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The role of risk assessments in the governance of genetically modified organisms in agriculture

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Abstract

Controversy abounds in the governance of genetically modified organisms (GMOs) for use in agriculture, partly due to ideological differences. Technological optimism and the "shallow" and the "deep" ecology movements are three influential ideologies that are seen to differ both on value commitments and factual beliefs with respect to GMOs. Factual matters are clarified but not resolved by science, since the scientific community faces uncertainty and apparent contradiction between different research perspectives, notably molecular biology, ecology and the social sciences.

Scientific advice plays a key role in the governance of GMOs and ought to be construed so as not to exclude legitimate arguments from ideological perspectives present in the process of governance. This paper analyses the role and use of risk assessments and argues that they be replaced by forms of advice that consider a broader spectrum of scientific evidence and insights, e.g. impact assessments and evaluations of inherent sources of uncertainty and ignorance. A few practical measures to that effect are discussed. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

In the governance of the deliberate release of genetically modified organisms (GMOs) for use in agriculture, controversy abounds on every level from local debate and activism to international politics. As for the latter, there are voluntary international guidelines [1–5], but both practices of governance and actual choice of policy are seen to differ widely between nations. Policies vary from a warm welcome to GMOs by the US government to the sceptic attitudes and absence of GMO crops in countries such as Norway [6].

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Scientific advice plays a key role in the regulation of GMO release. National legislation and governmental instruments of governance typically involve risk or impact assessments of the planned releases to be performed by biological experts. For instance, in the US, decisions are taken by a designated regulatory body (Animal and Plant Health Inspection Service), while in the European Union, decisions are ultimately taken by the European Commission on the request of member states and the advice of biological scientific committees [7]. However, scientific advice has not succeeded in resolving controversy. Indeed, as will be seen, the methods for producing scientific advice have also been in dispute.

The problem of governance of GMO release is a truly complex one that calls for the expertise of various academic disciplines, including molecular biology/biotechnology, ecology, political science and sociology, ethics and law, etc. The method of this paper can be recognised as empirically based philosophy. It does not present new empirical evidence or review any particular field of research in full detail. Instead, it tries to resolve *some* controversy by proposing a synthesis of insights from various scientific disciplines. The strategy is as follows: First, we will see that part of the controversy over GMOs can be attributed to legitimate differences of ideology (Section 2). Next, some sources of knowledge relevant to the GMO issue are identified and characterised in terms of context and perspective (Section 3). After a methodological remark (Section 4), these sources are used to construct an understanding of risk assessments, with their virtues and vices, that may be a candidate for consensus (Section 5). Finally, the potential implications of this understanding of risk assessments in terms of rational policies (Section 6) and practical measures (Section 7) are briefly discussed.

2. Ideological perspectives

Numerous ideological positions are represented in the political debate on the release of GMOs, and it is beyond the scope of this paper to present them all. Fortunately, to illustrate the importance of value commitments in the evaluation of risk assessments, it will suffice to discuss attitudes towards (a) technology and (b) non-human species. I will do this by constructing three *stereotypes*: technological optimism and the “shallow” and “deep” ecology movement (not to be confused with ecology as a biological discipline).

- *Technological optimism*: In this view, modern biotechnology is to be seen as means for benefit and progress such as increased global food production, environmental benefit by reducing the need for polluting chemicals in agriculture, and improvement of human health by medical biotechnology. Potential negative impacts are seen as minor compared to the benefits, and believed to be manageable. Arguments in favour of that view include (a) that risks of modern biotechnology are assessed and monitored at least as closely as any other comparable technology, (b) that history shows that although technology tends to cause occasional unanticipated adverse effects and that nothing is safe, science and technology also help solving such problems, and (c) that the reality of the needs, especially for food in the third world, outweighs the alleged hazards that so far remain in hypotheticality. Such positions are advocated by a number of scientists [8,9] and authorities [10].
- *The shallow ecology movement* as defined by Næss [11] is concerned with pollution and resource depletion as a threat to human health and welfare. Accordingly, shallow

