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Biotechnology versus agroecology: Entrenchments and surprise at a 2030 forecast scenario workshop

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A scenario workshop methodology was used to obtain various assessments of the prospects of multi-stress resistant plants. As biotechnological breakthroughs they are supposed to counter climate change and food shortages. In Europe, however, green biotechnology is highly controversial and positions have become rather entrenched. In our results, the scenario method showed itself to be highly suited to easing the grip of cognitive entrenchments and hierarchical communication structures. At least within the arena of the workshop, technologies as well as participants are on equal footing and can be grouped into various arrangements. This exposes participants to novel perspectives and engages them in deliberations on alternative science policy options, thus taking existing problems and needs into account rather than adapting society to the solutions and requirements of the envisioned technologies.

Keywords: innovation studies; green biotechnology; new cultivation methods; scenario method; alternative technologies; argumentative diversification.

1. Introduction

How to deal with a diverse range of technology development options from a science policy perspective? Participatory technology assessment (PTA) emerged on the scene with the promise to build ‘consensus’ among the stakeholders in technological controversies (Reed 2008; Susskind et al. 1999). Usually all sides applaud this proposal—hoping that during the procedure all opponents to their own vision would become convinced by their own arguments. Likewise, politicians are often happy to delegate the decision to such procedures since at least some technological conflicts are not so easily resolvable within the normal democratic polity: positions in biopolitical and environmental conflicts are often ‘oddities’ (i.e. not fitting into the usual party programmes and divisions between the parties). But, as history shows, the hope for ‘consensus’ is often illusory. Really entrenched positions are seldom given up within a participatory procedure. More generally, it might also be questioned whether the explicit aim of consensus building is even desirable (even if consensus was possible). More critical stakeholders might be prevented from joining the procedure, more controversial issues might be avoided, and rather vague recommendations (as the lowest common denominator) might be the outcome of the procedure (Coglianese 1999; van de Kerkhof 2006; Dryzek and Niemeyer 2006). Based on such considerations, Dryzek, in a constructive critique of deliberative democracy theory, has commented:

> In a pluralistic world, consensus is unattainable, unnecessary and undesirable. (Dryzek 2000: 170)

With regard to PTA this may mean that stakeholders should possibly find even more options or obtain a better understanding of the advantages, drawbacks and contradictions of the existing ones, but they need not necessarily agree on a single solution. In the face of risk and uncertainty, parallel development and experimentation with different options would probably be more resilient than the decision for the ‘one best solution’—be it a technology monopoly or a total ban on that technology. So, in contrast to most of the existing literature, we would like

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to show here that the scenario workshop method is useful to engage even rather entrenched stakeholders and their expertise without necessarily reproducing the already existing arguments over and over again. In our experience, the scenario workshop method has proved to be an effective instrument, even in the highly inert German genetically modified organisms (GMO) debate, engaging experts and counter-experts in more creative ways than would be the case when they enact their usual, and often highly ritualized, battles of words. Thus we do not propose consensus as a criterion for successful PTA procedures, but rather argumentative and/or technological movement and diversification away from the formerly entrenched positions.

The remainder of this paper is organised as follows. Section 2 sketches the specific problems and entrenchments that were at stake in the scenario workshop which we initiated to forecast the problems and possibilities of multi-stress resistant crop plants. Section 3 explains our application of the scenario workshop as a TA instrument. The resulting scenarios are described in Section 4, which provides— at least in some parts—a surprising fresh outlook on the future of green biotechnology. Finally, Section 5 discusses how the method can be further developed and used as a research policy tool.

2. Green biotechnology: Entrenched debate, new challenges

Green biotechnology has been developing since the 1980s, after it became possible to modify plants in the laboratory with the then new instruments of genetic engineering (Kloppenburg 2005; Wieland 2011). Major academic research institutions and life science corporations have invested heavily in personnel and laboratories. They therefore insist that genetic engineering is a key technology to address a wide range of agronomic problems. Monsanto, the largest life science corporation focusing on green biotechnology, invests US$1.5 billion annually in agricultural R&D, around a quarter of all private agricultural R&D in the USA.[1] The search for, and development of, individual traits is done in highly automated laboratories and is extremely costly. Monsanto managers estimate that the costs of developing and launching a new trait amounts to US$50–300 million (Goure 2004). In order for these investments to pay off, the sales volume of a new transgenic crop needs to exceed US$500 million per annum and to generate a margin of US$200 million (as compared against non-transgenic plants). This return will only be realised if cultivation areas for the respective crops are sufficiently large. Consequently, the traits developed to date and their respective cultivates are designed to meet the special needs of major agricultural producers in North America. However, the life science industry has made a considerable effort to attempt to push these traits into global agricultural markets. With each additional license and each extra bag of seeds sold, the respective corporation generates additional income, without the need of further R&D investment. Thus, the economies of scale and scope make an impact. The more agricultural practices and food production are aligned to the newly developed technology options, the greater the return on investment will be, and with it, the greater the new research investments into the already plotted research path will become.

Public resistance has emerged, particularly in Western Europe, but also globally. Mirroring the protagonists of the biotech industry, the resistance movement also focuses exclusively on genetic engineering and claims that that technology—irrespective of its application—poses potentially great hazards. Although not so obvious, the counter-movement has also invested heavily, even though the critics are less well-funded. Accordingly, the number of counter-experts and the size of their organisations have remained limited (Gill 2008). However, over the course of the past 30 years, the critical scrutiny of genetic engineering in the media has become considerable. If initially gene technology was an obscure topic, now the majority of Western European citizens are convinced that 'monopolists' such as Monsanto are intent on imposing transgenic plants, which are deemed superfluous and dangerous, on them for food crops. In response, the media allow ample space for criticism of gene technology and related topics (Durant et al. 1998; Weitze et al. 2012). This response by the media is, on closer inspection, the result of emergence, networking, and the polarisation of terminologies, narratives and image, which have been evolving slowly but steadily. As such, they form a less visible, but equally rigid fortress as laboratories, testing facilities, data bases, libraries, cultivates and corporate relationships on the side of the industry.

