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Environmental Issues in the German Delphi Survey 1993

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1 The Delphi Project

Growing competition on the world market and an increasing technological change are forcing economies and organisations to concentrate their research activities on selected areas.* Identifying emerging technologies and new applications is one of the key questions in research policy. One of the prominent foresight methods is the *Delphi technique*. The Delphi method is especially useful for *long-range forecasting* (20-30 years) where expert opinions are the only source of information available.

As by far the best experience in large Delphi foresight exercises was available in Japan, where especially the Science and Technology Agency (STA) since 1971 uses this method every five years for its technology foresight, it was decided to draw on this Japanese experience and to perform a German Delphi investigation principally along the Japanese guidelines (aims, topics, character and method) and to duplicate the fifth Japanese Delphi survey of 1991. One aim of this approach was to compare the Japanese and the German answers in order to analyse possible differences and to understand the cultural influences on technology assessment (see Cuhls and Kuwahara 1994).

For the survey, 16 technological areas were defined, containing topics for which expectations of realisation of defined stages of development (exploration [also

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* Section 1 of this paper is adapted from a publication of my colleagues Sibylle Breiner, Kerstin Cuhls and Hariolf Grupp: Technology foresight using a Delphi-approach: a Japanese-German co-operation, in: R&D Management 24, 2, 1994

called elucidation] => industrial development => first application => general application) were asked from participants in the survey (panelists).

For *each of the 16 technological areas one questionnaire* was developed. The questionnaires are identically structured and cover variables to assess each topic like importance, time of realisation, accuracy of the time determination, necessity of international co-operation, national levels of research and development (R&D) activities and major constraints for realisation. The variables were defined the following way:

Importance:	Impact of the topic on research and development, economy and society is high, medium, low or none.
Time of realisation:	Estimation of the period of realisation: before 1995, 2001-2005, 2005-2010, 2011-2015, 2016-2020, not before 2020, no opinion.
Accuracy of Time Determination:	Estimation if accuracy of time determination by the panelist is high, medium or low.
Necessity of International Co-operation:	Estimation if an international co-operation is absolutely necessary, necessary, helpful or not necessary at all for realisation of the regarded topic.
National R&D levels:	Which nation is leading regarding research and development (R&D): the USA, Japan, another country or Germany.
Constraints for Realisation:	Constraints for realisation concerning technical problems, legal aspects, cultural factors, development costs, shortage of investment capital, human capital, R&D-system or others (2 choices).

In addition, each panelist was asked to assess his or her individual degree of expertise as high, medium, low or none.

The results of the Japanese survey are presented in NISTEP (1992); the German survey results have been published by the German Federal Ministry for Research and Technology (BMFT 1993) which commissioned the underlying research project to ISI (Fraunhofer Institute Systems and Innovation Research).

The first round of the *German Delphi survey* started in August 1992, which meant a delay of about one year compared to the Japanese survey. The experts were chosen by the project team of the Fraunhofer Institute for Systems and Innovation Research (ISI). For this purpose, mainly two on-line databases were used. According to certain selection criteria, about 3000 addresses were chosen from the databases.

In total about 1050 experts participated in the first round of the German survey. The questionnaire was sent to the panellists in January 1993 for a second time, providing the findings of the first round in Germany but no information on the Japanese results ("blind experiment"). About 850 questionnaires (80% response rate) were sent back until 31st of March 1993 and were included in the final data evaluation.

Some *basic statistics* on the sample of the German Delphi are shown in Table 1 considering the response rates of round one and round two, gender, age, place of employment and type of employment. Although no direct influence could be exerted on the structure of the responding panellists, the German sample was geared towards similar structures and indeed turned out to be very close to the structure of the Japanese sample (see Table 1).

2 Results with regard to environmental issues

With its 16 technological areas from particle physics to topics relating to societal und cultural "technologies" (cf. table 3) the survey aims at covering the complete spectrum of issues relevant for the long-term development of (hard and soft) technologies. The topics either picture scientific/technical disciplines ("geosciences") or application fields ("transport"). For the field of environmental issues there are two approaches for analysis, the results of which are both presented in this section: by technological subfield 8 "ecology/environmental technology" and by a transversal analysis of all relevant topics for environmental issues contained in the 16 technological areas.

Because of the large numbers of topics (between 39 and 108) in each subfield, for the presentation of analytical considerations to the material, a selection has to be made. We have chosen to present the 10 most important topics. To show a list of only ten questions was an arbitrary decision because the following 10 or more questions might also have got a comparably high ranking. Furthermore, it should be born in mind that the top list represents collective assessments and may not include disputed topics that are highly esteemed by selected expert groups only. The material in the annex tables tries to give the reader a comprehensive scope of information though the richness of the material is only touched upon.

Presenting the results for the degree of importance and for the necessity of international cooperation, indexes are used. In both cases, the original answers "high", "medium", "low", and "unnecessary" were given values of, respectively, "4", "2", "1", and "0", and responses were indexed from a maximum of 100 (in the case where all respondents chose "high") to a minimum of 0 (in the case where all respondents chose "unnecessary").

Table 1 Basic Statistics on the German and Japanese Samples

	German Survey	**Enviroment issues in German Survey**	**Japanese Survey**
No. of topics	1147	50	1150
Participation First Round			
Questionnaires sent out	3534	510	3334
Valid Responses	1056	76	2781
Response Rate %	30	22	84
Participation Second Round			
Questionnaires sent out	1046	75	2781
Valid Responses	857	62	2385
Response Rate %	82	83	86
Distribution of Respondents (%)			
Male	96	95	99
Female	4	5	1
younger than 30 years	2	1	0
30 - 39 years	20	24	5
40 - 49 years	25	21	31
50 - 59 years	41	37	45
60 -69 years	12	15	18
70 years and older	1	1	1
from Business Enterprises	41	45	38
Higher Education	38	25	37
Government	15	24	15
Private Non-Profit	6	5	10
active in R&D	81	81	79
non-R&D	19	19	21

2.1 Technological subfield ecology/environmental technology

In the Delphi survey there is one technological subfield explicitly addressing environmental questions: *ecology/environmental technology* (subfield 8). It is one of the smaller technological fields in the survey, comprising 50 topics. Of these, some 60% address global problems while the remainder concerns problems of a more regional character. The importance given to this technological field in the survey has been raised substantially when compared to the 30 topics included in the fourth Japanese Delphi survey of 1986. Still, the relative neglection of environmental problems is being judged as a deficit from a number of Japanese experts and has raised heavy criticism among German experts.

With 62 respondents answering the round two questionnaires in the field of ecology/environmental technology, this subfield shows an active representation of experts. With regard to gender and age there are no significant differences to the average (cf. table 1). These do exist, though, with regard to the institutional setting: significantly less experts from higher education institutes, significantly more experts from research institutes outside the universities and from industry than on average have participated in this technological area.

Regarding the *topics with the highest rating of importance* given by German experts (table 2; for details cf. Annex-table 1) one can clearly see problems concerning climate change in front (questions 4, 12, 13). It is remarkable that the two highest ranked questions are clearly distinct with regard to the expected realisation time. The practical use of substitutes for fluorocarbon and halon is expected quite unanimously for the year 1999. A worldwide 20% reduction of the emission of carbon dioxide, however, is being expected only for the year 2009, the uncertainty about the realisation time being rather great. One fourth of the experts expects such a reduction only to be realised by the year 2020. This sceptical expectation can be found especially among the active experts in this field. In a number of comments to this question, too, a sceptical view was presented towards an early realisation of substantial reductions of CO_2 emissions. Summing up, it must be concluded that the greater part of German experts is doubting the realisation of the decisions of the Toronto climate conference of 1988, which aimed at a reduction of 20% until the year 2005.