ecology considers technological development a double-edged sword, especially when it encourages or resonates with short-term economic rationality at the expense of equity across the world or between present and future generations. The attempt of the Brundtland commission to distinguish between sustainable and non-sustainable development is easily recognised as shallow ecology. Hence, shallow ecology does not logically imply opposition to modern biotechnology. However, some authors who may be placed in this category [12], tend to differ from technological optimists on the following points: (a) The complexity of ecosystems and the present inadequacy of ecological science makes the risks of modern biotechnology especially hard to assess. (b) The alleged benefits to poor people are not obvious if modern biotechnology is introduced without accompanying social or political reform, since this high-tech industry is dominated by large companies with profit agendas. (c) The hypothetical hazards, in particular the destruction or reduction of global centres of "crop diversity", i.e. reservoirs of wild ancestors and relatives to agricultural plants, are too dramatic to take the risk. (d) The problem of human starvation can be solved by means other than GMOs.

- *Deep ecology* [11] argues against anthropocentrism, and thus disagrees with the view that technology should be assessed only in terms of its impacts on human welfare and sustainability. Granting *value* and the "right to live and blossom" to other life forms in themselves, independent of their present or potential utility to us, deep ecology finds modern biotechnology to contribute to an undesirable mode of human civilisation that has led to human over-crowding and ultimately the violation of many humans' and other life-forms' rights. A deep ecologist's opposition to GMOs thus does not have to be justified in any essential difference from conventional breeding or the outcome of a given risk assessment. Rather, it is founded in a critique of modernity which sees practices such as risk assessments of the largely unknown effects of extremely powerful technology as part of the hubris that led onto the wrong track in the first place.

The three stereotypes are by no means exhaustive to real positions. For instance, one may not feel comfortable with technological optimism, but still see no way around the use of modern biotechnology to try to decrease human suffering in the third world. Nonetheless, one will have to evaluate the alleged long-term hazards related to crop diversity, etc. Thus, at the heart of the issue lie not only central *value commitments* but also *factual beliefs* about nature and society, including the historical role of science and technology in the fate of mankind.

I want to stress the point that the ideological differences in part is a matter of dissent on factual matters. Furthermore, although these matters are studied by various sciences (broadly conceived as *Wissenschaft*, i.e. natural and social sciences as well as the humanities), they are presently not resolved, in the sense of academic consensus. Rather, different research perspectives have faced uncertainty and in part mutual contradiction. These differences should not be confused with ideology: although there may be cognitive affinities between a given ideology and an academic discipline (say, between liberalism and neo-classical economics), the relation is by no means one of logical necessity. The lack of scientific consensus and certainty does not, however, imply that ideological debate cannot improve from science. Indeed, one of the aims of this paper is to identify the conditions under which certain ideological positions should be given up (Section 6.2).

3. Research perspectives

Scientific approaches to modern biotechnology can be roughly divided into three categories, relating to the production of biotechnology, its ecological impacts, and social aspects, respectively. Again, I shall construct stereotypes to point out a few distinct features.

The field of *molecular biology and biotechnology* is primarily concerned with the construction and improvement of theory of molecular mechanism within organisms as well as experimental and technological methods, products, and practical solutions. It is largely an *experimental* discipline [13], meaning that questions like gene escape typically will be approached by laboratory experiments to detect such escape and attempts to solve the problem technically, such as the incorporation of suicide genes or sterility. Although molecular biologists and biotechnologists participate in the GMO debates, hypothetical speculation or theoretical meta-reflection is not generally considered an internal part of scientific work [14].

Although *ecology* is rapidly incorporating molecular technique, it differs from molecular biology by a wider scope, studying larger biological systems such as populations, communities and ecosystems, often by macroscopic methods. The ecological literature also differs from that of molecular biology in the use of observations of singular events (natural history) and hypothetical speculation. Referring to the many sources of uncertainty and ignorance in what they perceive as the profound complexity of nature, some ecologists have accused molecular biologists (and others) of being “too cavalier” [15]. Indeed, on occasions, biologists have disagreed rather fiercely on issues of environmental safety of release of GMOs [16–18].

Social scientists and scholars have also produced research related to modern biotechnology and GMOs, including (a) investigations that contribute *directly* to the governance and implementation of biotechnology, such as research on public understanding and attitudes, socio-economic and cultural impacts, innovation of deliberative and regulatory procedures and institutions, and legal matters. (b) Theoretical and partly empirical work that *interpret* and reflect upon aspects of biotechnology. For instance, the conceptions of risk and risk assessment have been subject of extensive sociological and philosophical study, including the case of GMO release [19–23].