The astonishing rise of the 'uncertainty potentials' metaphor (Gill 2003) may serve as an example. Each innovation represents a step into the unknown. Hence, this criticism can be raised against any new technology. Modern industrial societies have institutionally countered this criticism by pointing towards the constitutional freedom of research and commerce. Initially, critics attempted to identify specific hazards, but were faced with the fact that these were difficult to prove and, furthermore, did not materialise (or could not be attributed). But over time, the term 'uncertainty' was successfully placed into an extremely demonic, and at the same time, extremely vague context. This had the advantage that no specific claim was made, as it was left to the audience to imagine all sorts of hazard scenarios. Within this associative context, it became possible to establish the concept of 'genetic pollution' for the potential spread of the transgene into the environment (e.g. transgenic pollen infecting traditional crops). Since then, German courts have been faced with the dispute whether or not bee keepers, whose pollen was found to contain minute traces of transgenic DNA, can hold operators of experimental fields liable if the transgenic pollen was likely to have originated from those fields (Chotjewitz 2008; Jany 2012).

Against the background of sentiments expressed by the media, the EU has enacted legislation, which requires licensing for the cultivation and marketing of transgenic plants, hence, requiring extensive prior testing regimens. Thus, the internationally controversial 'precautionary principle' is being applied. It justifies government interventions even if suspicions are not very definite. At the same time, major supermarket chains in Europe complied with the boycott of transgenic food stuffs, which had been initiated by Greenpeace. It should be noted that most European farmers have not seen any benefit in the transgenic traits (herbicide resistance and insect resistance) which are currently commercially available. These traits have been developed with the agronomic needs of large-scale agricultural producers in the USA and are therefore largely useless in the European agricultural context, with its different climates and more small- to mid-size farms. Consequently, across the EU (and Japan), transgenic plants are currently neither cultivated nor marketed to any large extent.[2]

Accordingly, in Europe, and particularly in Germany, the debate over plant biotechnology can be characterised as 'entrenched' in the words of Collingridge (1980). Research at public institutes and universities is still publicly funded but commercial companies have mostly relocated their R&D departments overseas, thus drying up employment possibilities for students with this specialization. Heads of the research units complain that, in anticipation of their rather weak career chances, the brighter and more talented students would now avoid or leave plant biotechnology. As researchers at the end of their career, they themselves call for perseverance and hope for better times. Meanwhile, they invest quite some effort into 'educating the public' whom they conceive to be uninformed, romantic, and even silly. Since obviously this is not the best basis for a successful communication strategy towards the addressees—and a vast array of social science research on that subject has clearly shown that more of the same propaganda only can provoke reactance (Hampel 2012)—one may perhaps best interpret these activities as expressive rituals to avoid cognitive dissonance and to uphold the cohesion of their own research troops.

One might expect the critics on the other side of the entrenchment to be more relaxed, since obviously in the last 15 years they have won one discursive bastion after the other. But since transgenic crops are diffused in other parts of the world, namely by the large exporters of agricultural products (USA, Canada, Brazil, Argentina, Australia, and New Zealand) (James 2010), they fear a recapture, with the help of, and under the cover of, free trade agreements like the current Transatlantic Free Trade Area (TAFTA) negotiations. Seen from a perspective of 'latent interests', at least the non-governmental organisations and critics who have specialized in the defence against biotechnology are probably not too unhappy about the persistence of plausible threats, as it would be hard for them to shift their organisational missions and their intrinsic motivations to other targets.

The entrenchment now comes under pressure, not from the actors involved but from the outside. On the one hand, food scarcity has won new attention in the last five years when prices for grain rocketed in 2008 and again in 2011 in world markets, with hunger riots as a consequence in some developing countries.[3] Just 10 years earlier, the Food and Agriculture Organization of the UN (FAO), had withdrawn its warnings, pointing out the progress in cultivation methods (Bruinsma 2003). The growing world population and rising incomes in emerging markets are now emphasised, with their increased consumption of meat and, in consequence, increased land usage for the cultivation of animal feed. Furthermore, there are concerns that climate change will exacerbate the situation by jeopardising the yields and reliability of harvests through drought, heat and excessive rains (Zhu et al. 2011). The advocates of biotechnology appeal to those concerns when discussing the need to develop stress-resistant plants.

In this respect, the development of multi-stress resistant plants is perceived to be particularly interesting and demanding (i.e. the resistance of a plant to various types of stress, such as heat, drought and parasites). The project which we accompanied as social scientists was set up to make its contribution in this regard. Critics of genetic engineering state that multi-stress resistant plants already exist—in nature. Wild varieties are commonly well protected against a multitude of environmental conditions. The geneticists in our project interject that these are not high-yield varieties. The critics retort that multi-stress resistance will be difficult to introduce in high-yield varieties, as a large number of genes and complex regulation mechanisms are involved (Gurian-Sherman 2012). The geneticists participating in our project tried to explore these very mechanisms. However, during the expert interviews they admitted that they were still far from achieving this objective.