A second group of topics among the ten with the highest rating of importance concerns the destruction of the tropical rain forests. The elucidation of impacts exerted by destroying tropical forests upon climate and weather is being expected for the year 2003 (topic 26). As an option lying far ahead in the future (realisation in the year 2017) but nevertheless of great importance is seen the development of effective recovering technologies for reproducing the ecosystems of tropical rain forests. In comments to this question, though, also great doubts are being pronounced as to the principal feasibility.

The third thematic group among the ten most important questions concerns hard degradable or toxic chemical substances. Both the elucidation of lifecycles of hard degradable chemical substances in the environment, connected with the development of a method to predict their distribution in the environment (topic 45) and the development and the fixation of a taxonomy for toxic chemicals (no. 46) are judged as highly important. The realisation of the taxonomy is expected clearly earlier, in the year 2002. The prediction of life cycles of hard degradable chemical substances is estimated to be realised only in the year 2008.

Table 2: The ten topics ranked most important in technological subfield 8 "ecology, environmental technology"

	Topic	Index of importance
4	Practical use of materials that replace fluorocarbon and halon, that do not damage the ozone layer and cause no global warming problem.	96
12	Worldwide reduction of the emission of carbon dioxide (per year) by 20% of the current level.	96
13	Possibility of controlling an increase in the concentration of the greenhouse effect gases (other than carbon dioxide) in the atmosphere.	90
26	Elucidation of impacts exerted by destroying tropical forests upon climate and weather	90
38	Widespread use of product design techniques easy to recover and separate materials of disposed durable consumer goods for recycling purposes.	90
28	Development of effective recovering technologies for reproducing damaged tropical forest ecosystem.	89
32	Widespread use of fuel control technologies in virtually all types of automobiles, capable of meeting the emission control standard for nitric oxide on the order of 0.1 w 0.2 g/km. (The current level for heavy diesel motorcars is on the order of 4 to 5 g/km, and the standard control value for gasoline passenger cats in 1978 is 0.25 g/km.)	88
45	Accumulation of knowledge concerning the fate of hard degradable chemical substances after release into the environment in advance to their production.	87
35	Development of a compact, waste water treatment system applying biotechnology, enabling highly efficient treatment of hardly decomposable and harmful substances	87
46	Establishment of techniques, models, and data bases for biological testing and measurement of the harmfulness of chemical substances resulting in the construction of screening systems for harmful chemical substances.	86

The remainder of the questions of highest importance concerns differently complex topics and does not form a coherent group.

Within the field "ecology and environmental technology" the *period of realisation* is mainly seen in the nearer future. About 90% of the topics should, after esti mation of the experts, be accomplished within a period of 17 years (i.e. until the year 2005).

The greatest *constraints* in this field still are estimated to be of a technical nature, but the relative importance of technical problems is judged smaller than in other technological fields. In comparison, the problem of development costs is gaining ground. A distinct deficit is being remarked for the German R&D system concern ing impact research in various topics.

International cooperation is considered important especially with the global topics. The motivation seems to be rather the insufficient R&D system than the cost aspects of development.

In general, ecology and environmental technology are seen as a field in which Germany has a leading *position in research and development.* This is marked with the topics concerning the rather regional environmental problems, while with global environmental topics the USA are seen slightly leading.

2.2 Cutting across all technologies: results for the transversal issue of the environment

When talking about the environment, it is obvious that in other subfields than "ecology/environmental technology" there are to be found environmentally relevant questions, especially in the subfields 6: resources, water management; 7: energy; and 9: agriculture, forestry, fishery. A screening of all 1147 questions in all subfields as to their relevance for the environment identified 244 relevant questions from all subfields (table 3) with the exception of area 15: health care, where questions do not so much refer to the causes of diseases but rather to diagnostic and therapeutic problems. These 244 environmentally relevant questions from all technological subfields will be the basis of further analysis in this section. This procedure, too, must be discussed methodologically as to its impact on the results, a first outline of such a discussion is presented in section 3.1 of this paper.

In the following presentations, too, the *ten* highest ranking topics are presented (cf. the methodological remarks in section 2.0), if not an equal ranking of topics mentioned by the panelists enforces to present a larger number of topics. This is the case for the ranking of

- highest importance (where 11 topics are ranked first)
- the mean estimate of the earliest year of realisation (with 17 topics)
- the mean estimate of the latest year of realisation (11 topics)
- the highest ranking of assumed legal restraints for realisation (11 topics)
- the highest ranking of assumed problems for realisation due to development costs (14 topics).

Within the order of "highest ranking" we have maintained the ranking according to ordering numbers (technological field/number of the topic) which is absolutely arbitrary, too: results of this ranking method may, therefore, not be interpreted.

Among the ranking of each "top ten" in the eight fields analysed there are only eleven topics that are contained in two different rankings (table 4), so that the Annex-tables 1 - 8 contain 82 (34%) of the 244 topics refering to environmental issues in the Delphi survey.

The eleven *most important* environmental topics (Annex-table 2) were being estimated at almost the same level of importance (index between 98 and 96). They

Table 3: Composition of the transversal environmental topics

No	Technological Area	No of Topics in the German Delphi Survey	Topics concerning environment	
			number	**% of technological area**
1	Materials, Materials Processing	108	16	15
2	Electronics and Information Technology	107	7	7
3	Biosciences	98	18	18
4	Elementary Particles	40	10	25
5	Marine and Geosciences	82	27	33
6	Resources, Water Management	39	15	39
7	Energy	51	23	45
8	Ecology, Enviromental Technology	50	50	100
9	Agriculture, Forestry, Fishery	73	28	40
10	Production Technology	72	12	17
11	Urbanisation, Construction	65	17	26
12	Communication Technology	65	1	2
13	Aerospace	46	7	15
14	Transport	62	9	15
15	Health Care	108	0	0
16	Society, Culture	81	4	5
	Total	**1147**	**244**	**21**

can be grouped to subject areas: there are three questions concerning climate change (5/40, 8/4, 8/12), two questions each in the areas water resources (6/32, 11/45), energy (5/66, 14/15), waste and waste reduction (11/51, 9/69) and one each in the areas control/measurement (4/27) and urban planning and construction

Table 4: Correlation of topics - rank numbers

Topics		Importance	Earliest realisation	Latest realisation	Technical problems	Legal constraints	Development costs	Low level of human capital	Insufficient R&D-system
5 / 66	Control of artificial heat generation and accumulation of heat in the air through improved technologies for utilizing natural energy, leading to successful heat balancing of the earth.	1		8					
11 / 51	Development of waste recycling technology, enabling the amount of city waste (i.e., that must be disposed of) to be reduced to half its current level.	3	4						
9 / 69	Widespread and general use of biodegradable packing materials that can be decomposed naturally to harmless substances by microorganisms, enzymes or the like.	6					12		
5 / 40	Elucidation of the mechanisms of the formation, change; and extinction of the ozone layer surrounding the earth.	8	8						
8 / 4	Practical use of materials that replace fluorocarbon and halon, that do not damage the ozone layer and cause no global warming problem.	9			7				
3 / 97	Elucidation of the behaviour of microorganisms in the biosystem and practical use of genetically engineered microorganisms released into environments.		7			1			
5 / 41	Practical use of international monitoring systems for changes in the atmospheric composition of the stratosphere.		9					5	
6 / 19	Practical use of economical methods of segregating valuable substances in city garbage for their retrieval.		10		5				
5 / 22	Establishment of a comprehensive marine ecosystem theory, enabling elucidation of impacts on the ecosystem arising from marine development.							2	2
5 / 7	Development of technologies based on large-scale numerical models for forecasting changes in the global oceans.							1	5
16 / 10	Practical use of technologies that will eliminate NOx and other pollutants that cause today's air pollution.				9		13		

(11/43). The topics concern foremost problems and consequences of growing urbanisation which is one of the most relevant problems of sustainable development. It is mostly not the case of developing basically new technologies but rather of putting available technologies into practical use. Many of the topics are - to varying extents - in the process of being introduced into application in western industrialised countries (11/51, 11/43, 6/32, 15/15, 9/69, 11/45, 8/4). This is being supported when looking at the early realisation times which are expected mostly in the next decade. The main constraints, therefore, are less technical but rather cost problems.

