers can be seen as good luck, and cannot be achieved by careful planning of the innovation process because of its very nature of uncertain outcomes.

3. Few negatively judged events, described above in section 3, accompanied the R&D project, that might have been partly circumvented by improved planning and communication procedures. Apart from deficient measuring equipment of university institutes, primarily the one-year delay of registrating the new fertilizer because of the planned but delayed major amendment of the fertilizer ordinance, that had nothing to do with the innovation itself, had at least a partly negative economic impact because of later market introduction of fertilizers type ENTEC in Germany than intended.
4. Furthermore, potentially problematic situational circumstances had no negative impact on the innovation process: neither the reorganisation of the BMBF with a change in the responsible research project management body, nor the forced early retirement and subsequent replacement of the head of the BASF AD/E section played any significant role in this respect.

As described above, the innovation process is characterised by a common problem perspective, where each actor pursued his institutional duty. This general problem perspective can be identified as the development of an eco-efficient NI containing fertilizer competitive on the fertilizer market as a technical-fix solution for a high-tech oriented agriculture, that reduces the environmental burden due to agriculture and fits the requirements of existing environmental and health legislation. Differing (opposing) problem perspectives and solution strategies, as for instance advanced by organic farming and critics of industrialised agriculture, played no role in the innovation process and related discourse.[28]

Lastly, the rather pronounced strategic capability of BASF in managing innovations together with well established traditions in agricultural know-how, services, and contacts helped the AD/E section to manage such a publicly co-funded cooperative R&D project and to be accepted as its natural coordinator by the collaborating institutions.

As can be concluded with some plausibility from this description of essential determinants of actor strategies and the innovation process, their superposition should be more or less sufficient to explain the rather straightforward and successful development of the new DMPP containing fertilizer type ENTEC and its introduction on European markets. To refer furthermore to the interaction dynamics of these structural, institutional, situational, framing and action-oriented factors of influence which tend to mutually reinforce their impact on the innovation process appears to be a reasonable conceptual assumption. Without their substantial description, however, the conclusion that these interaction dynamics essentially underly the innovation process studied remains only a plausible hypothesis not tested by empirical reconstruction and evaluation.

[28] At least one of the referees of the project proposal emphasized the necessarily limited impact of the NI containing fertilizer to be developed on nitrate washout in soil and groundwater.

8 Typical features and summarizing conclusions

This final section tries to summarize the main characteristics of the case study and to draw corresponding conclusions.

1. The situational combination of organisationally entrenched self-interests, namely for BASF to develop sophisticated fertilizers in order to remain competitive on the fertilizer market, and for the BMBF to push promising environmental technology development in order to improve competitiveness of German industries, led to the initiation and formulation of a jointly funded R&D project to develop eco-efficient fertilizers. The head of PTWT utilised this window of opportunity to launch the project in 1995.
2. On the basis of past screening programs, intense literature analysis and available chemical facilities, BASF had good chances to detect a suitable NI by systematic screening efforts. Therefore, their subsequent monitoring and testing in DMPP containing fertilizer formulations was a rather straightforward project of completing an incremental product innovation within a relatively well-defined technological trajectory between 1996 and 2000, where its effective management could minimize the resources and time needed till market introduction by optimally coordinating and synchronising the various activities to be performed by different actors.
3. Just those types of actors with the scientific competences required belonged to a loose innovation network, which one could expect to participate in a cooperative R&D project with rather strict labour division well coordinated and co-funded by BASF as its key actor.
4. The innovation process met no serious obstacles in its technical and its social dimension, though finally some retardation in its time dimension due to the initial (incidental) coupling of the registration of the new DMPP containing fertilizer with the intended, but again and again delayed amendment of the German fertilizer ordinance. Willingness to compromise was prevalent in case of diverging actor interests (for instance: small separate amendment of the fertilizer ordinance; development of additional small-scale analytical methods for university institutes with deficient equipment in measuring instruments; location of the new fertilizer production plants), and substantial controversy could be hardly found in the whole innovation process.
5. There was also a clear labour division of policies concerned by the fertilizer development project. Respective actors in environmental, technology, and agricultural policy (BMU, BMBF, BML) cared for more or less appropriate framework conditions of the innovation project but were hardly involved themselves in the genuine innovation network. No serious attempts of substantive EP/ETP interpolicy coordination could be observed. At the concrete project level, this probably might just have led to additional bureaucracy with subsequent time-delays. At the level of appropriate framework conditions, there is clearly space for improved EP/ETP coordination stimulating environmental protection in agriculture.

6. The innovation offers a technical-fix solution to combine effective fertilizer application in modern agriculture and horticulture with environmental protection by ammonium stabilisators without (significant) (eco-) toxicological effects.
7. Altogether the R&D project studied can be seen as a rather ideal-type case of a well-defined successful environmental innovation with good market chances. Usually this cannot be expected under ordinary (chaotic) circumstances of typically rather diverging actor interests, perceptions and strategies, even if innovative orientations already prevail in environmental management.

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