On the other hand, the range of methods available to biotechnology has greatly diversified. Increasingly, detection and transformation devices are being developed, which can no longer exclusively be termed 'genetic engineering'. There is some debate on whether current gene technology legislation should still be applicable or whether resulting cultivates should, in future, be exempt from licensing and labelling requirements (European Food Safety Authority 2012; Lusser et al. 2011). Apparently, both advocates and critics are still undecided on how to assess this development. While the advocates hope to evade the strict regulatory requirements as well as public scrutiny, they fear that the identity of biotechnology is being diluted, thus jeopardising aspirations for the development of a ‘key technology’ status as a trigger to disproportionate research funding.

In recent years, new cultivation methods have been proposed as an alternative to biotechnology in order to increase yields per hectare and to prevent food shortages. One method to improve the stress resistance of crops is to harvest fungi which co-evolved with stress-resistant wild plants. It was discovered that the well-known resistances of the plants are not the result of their genomes, but of the symbiosis of plants and micro-organisms, namely mycorrhiza (Reardon 2012). Similarly, the so-called intensification of rice cultivation, a method discovered in Madagascar and now practised around the world, results in more resistant plants, which require less water (Namara 2003). These and similar methods are increasingly being proposed by various development agencies such as FAO, UN Environment Programme, UN Development Programme and the World Bank (IAASTD 2009; Zhu et al. 2011). Their key merit is that they require less investment, thereby allowing for increasing yields, without industrialising agriculture along Western lines (i.e. avoiding the paradigm of the ‘green revolution’) (Parayil 2003). This, however, represents a setback for Western agricultural corporations, whose opportunities for expansion are being diminished. The main obstacle to the diffusion of the alternative methods, however, is posed less by the resistance of the agro-industrial lobby, but by the fact that the methods require considerable expertise: they need to be adapted accurately to local conditions (Vanloqueren and Baret 2009).

3. Scenario workshop: Proceedings and methodology

Scientists of the Forplanta Association met with representatives of the horticultural and food industries, regulatory bodies and consumer protection agencies as well as with experts in food safety and environmental protection on 4 February 2013, at the University of Munich’s Center for Advanced Studies. In total, the group comprised more than 20 people. Due to the current ‘entrenched debate’ over plant biotechnology, the objective of the all-day workshop was the problem-oriented definition and discussion of the diversity of development alternatives for multi-stress resistant plants. Is there a societal need for multi-stress resistant high-yield variants? If so, how do innovation networks need to be organised, in order to take the requirements of application contexts into account at an early stage?

The concept of ‘exploratory scenarios’ (Georghiou et al. 2008; Gassner and Kosow 2010) was deemed appropriate for addressing these questions, as it allows for the various, sometimes diverging, expectations of the participants, as well as their visions, hopes or concerns, to be specified and to be supported through communication processes, where all participants are on equal footing. The multi-stage research design (see Fig. 1) which we used comprised three characteristic phases: analysis of the scenario field, scenario prognosis and formation, and scenario transfer (Gausemeier et al. 2009).

In the run-up to the scenario workshop, more than 40 in-depth interviews were conducted with experts in the fields of research, industry, regulators, stakeholders and potential users, in order to identify important trends and factors potentially influencing the future perspectives for multi-stress resistant plants. The results of these interviews were made available as ‘scenario input’ to participants in the opening speech and during the workshop in order to draw attention to this topic and to inspire discussions. Two different ‘pictures of the future’ in the year 2030 were projected, based on a catalogue of 20 possible drivers, outlining conceivable developments in the general levels of affluence, consumption patterns, technology and regulatory policies, climate change or the availability of arable land. One of these pictures assumed that growing pressure from demographic, economic and environmental needs will force the development of new multi-stress resistant plants and their penetration of the market. In contrast, the second picture left future developments quite open. Due to market concentration and the failure of the coexistence of agricultural systems with or without genetically modified (GM) plants in Europe, it is unclear whether we will see a moratorium on these plants or their triumph.

The scenario workshop itself comprised three stages which served to develop scenarios. During Stage 1 participants were split into three breakout groups, each composed heterogeneously (i.e. consisting of advocates, critics and regulators of green gene technology). Participants were to imagine a ‘journey into the future’ and compose two different scenario reports on agriculture and plant cultivation in Germany in the year 2030. Participants formulated suitable titles, so-called future headlines. Despite differences in the lines of reasoning and analysis, both reports were to include information on the general economic situation, policies, as well as consumption patterns and consumer lifestyles in 2030. Speculations were to be included on what roles corporations and small and medium-sized enterprises on the one hand and researchers on the other, would play in the market segment of plant breeding and what technologies and agricultural structures would be important.

In total, six scenario reports were prepared. These were presented in a plenary session which, in Stage 2, allowed for the exchange of reports among the groups. Participants were now asked to explore the causes and motivations behind the ‘foreign’ scenario reports and to devise plausible explanations for the emergence of these ‘futures’. What are the driving factors? How do they influence one