As for the mean estimation of the *earliest years of realisation* seventeen instead of ten topics have to be considered (Annex-table 3). The four topics expected to be realised earliest (i.e. until 1995 or 1998) have, in the meantime, indeed been realised, at least to a considerable extent. As one would have expected, they fall into the late categories of the innovation cycle, that is practical use or even widespread use. This makes clear that the foregoing phases of elucidation of a principle or establishment (of an acknowledged method) have already been passed. This situation makes it most intelligible that these topics have been ranked highest with regard to this dimension of analysis. The following 13 topics all are expected to be realised by the year 1999 (mean estimate). Again, most of them are concerned with the late innovation phases practical use or widespread use. They concentrate mainly on technical and organisational problems of water supply and waste water as well as on waste prevention and recycling in urban regions.

Eleven topics make up for the *latest years of realisation* (Annex-table 4) which refer to the years 2017 and later (until 2021), i.e. twenty-four to twenty-eight years after the survey was conducted. These are not simply the mirrored pictures of the topics with earliest realisation estimates. Among these highest rated latest realisation years there is no topic concerned with the diffusion phase of realisation ("widespread use"), although seven of the eleven topics (almost two thirds) concentrate on the phase of "practical use", indicating that the problems of putting ideas into working practice are expected to have been solved up to then. The topics concentrate on medium- or long-term problems of securing human living. Most of these topics are rated rather low as to their importance. We think that a contradiction becomes apparent between importance and the urgency of required solutions: the farther a solution is being expected for the future, the lower the importance is being estimated, even if essential conditions of human living are touched.When regarding the constraints for realisation of the proposed topics the experts were asked to choose up to two among the following seven: technical problems, legal aspects, cultural factors, development costs, shortage of investment capital, low level of human capital, insufficient R&D system in Germany. From the results it follows that the two most important constraints are technical problems (with 95 - 56% of the experts naming this for one of the topics) and development costs (named by 86 - 63% of the experts). These are followed on a lower level by a perceived insufficiency of the German R&D system (58 - 43%) and legal problems, whereas a low level of human capital was only diagnosed by 8 - 14% of the experts as being a major constraint for the realisation of the technologies in question.

The ten topics with the highest ranking of assumed *technical problems for realisation* (Annex-table 5) concentrate on questions of climate change and measurement/control with three topics each. Questions on climate change like the substitution of fluorocarbon and halon (8/4 and 16/10) also receive highest rankings as to importance while the relatively low rating (index 78) of the importance of changes in the cultivation of rice plants to minimise nitrogen emissions (9/9) may point to some degree of ignorance of German experts towards a problem which they are not familiar with. Unlike one might have expected there is no correlation of the ten topics rated highest with technical problems for realisation and the ten most important topics which cause realisation problems because of a low level of human capital, and hardly any correlation with the ten mostly named topics which state an insufficient German R&D system. The reasons for these unexpected results would have to be investigated.

For assumed *legal restraints for realisation* eleven topics were ranked highest (Annex-table 6). While the other topics were mentioned from between 47 and 27% of the experts as being among the most important for legal constraints, one topic excels by being rated from 73% of the experts: this concerns the practical use of genetically engineered microorganisms (3/97). Among the remaining ten highest ranked topics there are four more topics concerned with biotechnology (8/48, 9/12, 9/46, 3/25), two topics being concerned with radioactive waste (7/28, 7/27), and two topics which propose to use information technology/standards for a thorough observation and control of the state of the environment. These scorings certainly give a realistic estimation of the state of the public discussion of these topics in Germany, which is often followed by the action of political decision makers.

There were 13 topics ranked highest with regard to assumed *problems for realisation due to development costs* (Annex-table 7). The range of ratings amounts from 86% of the experts to 63% with the last four topics. There is a concentration on observation/measurement/control technologies of which three topics have been named (5/16, 5/12, 5/21) and on solar devices (7/15, 7/16). Among the 13 topics of assumed problems for realisation due to development costs there are also four topics with a high index of importance (between 97 and 91); these concern cleaning technologies for waste water (6/32), biodegradable packaging materials (9/69), the elimination of air pollutants (16/10), and the noise reduction of large freight vehicles (14/25).

Analysing, finally, the ten most prominent topics being judged as causing *problems for realisation because of an insufficient German R&D system* (Annex-table 8), most of them (some 70%) refer to the early phases of innovation (elucidation, development). While a concentration on marine topics may be explicable because Germany has no substantial marine resources and the concern thus is not being felt adequately, we have no explication why an insufficiency in the German R&D system is being judged as a prominent problem for realising solutions in impact analyses and prognoses (6/39, 5/22, 8/23, 11/42) or the use of biological systems for anthropogenic needs (10/21, 11/42). Among the ten topics rated highest as causing problems for realisation because of an insufficient German R&D system the ranking for "importance" has been judged rather high which we interpret as a sign of a high degree of sensitivity for environmental questions in Germany. The high ranking of these topics for the "necessity of international cooperation" may point to the need of compensation for the deficiencies being felt in the German system.

3 Interpreting foresight data and research priorities

Policy makers and strategic deciders in all organisations of society need to get information input concerning their decisions as to future developments. And of course they would like to have this information as precisely as possible - forecasting rather than foresight is what they want. But to predict future scientific and technological development is a task which is objectively spoken not possible. Any study dealing with technological foresight can only provide ideas and add more information to a process of long-range thinking and planning (for a review of studies cf. Grupp 1993). Still there remains the highly important question - what can be learnt by foresight exercises with regard to research priorities? Two aspects of this topic shall be shortly discussed here: methodological questions and the valuation of research priorities.

3.1 Methodological remarks

One main problem of a Delphi survey is the *generation of the foresight questions* asked. Regarding the research question of identifying those technologies which will have the greatest impact on economic as well as on social development, the creation of the questions is a very difficult task. In order to complete this task as successfully as possible a steering committee was set up to prepare the fifth Japanese Delphi survey (which was deliberately duplicated in the German survey 1993). High ranking personalities from industry, academia and public organisations were asked to join this steering committee which was in charge of the study. This steering committee decided on *16 technological areas* which were covered by the survey (cf. table 3). For each area a subcommittee of 5 to 10 experts developed guidelines for selecting those topics which were judged to be of major importance considering future directions of technological development for each area. About half of all topics were reprinted from the previous fourth Delphi survey depending on the development during the last five years. If a topic had been realised during this period it was either omitted from the questionnaire or the wording was changed towards another stage of development. The other part of the topics were new, generated for each technological area using suggestions from the experts and comments from the participants of the fourth Delphi survey.