Social scientists study people. Occasionally, the research objects may disagree with the results of such research (as in the “Science Wars”). Their dissent does not necessarily invalidate the results, since the task of the social scientist or the scholar is to provide novel perspectives on human affairs. It adds, however, to the complicated situation of contradictory bodies of knowledge relevant to the governance of GMOs.

4. Multiple perspectives: a methodological remark

There is de facto a plethora of ideological perspectives on the release of GMOs, as well as on how governance of such release should be arranged (Section 2). The ideological debate involves dissent both on values and factual matters. The latter are investigated by research which also experiences a multitude of perspectives and lack of consensus (Section 3). On the other hand, decisions have to be made. How should incompatible perspectives be dealt with?

Quite a few participants in the GMO debate seem not to express doubt about their own view. Different expressions of opinion are sometimes explained by opponents' lack of knowledge, reason or moral standards. For instance, proponents of modern biotechnology have claimed that opponents are ignorant or irrational [9,24], while the biotechnology industry faces distrust in return [25]. Easily forgotten in a fierce debate, there is also genuine doubt about GMOs, nicely put by the Union of Concerned Scientists [26] as follows: "The issues (of deliberate release of GMOs in agriculture) are complex and people of goodwill differ on the answers."

There are several ways to *live with* the presence of multiple and apparently irreconcilable perspectives. Simple ways are often unsatisfactory, especially if they are experienced as unfair. Distrust and non-compliance is especially costly with regard to large-scale technologies [27]. A well-known alternative is to delegate decisions to a trusted body. Porter [28] interpreted the US practice of hyper-precise cost-benefit analyses as a case of delegation: The objectivity of statisticians did not lie in privileged access to truth, but in trust to their disinterested method. However, this particular solution does not work in the GMO debate, in which expert methodologies including risk assessments are in dispute.

Currently, innovative research is being done on the use of techniques that facilitate communication across perspectives, also in the case of GMOs [29]. From the research perspective of sociology and political science, one may also ask what kind of institutions may promote trust and fairness.

Reducing the differences across perspectives is one of the things to do *inside* those procedures and institutions that are devised. One such institution is science itself. At this point, the present paper will have to make a methodological choice. One option is to conclude with the lack of full scientific consensus and certainty on GMOs and investigate the implications of this insight in terms of the need for supplementary and complementary approaches, in particular participatory techniques. This is an important track to follow, but not for this paper. Instead, I will proceed by making the working assumption that differences in perspective at least sometimes complement rather than contradict one another, and attacking some pieces of scientific evidence with the aim of providing an improved understanding of the nature of risk assessments.

5. The role of risk assessment in the governance of GMOs

5.1. The standard conception of risk assessments of releases of GMOs

The methodology of risk assessments of planned release of GMOs is debated [18]. For instance, Kareiva et al. [30] think of risk assessments as to 'ask whether "what could in theory happen" is likely to happen, given what we know about ecological invasions'. Such invasions have so far primarily been studied by natural history, and molecular biologists have expressed doubts about such "soft" knowledge, seeing ecologists as "alarmists" [15]. Other ecologists [31] stress the limitations of current theoretical knowledge: "We can only ask the questions (test the hypotheses) of which we are aware. The range of these may be narrow and their number few."

Some see a paradox when expert bodies conclude with "no significant risk" but still require monitoring; in one sense this is the essence of field trials. "They are saying there is no risk to the environment, but on the other hand, they want to see what it will do" [32]. On the other hand, this apparently paradoxical practice can be interpreted as a precautionary attitude. Perhaps more acute, it has been asked how conclusions of no risk can be drawn from evidence produced in the artificial settings of the laboratory or short-term, small-scale field trials. Indeed, those who worry, are afraid of dramatic consequences of presumably rare events. In sociological terminology, the closure of such risk assessments seems to be underdetermined: there is an unexplained leap of logic, and the scientifically open questions are simply silenced or delegated away. One approach is then to "sociologise" by looking for social and cultural factors that may explain closure. Thus, Wynne and Mayer [19] conclude: "This seems to reflect the epistemic culture of control, an obsession with controlled knowledge means that when anything less than this 'gold standard' is available, it cannot be contemplated because it is not gold, thus avoiding any responsibility" (p. 58).