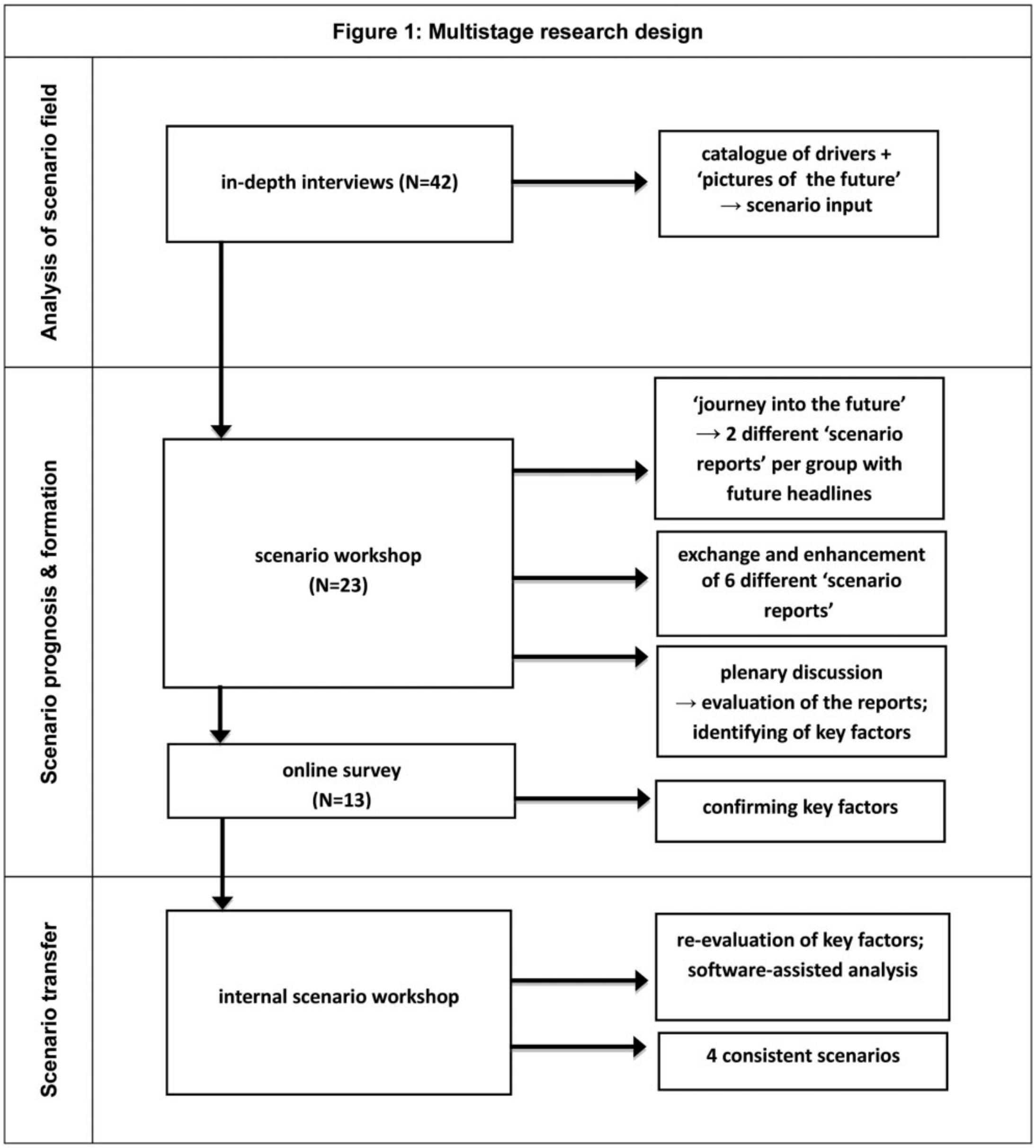

Figure 1. Multi-stage research design.

another? Which agents play a decisive role on the path towards these futures?

In doing so, participants enriched the Stage 1 scenario reports during Stage 2. According to their respective characterisations of the driving factors and their particular impact on the development of new plants, the resulting six reports could roughly be divided into three types: besides a more systemic agro-ecological approach (such as Report 1 'high yields thanks to plant symbionts like mycorrhiza'), participants considered the coexistence of two opposite agricultural systems (e.g. Report 5 'GMO-free and non-free') and also GMO-dominated developments (e.g. Report 6 '80% transgenic multi-stress resistant plants'). These scenario reports describe and analyse not only potential developments of different agricultural systems with or without new stress-resistant plants in the future, they also allow key factors to be identified. And, as we shall see after the software-assisted analysis, the six reports contain substantial information for our final four scenarios.

The scenario reports for 2030 were evaluated in a final plenary discussion (Stage 3). This stage demonstrated that a consensus about the description of different technological possibilities can emerge even if their feasibility and desirability is highly controversial. This descriptive consensus could be confirmed during the final two phases, which were dedicated to scenario formation and scenario transfer.

First, using the results generated during the workshop, a questionnaire was developed, containing 14 statements on the future of multi-stress resistant plants and molecular–biological methods. A week after the event, the questionnaire was sent to participants by email. The questionnaire was completed and returned by 13 participants, some of whom included extensive comments.

Based on these results and the scenario reports developed during the workshop, the core team reevaluated key factors during an internal scenario workshop. Two or three alternative potential paths into the future were formulated for each factor. The interactions between these factors were discussed exhaustively within the core team and external experts were also consulted. The interactions were mapped as a qualitative network (see Fig. 2). Furthermore, a software-assisted analysis[4] of this network resulted in four clusters of consistent scenarios (see Table 1). These circumscribe a future which is compatible with the results of the expert interviews and the online survey.

A key objective of working with exploratory scenarios and future headlines involved members of the respective breakout groups being able to agree on specific scenario reports, which opened up new perspectives and options for development, without, however, there being a need to arrive at an interpretation which was shared by all. Within small, purposely heterogeneous groups, this turned out to be easier than in plenary sessions. In smaller groups, there is a greater need to represent one's case, entrenched positions are more easily modified, and participants as well as introduced technologies are on an equal footing. Hence, due to the changing composition, novel arrangements emerge. Finally, participants tend to perceive that their positions are better represented if the results have been determined by the group, and the results clearly diverge from those of more common, frequently hierarchical, types of discourse. Viewed from the perspective of group dynamics, the entire process of the workshop aimed to achieve a commitment on the part of the participants to 'their scenarios' and to develop an open mind to alternative perspectives (Schwartz 1991; Masini and Vasquez 2000).