In total about 1050 experts participated in the first round of the German survey. This response rate of 30% may seem low, but taking into account that such a survey was done in Germany for the first time, the project team was quite content with this response rate. Three main reasons may explain this relatively low response rate. First, up to very recently the German government was not very active in technology foresight activities. With the notion of "unpredictability" of events in science and technology, this activity had not been appreciated by other public science bodies, either. Therefore, the confidence of the respondents in meaningful results was assumed to be low. (One typical German respondent argued "I hope that - in the best case - the policy impact of the Delphi will be zero. You cannot predict science. Government planners should know this. Strong priority setting enforces meaningless projects...".) The second reason is that - due to the *pilot character* of the survey in Germany - it was difficult to predetermine the most pertinent sub-area of expertise of each respondent. To overcome this difficulty at least partly, more than one questionnaire was sent out to some industry experts in order to let them choose their special fields themselves. The other experts, too, were provided with the possibility to change the subject of the questionnaire which had been sent to them to another technical area. Lastly, the Japanese procedure used a filter survey just asking for the willingness to respond to the Delphi process, and sent questionnaires only to those persons affirmative to the initialising procedure, this explains the high Japanese respondance rate which is not comparable to the German one in the first round.

In sociology, most scientists assume that there is a positive relationship between involvement in a specific research area and the assessment of it and that this relationship derives from the tendency of scientists to select problems in areas where there is high pay-off for successful solutions and career. The tendency to overrate fields in which a person works may be termed "bias". Shrum (1985) found not only a tendency toward positive bias for fields in which researchers have been active, but also this bias to be stronger in less innovative sub-fields. A test for Delphi expert biases in the *energy* area (Shrum's investigation also dealt with energy research) tends to support this view in specific technology fields of the survey: active experts rate the importance of their own reserach speciality significantly higher than the other experts - both in Japan and in Germany. At the same time, the top experts downplay technical constraints in Germany (less so in Japan).

The selection of experts for the area of ecology/environmental technology (technological subfield 8) has proved to be difficult. Though the original pool of experts identified through the on-line databases was relatively large (510 addressees) a slightly lower than average respondance rate signals difficulties in participation. This is confirmed when analysing the expertise of the respondents: with the majority of topics, experts with "minor" expertise (knowledge drawn from journals/other experts) is predominant. This is probably due to the heterogeneity and the extreme breadth of the field, so that most experts have only a small segment of own expertise and only minor knowledge about the other topics. Topics with a concentration of expertise (one third or more answers from respondents with great or medium expertise ["active experts"]) refer to

global aspects

- acid rain (topics 20, 21)
- reduction of CO_2-emissions (topic 12)

regional aspects

- practical use of techniques for decontamination of soil (topic 50)
- widespread use of product design for recycling (topic 38)
- substantial rise of heat efficiency for waste fuel power generation plants (topic 41)
- development of methods to assess socio-economic damage because of the destruction of the natural environment and use of these methods for preventive purposes (topic 42)
- establishment of methods for screening systems for harmful chemical substances (topic 46)
- widespread use of environmentally friendly vehicles (topic 49).

From the numerous comments of the German experts it becomes evident that there exists quite some uncomfortness with this Japanese approach to foresight of the future development of the topic of ecology/environmental technology. In various cases, the topics have been estimated as being too strongly technically oriented and also, to some extent, too Utopian. This concerns especially possible strategies of storing or fixing CO_2 in large quantities. This techno-centric approach would lead to cure symptoms instead of tackling the causes and the global interactions of the environmental problems. Furthermore, the German experts claim that plenty of the topics dealt with are technically solved already or will be in the near future, but because of political reasons are not fit for accomplishment.

Generally, it has been criticised that the technical subfield "ecology/environmental technology" contained too few truly ecological questions. A large part of the themes rather were concerned with technical remedies for environmental problems. From this point of view, there resulted a couple of propositions to add questions, especially concerning the elucidation of complex ecological connections including biological components.

While for the analysis of environmental topics it would not have been adequate to restrict it to subfield 8: ecology/environmental technology, our procedure to include topics from all subfields raises a methodological problem. The information gathered in the other subfields has been collected in its respective context - without reference to it being environmentally relevant, i.e. Taking into account that the experts have answered from their specific perspective to the subject, we have to be aware that especially the weighting of importance will not be comparable amongst each other: judgement on the importance of a question in the technological subfield "transport" will reflect the hierarchy of preferences for tranport problems, not necessarily the one for environmental problems, though these might be heavily affected.

The questions asked in a Delphi survey have of course a great influence on the findings and on further interpretations. As the questions were translated from the Japanese questionnaire a strong Japanese influence on the survey design is obvious. This might be one explanation why Japanese experts rated the importance of all questions generally higher than German experts. In order to find out if a difference in judgement already exists on the level of selection, typical German (or European) questions have to be developed. Developing these questions and comparing the results of a second German survey to the questions and results of the Japanese survey was a logical next step towards establishing Delphi foresight as a tool for research policy and strategic planning in Germany which is being finalised at present (midyear 1997) by ISI with the funding from the German Federal Ministry for Education, Science, Research and Technology (BMBF).

3.2 Consequences for research priorities in environmental issues

When comparing Japanese and German results of the Delphi survey, two principal results were found.

- For many topics the results of the German survey proved to be more or less the same as in Japan. In these cases, this provides evidence that the Delphi procedure does not depend on national influences and peculiarities to any great extent. Progress in technology does appear to be truly international in nature with practically no information deficits in major industrial countries. This could indicate towards growing openness of world-wide scientific and technological information (including its flowing to and from Japan despite the language barrier).

- In the other extreme, for several items strong discrepancies in both surveys are found in many fields and in many details, pointing to the dominance of national communities and systems of innovation. The main conclusion for these cases is that Delphi inquiries on technology should always be undertaken with an international panel including people from many countries and continents.

For many other topics, no such extreme nor simple results were found but a mixture of congruent and diverging results.

The accuracy of estimations is - for Japanese and German experts likewise - strongly and positively correlated with the time of realisation. Topics estimated to be realised earlier are easier to predict and accuracy of the judgement is higher. This finding was expected, as short-term innovations are easier to foresee than innovations which will be made in the long run. Innovations to be made during the next decade are present in the laboratories today, that is why the judgements of the experts are rather identical concerning the time of realisation.

Japanese organisations tend to look for international co-operations for those topics which have a long-term perspective for realisation. German results show no correlation between necessity of international co-operation and time of realisation. Interpreting these findings leads to the conclusion that one element of Japanese innovation strategies is seen in international co-operations but not in the short or medium term. However, long-term co-operations are considered to be an adequate tool for overcoming own weaknesses like an unsatisfactory research and development system. For short- or medium-term realisations the danger of undesired knowledge transfer to countries and organisations which will very soon be rival on the international market are one explanation why Japanese experts do hardly consider short- and medium-term co-operations. There is also a significant correlation between constraints and a high degree of necessity for international co-operations, whereas German findings show hardly any correlation between constraints and degree of international networking.

There is no scientific way to determine *research priorities*, because all such determinations include value decisions which must be politically discussed and decided. Scientific investigations can, though, deliver and analyse information which is needed to allow for informed decisions. This is what Delphi surveys and their scientific analysis aim at.