Using exploratory scenarios helped to define divergent visions and generate new ideas about all conceivable futures. Furthermore, the group discussed the basic factors and trends underlying these futures with regard to their socio-economic, technological, or ecological assumptions and analysed interactions and potential (unexpected) consequences. This helped to clarify the participants' personal values. In particular, the various technological options of plant development were not perceived to be neutral, but to be connected, directly and

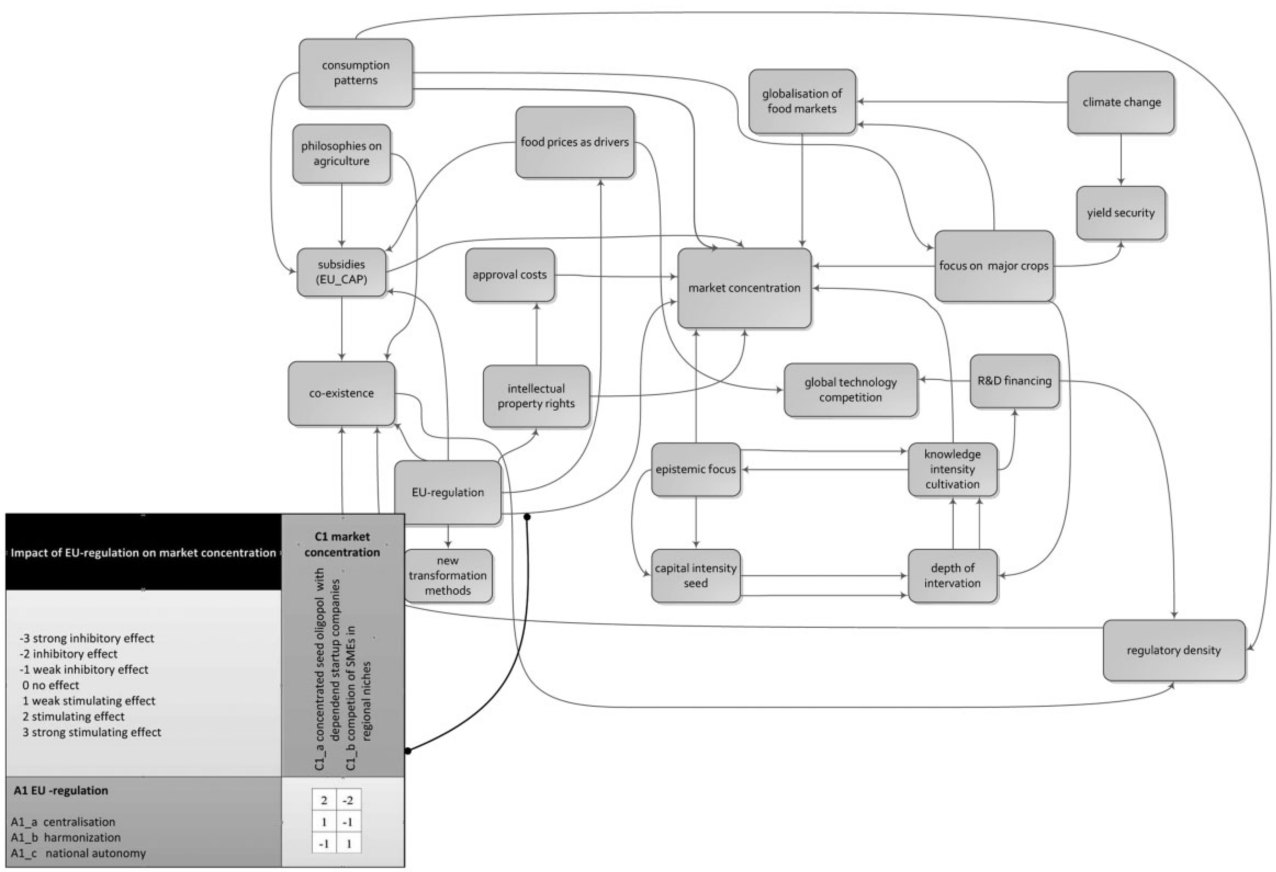

Figure 2. Qualitative interactive network of the 21 key factors.

Table 1. Four qualitative scenarios for the development of multi-stress resistant plants (based on alternative paths (a–c) of 21 key factors)

<table>
<tr><th colspan="2">Key factors</th><th>Scenario I
Transgenic agro-industry</th><th>Scenario II
Co-existence GMO/non-GMO</th><th>Scenario III
Ecological systems technology</th><th>Scenario IV
Conventional agriculture</th></tr>
<tr><td>A1</td><td>EU-regulation</td><td colspan="2">a: centralisation</td><td>b: harmonisation</td><td>c: autonomy</td></tr>
<tr><td>A2</td><td>coexistence</td><td>a: no separation</td><td colspan="2">b: balance of interests</td><td>c: zero-tolerance</td></tr>
<tr><td>A3</td><td>intellectual property rights</td><td colspan="2">a: expanding patent protection</td><td colspan="2">b: only variety protection</td></tr>
<tr><td>A4</td><td>R&D financing</td><td colspan="2">a: major industrial R&D</td><td colspan="2">b/c: SME and/or public</td></tr>
<tr><td>A5</td><td>regulatory density</td><td>a: high</td><td>b: low</td><td>b: low</td><td>c: prohibition of GE</td></tr>
<tr><td>A6</td><td>new transformation methods</td><td>a: no authorisation</td><td colspan="3">b: authorisation requirement</td></tr>
<tr><td>B1</td><td>epistemic focus</td><td colspan="2">b: atomistic</td><td colspan="2">a: systemic</td></tr>
<tr><td>B2</td><td>capital intensity (seed)</td><td colspan="2">a: high</td><td colspan="2">b: low</td></tr>
<tr><td>B3</td><td>knowledge in-tensity (cultivation)</td><td>a: low</td><td colspan="2">b: high</td><td>a: low</td></tr>
<tr><td>B4</td><td>depth of intervention</td><td colspan="2">a: high</td><td colspan="2">b: low</td></tr>
<tr><td>C1</td><td>market concentration</td><td colspan="2">a: high</td><td colspan="2">b: low</td></tr>
<tr><td>C2</td><td>subsidies (EU-CAP)</td><td>a: agro-industrial</td><td colspan="3">b: multifunctional agriculture</td></tr>
<tr><td>C3</td><td>global technology competition</td><td>b: Germany keeps pace</td><td colspan="2">a: Germany as an export nation</td><td>b: Germany keeps pace</td></tr>
<tr><td>C4</td><td>globalisation of food markets</td><td colspan="3">a: open markets</td><td>b: national isolation</td></tr>
<tr><td>C5</td><td>food prices as drivers</td><td>a: rising</td><td colspan="3">b: moderate</td></tr>
<tr><td>C6</td><td>yield security</td><td colspan="2">a: increased yield revenue</td><td colspan="2">b: reliable income</td></tr>
<tr><td>C7</td><td>approval costs</td><td colspan="2">a: high</td><td>b: low</td><td>c: prohibition</td></tr>
<tr><td>C8</td><td>focus on major crops</td><td colspan="2">a: high</td><td colspan="2">b: low</td></tr>
<tr><td>D1</td><td>consumption patterns</td><td>a: much and cheap</td><td colspan="2">a: cheap / b: nutritional awareness</td><td>b: nutritional awareness</td></tr>
<tr><td>D2</td><td>philosophies on agriculture</td><td>a: indifferent</td><td colspan="2">a: indifferent / b: appreciation</td><td>b: appreciation</td></tr>
<tr><td>E1</td><td>climate change</td><td>a: dramatic</td><td colspan="3">b: modest consequences in Germany</td></tr>
</table>

indirectly, with the value orientations of the providers or users of technology. The process of developing future reports also represents an evaluation of technological developments (Schulz-Schaeffer 2013).

4. Results: Scenarios, consensus and dissent

Using this procedure, the core team identified a total of 21 factors of central significance in the development of multi-stress resistant plants in Germany up to the year 2030. These factors are related to both local and global conditions. They epitomise relevant developments in five spheres of influence: politics and legislation, technology, economy, society, and ecology. Two or three alternative projections were devised for each of these factors.

Following the identification of these key factors and their potential evolutionary paths, mutual interdependencies were then analysed. This was not done by 'intuitive logics', but systematically using the cross-impact balance analysis (CIB), a method of qualitative system and scenario analysis (Weimer-Jehle 2013). This method is a modernised version of the cross-impact analysis. It consists of a balanced combination of expert discourse and an analysis algorithm. In our case, the core team discussed the interaction between the key factors and formulated 'cross-impact judgments' in the form of qualitative evaluations on a scale from −3 ('strong inhibitory effect') to +3 ('strong stimulating effect'). Using the CIB algorithm, these evaluations were condensed into consistent configurations ('consistent scenarios') of the impact network. They reflect the systemic balance of influences on the network including all direct and indirect effects and provide a set of plausible future system states.

Fig. 2 depicts the results as a qualitative interactive network of the 21 key factors. For the sake of clarity, only selected relationships are plotted. The relationship between EU regulations (A1) and market concentration (C1) is shown in the enlarged section within Fig. 2. The evaluation '+2' expresses the conclusion that centralised licensing of GM food stuffs and animal feeds (A1_a) is likely to be a promoting influence on the formation of a seeds oligopoly with dependent start ups (C1_a). On the whole, the network of relationships visualises the fact that some legislative developments on the level of the EU, such as the definition of new transformation methodologies or centralised regulation as well as economic factors (e.g. the intensified competition or access to global markets), will exert a greater and more direct influence than soft factors (e.g. ideals of agriculture by consumers).

Nevertheless, a systematic analysis of an interaction network goes far beyond such detailed observations. The cross-impact balance sheet algorithm establishes four clusters of consistent scenarios (see Table 1). These scenarios cover a wide range of possibilities for the development of multi-stress resistant plants. They range from a 'transgenic agro-industry' (Scenario I), 'coexistence of traditional and transgenic solutions' (Scenario II), to a society, which will discover 'ecological systems technology' (Scenario III) or will prefer a 'conventional agriculture without gene technology' (Scenario IV).

In Scenario I (transgenic agro-industry), green gene technology is strongly interlinked with the agro-industrial complex. Processes of commercialisation and concentration, which had already begun much earlier with the hybridisation of seeds, are further expanded and reinforced in this scenario. In the process of emulating the USA, labelling requirements for GM foods are abolished and new transformation methods no longer require regulation. The intended 'transgenic solution' for the development of multi-stress resistant plants involves heavy private investment: hence, it requires an expansion of patenting rights. On the other hand, 'transgenic agro-industry' needs to make provisions for rising licensing costs and a centralised EU licensing system for GM food stuff and animal feeds. Furthermore, this scenario is the only one that assumes dramatic consequences of climate change for Germany, while all other scenarios are based on a moderate impact (if dramatic consequences are assumed there, they occur in other regions, but not in Germany). The workshop participants were in agreement that the concept of transgenic foods needs to convince consumers through unique benefits in order to gain acceptance (e.g. prevention of food shortages, decidedly lower retail prices, or attractive new product features). This scenario perceives that the majority of consumers do not have a relationship with agriculture. Rather, they are ascribed a utilitarian mentality, with a wish for practical, quick, and cheap foodstuffs.