Because of the differing priorities of aims of different groups of actors, the material of Delphi surveys has to be evaluated according to their respective frameworks of aims and means. To illustrate shortly the possibilities concerning priority setting on the basis of Delphi survey results, this paper assumes the position of a decider for public technology policy measures. Certainly one of the most important variables available from the survey is the estimation of importance of the topics by the expert panelists. Asssuming a general situation of need for and shortage of financial means to support research and development activities, it would be advisable to concentrate on those topics which were rated as the most important ones among the 244 concerning the transversal issue of environment (but see also the remarks about minority opinions in section 3.1 of this paper). But it would certainly not suffice for priorisation to be based on this sole factor. For all other information collected in the survey there is no unambiguous way to evaluate and include the variables into R&D priority decision making.

Three practical *examples shall illustrate the possibilities of research priority setting* on the basis of the information gathered in a Delphi survey:

(1) Topic 11/51: Development of a waste recycling technology which enables the amount of city waste which must be disposed of to be reduced to half its current level (cf. Annex-table 2)

This topic concerns the development phase of an innovation process. German experts rated this topic almost unanymously as important (index 98). Almost half of the experts (48%) judge that Germany is leading in R&D in this field, whereas none holds Germany's strongest competitors Japan or the USA as leading. The necessary further development still incorporates significant technological problems (named by 40% of the experts, which attaches this topic to the upper region of such topics) and suffers from the amount of development costs needed (with 44% of the experts' votes also belonging to the upper ranges of these constraints for realisation). An insufficient R&D sytem was named by only 20% of the experts which means that it was rated as being rather less important. Concerning the diffusion phase of innovation there is a relatively low level of expected legal constraints for realisation (8% of the experts); together with the experts' judgement of a low level of a lack of investment capital (8%) this points to the expectation of the experts that the diffusion phase after the expected early realisation in the year 1998 should not be hampered too much by the constraints investigated.
Taking these features into account, this topic might be a prototype example for an innovation-oriented R&D support. The intention of public policy to prioritise this topic might be derived from the expectation of gaining a „double dividend" of environmental relief and economic success. The German position indicates an international lead in R&D. Japan was not named by any of the German experts as leading in R&D in this field; but as Japan suffers from a comparably tight situation with municipal wastes, this indicates a potential for exportation for possible German technologies (also covering other (European) countries), though possibly not to the USA, because the environmental

pressures there are being felt less strongly (which possibly explains why the USA are not being judged leading in R&D for this topic).

(2) Topic 8/38: Widespread use of product design techniques for easy recovering and separating materials of disposed durable consumer goods for recycling purposes (cf. Annex-table 1)

Since two decades or more, a majority of OECD memeber countries consider innovation (understood as practical application of processes or market entrance of products) and diffusion of supported technologies as one of the goals of public research and technology policies. Considering the goal of environmental relief, public policy aims at the widespread use of the best available technology. This "far end" of the innovation process does not normally belong to research and technology policy, yet it can contribute to this goal.
From the evaluation of topic 8/38 which is judged highly important by the experts (index 90) there follows a series of reasons for a public research and technology policy: although "design for environment" (DFE) is developing since a couple of years already, 43% of the experts state that there still exist technological problems, and also 43% rate high development costs as major constraint for the realisation of this goal. Both these factors may well be reasons for activities from public research and technology policy. Together with the estimation of 45% of the experts that Germany is leading in R&D in this field this would make a good chance to at least deliver the technology in time so that the status of widespread use may be reached until the year 2004 (mean estimation of the time of realisation). But 21% of the experts also point to legal aspects as a major constraint for the achievement of the goal. Most probably there is no remedy from research and technology policy for this problem which may severely delay realisation.

(3) Topic 6/27 (cf. Annex-table 3) seems to provide an example where research and technology policy can deliberately set a posteriority. The "effective use of water resources with very few cases of leakage of waterworks" is being judged as medium important (index 76) and there seem to be only few technical problems (28%) and even no problem from high development costs; furthermore, the German R&D system is widely judged as being sufficient. The main constraint for realisation is seen here in a shortage of investment capital (56% of the experts). So if not there is a chance to reduce the need for investment capital through R&D, this topic would probably need no priority attention from research and technology policy.

These examples could only sketch the possibilities to analyse the material from the Delphi survey from the point of view of a political decision maker. It has become clear already from this short sketching that the material has to be amended with other information in order to come to priority decisions. Furthermore, it is necessary to include value decisions to achieve priorisations. The same holds true, of course, for decision makers in other organisations likewise.

Concerning the usefulness of the whole investigation, it is expected that not only the analytical part of the Delphi survey will provide important information for future German technology policy but also that there was and will be an impact on the panelists themselves. Through answering the questions and checking their opinion with the anonymous assessments of other experts, the participants in the survey are likely to benefit from a learning effect. They were all provided with the estimates of other panellists in the course of the study and are free to make use of this information during their own future research.

A Delphi survey is only one possible approach among many others to be used for technological foresight studies. Any technological foresight has to be integrated into global studies which also take into account social and economic developments in the future. Foresight can only contribute to a "better" future if *all aspects of human life* are integrated into a global picture. In order to develop detailed studies which consider technological as well as social and economic topics the scope of any foresight has to be restricted to certain aspects of the future - such as the development of a specific economic sector or societal bottleneck.

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Annex Tables

Annex Table 1: The ten topics ranked most important in technological subfield 8 "ecology, environmental technology"

	Topic	Index of importance	Time of realisation: lower estimation	Time of realisation: mean value estimation	Time of realisation: upper estimation	Index for necessity of international co-operation	International comparison of the research and development levels (%): USA leading	Japan leading	another country leading	Germany leading	Constraints for realisation (%) 2 choices: technical problems	legal aspects	cultural factors	development costs	shortage of investment capital	low level of human capital	insufficient R&D-system
4	Practical use of materials that replace fluorocarbon and halon, that do not damage the ozone layer and cause no global warming problem.	**96**	1997	1999	2003	84	20	4	7	35	63	9	6	43	13	0	17
12	Worldwide reduction of the emission of carbon dioxide (per year) by 20% of the current level.	**96**	2003	2009	2020	96	12	14	7	40	44	9	33	44	19	2	2
13	Possibility of controlling an increase in the concentration of the greenhouse effect gases (other than carbon dioxide) in the atmosphere.	**90**	2003	2007	2012	98	9	11	9	34	60	6	25	42	17	2	11
26	Elucidation of impacts exerted by destroying tropical forests upon climate and weather.	**90**	1999	2003	2008	91	22	2	24	16	31	0	8	18	14	2	39
38	Widespread use of product design techniques easy to recover and separate materials of disposed durable consumer goods for recycling purposes.	**90**	2001	2004	2010	59	6	9	11	45	43	21	17	43	6	4	8
28	Development of effective recovering technologies for reproducing damaged tropical forest ecosystem.	**89**	2010	2017	2022	83	9	2	18	5	41	0	20	30	18	5	30