In contrast, Scenario II (coexistence) treats new transformation methods as requiring regulation; the requirement for labelling remains in place. Divergent interests are reconciled in the coexistence of agricultural systems with or without GM plants (i.e. the thresholds mandated by policies and minimum distances expressly allow for the coexistence of opposite agricultural systems). Some participants in the workshop deemed it possible that by 2030, plants would be available that cannot spread on their own: this would facilitate a separation of both value chains. Participants in the workshop were convinced that the coexistence scenario would prevent the seed oligopoly from becoming dominant. Rather, there will be economically sustainable niches for seed producers, who, in Germany, tend to be mid-sized companies. EU agricultural policies could contribute towards this outcome, if subsidies were to primarily benefit multi-functional agriculture. In contrast to the 'transgenic agro-industry', a certain proportion of consumers are perceived to be conscious of nutrition and to appreciate more natural agriculture.

A different philosophy comes to bear in Scenario III (ecological systems technology), which, by 2030, predicts agriculture to flourish beyond the realm of the agro-industrial complex. In this scenario, familiar as well as new methods of green gene technology can be employed, such as cis-/SMART breeding, as long as they can be adapted to a context-sensitive agriculture (i.e. an agriculture that respects local environmental conditions and social structures). New methods in gene technology are to be regulated and GM foods to be labelled. There is no expansion of patenting rights, only protection of plant varieties. However, innovative methods of cultivation are at the very core of 'ecological systems technology'. Publicly funded research is the driver of the development and efficient use of modern cultivation techniques which are highly complex and require considerable prior expertise and experience both among technology innovators and farmers on cultivation systems, soils, crop rotations, micro-organisms, seeds etc. To this end, entirely different training methods will be required than in the 'transgenic solution'. The innovative cultivation methods, conventional plant breeding and gene technology in Scenario III, do not necessarily result in different agronomic traits. Even if the methods differ, the objectives could be identical. Substances made from mycorrhiza may serve as examples: mycorrhizae are fungi that through a symbiosis with the root system may convey resistance to diseases, heat, cold, salt and drought to a plant. The advocates of mycorrhiza consider their method to be superior to genetic engineering. They argue that to produce resistance to drought, genetic engineering would need to switch on each metabolic pathway individually, which is expensive and time consuming. Fungi can activate all of these metabolic paths simultaneously, as these symbioses emerged in nature through a process of co-evolution and can therefore be utilised with comparative ease (Reardon 2012). Ecological systems technology might be beneficial, especially for those crops that are relevant in developing countries, but have been ignored by the 'transgenic solution'. Workshop participants would charge government with the task of ensuring that the expertise and technologies developed through research be made accessible to all farmers at affordable prices, and that the trend towards privatisation of agricultural research and consultancy would be reversed.

In contrast, Scenario IV (conventional agriculture) refrains from using any new methods. The scenario postulates that in Germany in 2030, conventionally bred multi-stress resistant crops will be cultivated in both industrial and organic agriculture. The moderate effects of climate change do not warrant massive change. Alternatives, generated through genetic engineering, have not resulted in advantages for either consumers or farmers: they were neither healthier, nor better, nor more economical. In short, gene technology has been disappointing and there will be no reasons in 2030 to resort to it. The economic potential is low, even if only because of the obstacles posed by limited patenting rights for traits and production methods. Furthermore, a broad public consensus is opposed to genetic engineering. The wider public tends to associate genetic engineering with multinational corporations, whose 'major crops' (like maize) destroy locally adapted structures, which are based on small farming operations. Instead, policy-makers and stakeholders in civil society will prefer a multi-functional agricultural strategy, which will provide the social and economic needs of the public without the use of gene technology. This paradigm shift will trigger an agricultural reversal towards purely conventional breeding and non-industrial agriculture. Further development of smarter cultivation methods (e.g. drip irrigation) are part of this strategy. In 2030, gene technology will, at last, be outlawed.

All four scenarios assume a more or less rising societal need for multi-stress resistant plants. The results of both the plenary discussion and the subsequent online survey demonstrate that these plants, given the conditions of climate change, growing global population, and rising affluence in emerging markets will be needed even more than at present, especially in countries with unfavourable climatic conditions. There was also a perception among workshop participants that, in principle, various techniques are conceivable in parallel, such as gene technology, conventional or molecular–biological methods for plant breeding. Irrespective of which of these techniques was preferred, there was a consensus that the success rates of the respective methods were difficult to estimate in advance. Despite new research tools, transformation methods and the emergence of bio-information science, the high complexity of modern plant breeding would not facilitate quick successes in providing applications. As such, there was a consensus that

> ... currently, no ecologist, bio-chemist or geneticist nor a molecular biologist fully understands the totality of responses of the plant to various biotic or abiotic environmental changes (...) On the other hand, policy makers massively underestimate the importance of plant research. If we had the same level of support as, say, neuro-science, we could tackle the 'plant system' holistically from all angles, regardless of whether with the aid of gene technology, ecological or agricultural methods or new breeding techniques. This will be important for our survival. (Prof. C in the plenary discussion during the workshop)

Apart from this appeal to policy-makers to give increased support to plant breeding and cultivation systems, there was also a common perspective that research funding should be public, as new insights into cultivation systems and traits should be made available to all. Research on multi-stress resistance should not be left to the agro-industry. Rather, it should be a matter of public interest to systematically develop innovative cultivation methods and to also make improvements available for those crops that are increasingly being ignored by commercial corporations. However, this basic open-mindedness towards a pluralism of methods and publicly funded research did not imply that there was consensus on intellectual property rights. While critics of green gene technology considered the current plant variety protection to be sufficient and strongly resisted patenting rights on plants ('regardless how they were derived'), advocates voted for expanded patenting rights to drive research and the introduction of innovations into the market place.