32	Widespread use of fuel control technologies in virtually all types of automobiles, capable of meeting the emission control standard for nitric oxide on the order of 0.1 w 0.2 g/km. (The current level for heavy diesel motorcars is on the order of 4 to 5 g/km, and the standard control value for gasoline passenger cats in 1978 is 0.25 g/km.)	**88**	2000	2003	2007	61	24	29	7	31	44	22	7	42	11	0	9
45	Accumulation of knowledge concerning the fate of hard degradable chemical substances after release into the environment in advance to their production.	**87**	2003	2008	2013	69	10	8	15	31	44	6	10	19	10	6	42
35	Development of a compact, waste water treatment system applying biotechnology, enabling highly efficient treatment of hardly decomposable and harmful substances	**87**	2001	2003	2005	52	4	15	15	40	68	0	2	43	19	0	17
46	Establishment of techniques, models, and data bases for biological testing and measurement of the harmfulness of chemical substances resulting in the construction of screening systems for harmful chemical substances.	**86**	1999	2002	2005	79	18	10	16	31	20	8	14	37	10	8	35

ISI: German Delphi (basic data: BMFT 1993)

Annex Table 2: Enviromental issues - 11 most important topics

Topic		Index of importance	Time of realisation			Index for necessity of international co-operation	International comparison of the research and development levels (%)				Constraints for realisation (%) 2 choices						
			lower estimation	mean value estimation	upper estimation		USA leading	Japan leading	another country leading	Germany leading	technical problems	legal aspects	cultural factors	development costs	shortage of investment capital	low level of human capital	insufficient R&D-system
5 / 66	Control of artificial heat generation and accumulation of heat in the air through improved technologies for utilizing natural energy, leading to successful heat balancing of the earth.	**98**	2008	2017	2021	82	10	5	10	30	50	0	15	45	10	0	30
11 / 43	Development of planning and construction technology enabling new urban development or urban redevelopment in harmony with the natural environment.	**98**	2001	2004	2009	81	7	4	11	19	7	4	15	44	11	7	48
11 / 51	Development of waste recycling technology, enabling the amount of city waste (i.e., that must be disposed of) to be reduced to half its current level.	**98**	1996	1998	2000	48	0	0	20	48	40	8	8	44	8	0	20
4 / 27	Practical use of large-capacity recording equipment with a writing speed of 1 GB or more per second.	**97**	2000	2002	2004	79	29	65	6	0	76	0	0	24	12	0	6
6 / 32	Widespread use of technologies for removing wider range of pollutants than such ordinary pollutants as BOD substances in the treatment of waste water.	**97**	2005	2008	2012	77	7	11	0	37	44	4	11	70	37	4	4

14 / 15	Widespread use of motorcars with extremely low fuel consumption that is 30% lower than the current fuel consumption for the same interior size owing to reduced weight achieved by significant introduction of new materials such as ceramics, aluminium and resins and improved output achieved by higher engine efficiency (e.g., the use of 2-cycle, direct-injection engines).	**97**	2000	2003	2008	67	4	28	6	43	55	9	4	19	9	2	13
5 / 40	Elucidation of the mechanisms of the formation, change; and extinction of the ozone layer surrounding the earth.	**96**	1996	1999	2003	96	55	5	14	23	45	5	9	32	9	5	36
8 / 4	Practical use of materials that replace fluorocarbon and halon, that do not damage the ozone layer and cause no global warming problem.	**96**	1997	1999	2003	84	20	4	7	35	63	9	6	43	13	0	17
8 / 12	Worldwide reduction of the emission of carbon dioxide (per year) by 20% of the current level.	**96**	2003	2009	2020	96	12	14	7	40	44	9	33	44	19	2	2
11 / 45	Improvement of water quality by building various water treatment facilities, seawater exchanging facilities, etc. in estuaries and bays near metropolitan areas suffering severe pollution and contamination.	**96**	1999	2002	2009	77	5	10	20	10	10	5	10	65	30	0	5

ISI: German Delphi (basic data: BMFT 1993)

Annex Table 3: 17 topics with earliest time of realisation (mean estimate)

Topic		Index of importance	Time of realisation			Index for necessity of international co-operation	International comparison of the research and development levels (%)				Constraints for realisation (%) 2 choices						
			lower estimation	**mean value estimation**	upper estimation		USA leading	Japan leading	another country leading	Germany leading	technical problems	legal aspects	cultural factors	development costs	shortage of investment capital	low level of human capital	insufficient R&D-system
5 / 10	Control of artificial heat generation and accumulation of heat in the air through improved technologies forutilizing natural energy, leading to successful heat balancing of the earth.	27	1993	**1995**	1998	27	11	0	16	11	21	0	0	63	16	0	0
5 / 37	Widespread use of various undersea robots for use in observation, inspection, and other work operations at a depth of 300 m.	63	1993	**1995**	2000	38	38	10	29	10	48	5	0	57	0	0	0
7 / 51	Domination of non-Freon type air-conditioning systems.	94	1996	**1998**	2000	73	13	10	11	48	44	18	7	49	8	2	5
11 / 51	Development of waste recycling technology, enabling the amount of city waste (i.e., that must be disposed of) to be reduced to half its current level.	98	1996	**1998**	2000	48	0	0	20	48	40	8	8	44	8	0	20
1 / 104	Elucidation of adhesion mechanisms of metal-polymer interface.	67	1996	**1999**	2003	79	25	2	9	25	23	16	7	45	11	5	18
3 / 80	Establishment of controlling technologies and practical application of technologies that use complex system of microorganisms to produce useful substances.	74	1995	**1999**	2003	62	24	31	20	14	61	20	6	22	12	0	12

3 / 97	Elucidation of the behaviour of microorganisms in the biosystem and practical use of genetically engineered microorganisms released into environments.	73	1996	**1999**	2005	77	47	20	24	6	14	73	35	8	2	0	12
5 / 40	Elucidation of the mechanisms of the formation, change; and extinction of the ozone layer surrounding the earth.	96	1996	**1999**	2003	96	55	5	14	23	45	5	9	32	9	5	36
5 / 41	Practical use of international monitoring systems for changes in the atmospheric composition of the stratosphere.	90	1997	**1999**	2002	98	45	5	10	15	45	0	10	55	15	10	15
6 / 19	Practical use of economical methods of segregating valuable substances in city garbage for their retrieval.	93	1996	**1999**	2002	54	7	4	4	59	67	22	7	59	4	0	4
6 / 26	Widespread use of recycling systems for sewage and waste water even in small-scale plants, based on advances in treatment technology.	86	1997	**1999**	2003	52	9	0	13	47	47	6	0	56	19	3	13
6 / 27	Effective use of water resources with very few cases of leakage of waterworks.	76	1997	**1999**	2004	44	4	8	4	28	48	0	0	56	12	4	12
7 / 11	Practical use of a wind power generation system of a megawatt scale.	59	1996	**1999**	2003	33	17	1	41	33	39	26	13	66	6	1	1
8 / 50	Practical use of techniques for on-site detoxification of soil contaminated with heavy metals or chemical substances (e.g., residue of agricultural chemicals).	79	1997	**1999**	2003	45	9	0	13	43	51	2	4	60	13	0	15
10 / 8	Widespread use of methods for processing materials that have been produced by ultra-precision casting or forging, by grindstones to replace the cutting methods of processing.	62	1997	**1999**	2003	42	10	23	8	38	72	0	5	38	5	0	18
11 / 3	Establishment of comprehensive, wide-area water control and management technology for rivers, dams, and other water resources in the vicinity of major cities, enabling a more effective use of water resources.	85	1996	**1999**	2002	72	8	4	0	38	17	21	17	54	17	0	21
16 / 24	Widespread use of various artificial products that provide a touching sensation similar to that of natural substances such as mink to aid the conservation of nature.	35	1996	**1999**	2004	45	15	3	6	12	15	3	39	21	9	0	0

ISI: German Delphi (basic data: BMFT 1993)

Annex Table 4: 11 topics with latest time of realisation (mean estimate)

	Topic		Time of realisation				International comparison of the research and development levels (%)				Constraints for realisation (%) 2 choices						
		Index of importance	lower estimation	**mean value estimation**	upper estimation	Index for necessity of international co-operation	USA leading	Japan leading	another country leading	Germany leading	technical problems	legal aspects	cultural factors	development costs	shortage of investment capital	low level of human capital	insufficient R&D-system
8 / 16	Creation of coral reefs capable of fixing carbon dioxide at the rate of 5 kg/m2 per year or more.	42	2015	**2021**	2023	57	0	17	4	0	61	4	4	22	26	0	13
13 / 27	Practical use of lunar materials (e.g., Si, O_2 and ^3He) as natural resources.	45	2017	**2021**	2023	100	50	0	18	5	50	0	0	59	36	0	5
7 / 9	Development of space solar power generating systems.	27	2014	**2020**	2022	86	46	7	4	4	60	1	3	56	15	0	10
8 / 15	Practical use of technologies for collecting carbon dioxide from large boilers at thermal power plants and the like, and for dumping it without causing serious environmental impact to the ocean deep (3,000 m or deeper), gas fields and the like.	46	2013	**2020**	2023	59	5	13	8	15	59	5	10	46	13	0	5
9 / 50	Practical use of technologies for constructing seaweed "pastures" in undeveloped areas such as sandy beaches and estuaries to exploit the potential productivity of marine organisms.	15	2018	**2020**	2023	44	0	0	17	0	17	17	17	17	0	0	0
8 / 44	Determination of presence or absence of trans-generation effects of environmental contamination on human beings.	69	2008	**2018**	2022	74	14	0	12	10	29	0	12	21	12	2	33

2 / 90	Practical use of systems to guard information from destruction or loss due to natural disasters or human intention.	71	2007	**2017**	2022	86	22	3	9	0	63	3	19	9	6	0	6
5 / 66	Control of artificial heat generation and accumulation of heat in the air through improved technologies for utilizing natural energy, leading to successful heat balancing of the earth.	98	2008	**2017**	2021	82	10	5	10	30	50	0	15	45	10	0	30
7 / 26	Practical use of sophisticated reprocessing technologies capable of group separation. The separation of nuclides from high-level radioactive wastes according to half-life or the like (e.g., the separation of TRU elements, 137Cs, 40Sr, and elements of the platinum group).	48	2012	**2017**	2021	79	5	6	28	8	57	23	8	29	6	0	8
7 / 29	Development of quenching processing technology for radioactive waste based on high-energy elementary particles.	61	2011	**2017**	2022	86	15	2	26	4	62	11	4	34	4	2	13
8 / 28	Development of effective recovering technologies for reproducing damaged tropical forest ecosystem.	89	2010	**2017**	2022	83	9	2	18	5	41	0	20	30	18	5	30

ISI: German Delphi (basic data: BMFT 1993)

Annex Table 5: 10 topics with highest ranking of assumed technical problems for realisation

Topic		Index of importance	Time of realisation			Index for necessity of international co-operation	International comparison of the research and developmet leves (%)				Constraints for realisation (%) 2 choices						
			lower etimation	mean value estimation	upper estimation		USA leading	Japan leading	another country leading	Germany leading	technical problems	legal aspects	cultural factors	development costs	shortage of investment capital	low level of human capital	insufficient R&D-system
4 / 25	Development of charged-particle detectors with a time resolution of 10 ps.	65	1998	2001	2004	53	5	10	20	10	**95**	0	0	5	15	0	5
2 / 49	Development of biosensors continuously usable for at least 3 years.	77	2005	2009	2014	74	29	12	12	12	**94**	0	0	12	0	0	12
3 / 19	Development of biomimetic devices (stable molecules which have the same functions as those of biological molecules and which are made up of components other than peptide).	57	2002	2006	2011	61	14	10	10	7	**72**	7	3	14	10	0	21
5 / 4	Practical use of automatic observation systems which are fixed at open sea and are capable of long-term (a few years) monitoring of marine phenomena and conditions from the vicinity of the sea surface down to 6,000 m depth.	56	2000	2005	2009	86	24	5	29	5	**71**	0	0	57	5	0	14
6 / 19	Practical use of economical methods of segregating valuable substances in city garbage for their retrieval.	93	1996	1999	2002	54	7	4	4	59	**67**	22	7	59	4	0	4
14 / 54	Development of innovative quiet helicopters that satisfy environmental standards even if taking off or landing near urban districts.	58	2004	2008	2012	58	25	4	4	17	**67**	8	0	13	17	0	8

8 / 4	Practical use of materials that replace fluorocarbon and halon, that do not damage the ozone layer and cause no global warming problem.	96	1997	1999	2003	84	20	4	7	35	**63**	9	6	43	13	0	17
5 / 18	Construction of artificial islands for processing waste for offshore dumping in waters to about 100 m depth. (Refuse is completely disassembled and decomposed for the purpose of dumping harmless parts and recycling useful parts of the refuse).	26	1998	2011	2013	29	8	8	0	8	**62**	31	8	38	0	0	8
16 / 10	Practical use of technologies that will eliminate the NOx, and other pollutants that cause today's air pollution.	95	2003	2008	2012	88	13	13	5	34	**61**	0	5	63	18	0	5
9 / 9	Practical use of rice plant cultivation by developing and utilizing symbiotic algae and fungi with a high nitrogen fixing function.	78	1999	2003	2007	72	6	32	12	0	**56**	3	3	15	18	6	18

ISI: German Delphi (basic data: BMFT 1993)

Annex Table 6: 11 topics with highest ranking of assumed legal restraints for realisation

Topic		Index of importance	Time of realisation			Index for necessity of international co-operation	International comparison of the research and development levels (%)				Constraints for realisation (%) 2 choices						
			lower estimation	mean value estimation	upper estimation		USA leading	Japan leading	another country leading	Germany leading	technical problems	**legal aspects**	cultural factors	development costs	shortage of investment capital	low level of human capital	insufficient R&D-system
3 / 97	Elucidation of the behaviour of microorganisms in the biosystem and practical use of genetically engineered microorganisms released into environments.	73	1996	1999	2005	77	47	20	24	6	14	**73**	35	8	2	0	12
8 / 48	Establishment of an evaluation system for man-made microorganisms which are created by biotechnologies including gene manipulation in open systems, and utilization of organisms useful for purifying the environment.	62	1999	2004	2010	82	33	6	8	11	17	**47**	22	6	3	0	25
9 / 12	Practical use of weed control technologies utilizing the characteristics of physiologically active substances or other organisms.	76	1996	2000	2004	72	15	5	18	5	45	**45**	8	18	8	3	13
7 / 28	Practical use of technology for the safe disposal of highly radioactive solid waste.	91	2001	2004	2008	89	11	9	33	28	46	**40**	36	19	1	1	6
1 / 50	Practical use of composite systems capable of garbage disposal based on the high-temperature methane fermentation technology and of waste combustion disposal.	85	1998	2002	2004	56	0	3	17	42	50	**33**	11	31	0	0	6
8 / 31	Completion of an internationally unified standard for environmental information which is based on worldwide monitoring of pollutants (air, water, etc.) and satellite communications.	79	2001	2005	2010	97	36	8	14	8	18	**32**	14	26	32	0	16