As mentioned above, disagreement exists concerning licensing requirements, which arose across the scenarios. Are new methods like cis-/SMART breeding subject to regulation, even though, going by current definitions of the German Gene Technology Act, they do not create GMO? Different interpretations emerge not only among workshop participants but also among policy-makers. In Canada, for instance, plants resulting from SMART breeding are, in contrast to the EU, subject to the same licensing processes as transgenic plants. As such it is conceivable that even older methods, like mutagenesis breeding, will become subject to licensing requirements, especially since mutagenesis manipulates the genome of plants by radioactive radiation or massive use of chemicals. There was, however, a consensus that cis-genetic methods are preferable to transgenic modification, because the consequences were easier to evaluate.

Using these results as an example, the value of our exploratory scenario methodology becomes apparent. It provides an opportunity for characterising familiar as well as novel visions and expectations in the future in a transparent manner that is accessible even to the wider public. Even though the selection of key factors and interdependencies may be based 'merely' on expert evaluations, their intellectual base is clearly defined. In the spirit of a 'vision assessment' (Grunwald 2009; Nordmann 2013), the basic lines of argument and their potential for implementation can be examined. These visions frequently reflect real possibilities despite their inherently speculative nature. They influence risk assessments and research funding, they mobilise and focus resources, they convey meaning and give direction to the epistemic community (Grunwald 2013). As such, the devised scenarios are not prognoses: rather, they plot coordinates of an indeterminate future, and thus provide a differentiated background for the early assessment of technological developments.

Multi-stress resistance already has become an important objective in plant breeding. There will probably be major innovations in this field in the future. Our scenarios can provide guidance on how to structure research programmes, but also assist in evaluating the adequacy of policy and legal frameworks, especially in questions of licensing requirements for new transformation methods or tolerance limits for the coexistence of agricultural systems with or without the use of gene technology.

5. Discussion and conclusions

Scenarios I, II and IV contain no surprises. Scenario I represents the entrenched vision of the GMO protagonists, Scenario IV the mirrorlike entrenched vision of the GMO antagonists, and Scenario II is the coexistence compromise, which may be also interpreted as the 'wait and see' approach. But Scenario III is new, showing alternatives to the well trodden paths of argumentation. New technologies like mycorrhiza symbiosis may emerge or old ones may be rediscovered to meet the challenges of climate change and of rising demand for food and fodder crops (for broader discussions of alternatives see IAASTD 2009; Zhu 2011; Vanloqueren and Beret 2009). In principle a fifth scenario would also have been possible, where the potentials and challenges of the new genetic engineering methods would have been more thoroughly spelt out—they had been repeatedly mentioned at the workshop, but none of the experts or counter-experts took the initiative to put them centre stage.

In that way the scenario method showed its aptitude as a forecasting instrument for research policy. New fields for funding may emerge, new regulation challenges can also be identified. But the scenario method exercise may also prove worthwhile for the experts who participated in it. They could discover new combinations and perspectives for innovation, or—if they are younger—the possibility to shift their careers in other directions if the entrenched vision they have followed proves to be a blind alley. According to our observations, the age and career stage of the participants is of more general concern. If they are conceptually more senior, they usually have a broader overview over technological possibilities and their applications. But for the corresponding reason of being older, they are less willing to shift their visions and are more eager to defend what they see as their life work against any criticism. As leaders of research units, by definition they have power and the 'last word'. They are less willing to engage in a workshop where they have no privileged speaking position and where they cannot control the outcome. For that reason further experiments should be done with different career stage groups (graduates, postdoctoral fellows and chairs being separated), so that the younger are willing and able to discuss their views, which might be too sceptical to be expressed in the face of the rallying calls of their superiors.

In that way the scenario workshop method may prove to be successful in breaking up entrenched visions and engaging the participants in more open and more fruitful discussions. But if so, another question arises. Are entrenched visions always dysfunctional (cf. Nordmann 2013)? In earlier stages of industrialisation, they may be functional in a technology push perspective to reach seminal breakthroughs, but they may also keep research groups and whole societies stuck in dead ends. The scenario method and PTA more generally, moves the technological evolution nearer to a demand pull perspective More stakeholder are invited, a higher plurality of needs and concerns are focused and more technological alternatives are taken into account. With this shift, technology will be 'democratised' to a certain extent instead of social structures being strongly 'technocratised' by laboratory imperialism. Perhaps this may prove to be the more adequate way when societies are becoming mature.

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Notes

1. See <http://www.monsanto.com/investors/Pages/corporate-profile.aspx> and <http://www.ers.usda.gov/data-products/agricultural-research-funding-in-the-public-and-private-sectors.aspx#.UtK-ubR0k3h> both accessed 12 January 2014.
2. They are, however, imported as animal feeds. In this area, supermarket chains consider the boycott too costly.
3. See <http://www.fao.org/worldfoodsituation/foodpricesindex/en/> accessed 13 January 2014.
4. Carried out using ScenarioWizard 3.2 <www.cross-impact.de/deutsch/CIB_d_ScW.htm> accessed 30 August 2013.

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