10 / 28	Widespread use of designing, producing, collecting and recycling systems which make it possible to recycle most used materials through legally establishing manufacturers' responsibilities for collection and disposal of disused products.	94	1998	2001	2003	77	2	6	4	66	54	**30**	4	58	16	0	10
9 / 46	Possibility of creating marine species that are highly resistant to water temperature changes and diseases by cell fusion, gene manipulation and other similar technologies so that they are advantageous for breeding.	26	1999	2006	2010	58	12	18	12	0	41	**29**	24	6	12	6	6
7 / 27	Practical use of reusing technology of low-level radioactive wastes.	60	2004	2008	2013	76	7	6	26	16	55	**28**	13	30	3	1	12
3 / 25	Development of technologies for developing germinal stem cells (germinal cells in the very early stage) to individuals by themselves.	61	1999	2004	2017	68	14	3	24	19	49	**27**	24	8	8	0	8
12 / 29	Widespread use of systems for gathering information of all kinds, (e.g., meteorological, environment monitoring, road traffic control) from a dense nationwide networks of telemeters by means of intersatellite communications integrating geomobile and geostationary satellite.	70	2000	2003	2007	92	36	11	5	7	34	**27**	9	43	25	0	0

ISI: German Delphi (basic data: BMFT 1993)

Annex Table 7: 14 topics with highest ranking of assumed problems for realisation due to development costs

Topic		Index of importance	Time of realisation: lower etimation	Time of realisation: mean value estimation	Time of realisation: upper estimation	Index for necessity of international co-operation	International comparison of the research and development levels (%): USA leading	Japan leading	another country leading	Germany leading	**Constraints for realisation (%) 2 choices**: technical problems	legal aspects	cultural factors	**development costs**	shortage of investment capital	low level of human capital	insufficient R&D-system
7 / 15	Widespread use of solar cells for residential power supply.	60	2002	2006	2011	39	15	21	13	37	22	11	7	**86**	18	1	1
5 / 16	Widespread use of continuous observation by using automatic floating observation boxes which move with the deep currents from the Antarctic Ocean to the northern hemisphere.	70	1996	2001	2004	91	25	13	31	6	38	0	0	**81**	13	0	0
7 / 16	Practical use of innovative passive solar houses which effectively use natural energy.	78	1998	2001	2004	30	9	5	25	42	11	25	9	**79**	25	2	2
5 / 12	Development of remote sensing technology using sea bottom stations that monitor temperature, current direction and speed, salinity, oxygen concentration, and other parameters at all depths.	68	1999	2003	2007	65	33	14	19	19	57	0	0	**76**	14	0	5
16 / 13	Widespread use of household trash boxes capable of automatically sorting refuse for easy carrying of the sorted refuse.	52	2003	2008	2014	35	0	3	3	35	44	9	0	**71**	12	0	3
6 / 32	Widespread use of technologies for removing wider range of pollutants than such ordinary pollutants as BOD substances in the treatment of waste water.	97	2005	2008	2012	77	7	11	0	37	44	4	11	**70**	37	4	4

8/49	Widespread use (e.g. globally more than 10%) of automobiles as urban transportation system (e.g. electrical automobiles) which do not cause conventional atmospheric or noise pollution.	71	2003	2007	2014	60	21	23	12	21	40	8	8	**69**	12	2	4
5 / 24	Development of safe, economically feasible technology for removal/detoxification of sea-bottom sludge, enabling widespread use of decontamination/recovery of fishery grounds (already employed at specific locations experimentally).	79	1999	2003	2007	62	13	13	20	7	67	7	0	**67**	13	0	13
16 / 14	Widespread use of recycling systems for fabrics and apparel, food packaging materials, and other home materials.	85	1997	1999	2003	37	0	0	0	58	37	12	19	**67**	9	2	0
14 / 25	Reduction of the noise of large freight vehicles to the noise level of the current regular passenger cars primarily through improved engines, transmissions, mufflers and tires.	91	2000	2004	2008	57	3	0	11	50	66	5	0	**66**	0	0	11
1 / 70	Widespread use of new alloys utilizing the principle of mechanical alloying.	51	1997	2000	2003	46	20	13	8	20	65	3	0	**63**	8	0	5
5 / 21	Inauguration of long-term integrated observation for the investigation mechanisms of coral reef as growth useful for carbon dioxide fixation by installing large-scale artificial reefs.	25	1998	2004	2013	38	6	6	19	13	50	0	0	**63**	6	0	6
9 / 69	Widespread and general use of biodegradable packing materials that can be decomposed naturally to harmless substances by microorganisms, enzymes or the like.	97	1998	2001	2004	78	8	3	5	23	33	5	13	**63**	0	0	10
16 / 10	Practical use of technologies that will eliminate NOx, and other pollutants that cause today's air pollution.	95	2003	2008	2012	88	13	13	5	34	61	0	5	**63**	18	0	5

ISI: German Delphi (basic data: BMFT 1993)

Annex Table 8: 10 topics with highest ranking of assumed problems because of an insufficient German R&D system

Topic		Index of importance	Time of realisation			Index for necessity of international co-operation	International comparison of the research and development levels (%)				Constraints for realisation (%) 2 choices						
			lower estimation	mean value estimation	upper estimation		USA leading	Japan leading	another country leading	Germany leading	technical problems	legal aspects	cultural factors	development costs	shortage of investment capital	low level of human capital	**insufficient R&D-system**
6 / 39	Development of technologies enabling accurate forecast of environmental impacts caused by very small amounts of pollutant.	81	2001	2006	2014	85	16	3	10	26	42	3	0	19	13	3	**58**
5 / 22	Establishment of a comprehensive marine ecosystem theory, enabling elucidation of impacts on the ecosystem arising from marine development.	67	2000	2004	2014	76	16	5	16	5	5	0	11	16	5	11	**53**
10 / 21	Development of machines which apply the biological energy converting mechanism to provide high energy converting efficiency.	87	2008	2013	2020	74	5	11	0	11	89	0	5	5	11	0	**53**
8 / 23	Elucidation of impacts exerted by marine pollutants upon the marine ecosystem.	79	2002	2006	2018	77	15	18	15	8	30	0	3	23	25	3	**50**
5 / 7	Development of technologies based on large-scale numerical models for forecasting changes in the global oceans.	72	1998	2003	2009	82	33	10	14	5	43	0	0	29	5	14	**48**
8 / 9	Possibility of accurate forecast of the sea level rise caused by global warming.	82	2001	2005	2009	93	30	2	14	18	52	2	5	20	9	2	**48**

11 / 28	Incorporation of countermeasures for harmful effects of noise, vibration, and lack of sunshine, etc., based on the establishment of methods of assessing the related social and economic loss as well s better understanding of their physical and psychological effects.	89	1998	2001	2004	67	8	4	13	21	13	21	42	17	0	4	**46**
11 / 42	Widespread use of techniques of urban planning, silviculture, and landscaping through scientific elucidation of the relationship between contact with forests and other plant life in natural settings and physiology and psychology.	90	2000	2003	2006	74	12	0	15	31	12	0	4	46	12	12	**46**
8 / 11	Determination of impacts of global warming on the whole world's agricultural production.	83	2001	2004	2008	90	29	2	24	10	43	4	8	27	12	0	**43**
8 / 29	Elucidation of impacts exerted by desertification upon climate and weather.	73	2001	2006	2009	77	13	0	28	3	30	0	3	18	10	0	**43**

ISI: German Delphi (basic data: BMFT 1993)