If this is interpreted to suggest that experts desire to avoid responsibility, my guess is that many members of scientific committees would disagree with Wynne and Mayer, which does not invalidate their results (Section 3), but indeed impedes dialogue. In my view, part of the disagreement lies in different conceptions of what a risk assessment ought to be. Although it is easy to give a superficial definition of risk assessments (the estimation of probabilities of undesired future events following a course of action), there are in fact philosophical problems involved here, relating to our notions of causality and knowledge, to be attended in the following (arbitrarily chosen) example.

In the EU, the Commission approved in 1998 of Monsanto's GM maize expressing the Bt *cry*IA(b) gene for tolerance to insect damage. What will happen when it is grown in European fields? *That we cannot know*. Instead, we make the following *intellectual construct*: We imagine a future time span beginning with the growing of the Monsanto maize. Now, this future may entail almost anything, including unprecedented and unimaginable events, especially if the span is to be large enough for the occurrence of such events that some people fear (such as the destruction of crop diversity). Indeed, if we were to extrapolate our recent history, the rational forecast is one of essentially novel technology with unprecedented natural and social impacts that may make the GM maize seem utterly insignificant [33]. To write that in an expert report would nonetheless be considered as unsuitable and strange: it is not what a risk or impact assessment is about.

Indeed, naive questions about the future are replaced with questions like "Given our current body of knowledge, what can we infer about the effects of the growing of the Monsanto maize?" Now, the answer to this question actually depends both on one's general theory of human history (*sic*!) and on one's definition of "effect". The question implies imagining two futures, with and without the Monsanto maize (but probably both with today's technologically based intensive agricultural practices). But again, in view of the apparent complexity of human affairs, one would expect very large and wholly unknown long-term differences between the two futures. Indeed, a striking feature of history is the drastic impact of seemingly small details.

Thus, if the "effects of X" is to denote the difference between the set of events following X, and the set of events in a parallel system without X, almost anything can be an effect, and almost any effect can happen. Normally we avoid this mess by restricting the concepts "cause" and "effect" to *law-like behaviour*, i.e. relationships between classes of relatively similar events that are not too sensitive to the particular choice of initial conditions. In other words, when chaos theory tells us that an extra flap of the wing of a butterfly may lead to a hurricane in America, we hesitate to say that the butterfly *caused* the hurricane. Indeed, philosophy ever since Kant has moved away from thinking of causal relationships as meta-physical properties of things in themselves. John Stuart Mill, for instance, defined cause and effect in terms of the knowledge of constant correlations that can be inferred from certain experimental designs, such as perturbation-control experiments under otherwise equal conditions [34].

To ask for the effects of the Monsanto maize would then amount to ask whether we know of scientific causal laws that can be applied to predict specific (maybe probabilistic) outcomes. In my view, the deliberations of committees like the EU Scientific Committee on Plants ought to be understood in this way. The committee seems to look for relevant causal laws in the scientific literature. If there are none (and that is frequently the case), it is concluded that there is no evidence to indicate that the GM product is likely to cause adverse effects to health or the environment.

Thus, the standard conception of risk assessments appears to be *an investigation as to whether specific adverse effects can be identified and known causal laws (deterministic or probabilistic) apply to the case of concern*. This conception is compatible with and justifies the actual practice of expert panels. It is also compatible with the above mentioned sociological analysis [19], if the latter is interpreted as a way of looking at its *consequences*.

This conception of risk assessments is not unproblematic, and two of the problems will be attended below: Can and should other types of knowledge than causal laws be included in the risk assessment? And what are risk assessments good for?

5.2. Biological knowledge to be incorporated into the assessment

Philosophers have disagreed on the relevance of the standard conceptions of natural laws and causal explanation and prediction [35,36]. Indeed, a lesson from the rise and fall of logical empiricism in the 20th century is that attempts of rigorous logical formalisation of scientific knowledge tend to produce implausible results [37]. The current trend in the philosophy of science is thus to study the legitimate disunity of types of scientific knowledge and practice [38,39]. Unfortunately, these insights have yet to be incorporated into scientific textbooks.

The molecular life sciences mainly produce knowledge of in vitro systems, which can be used directly (barring the practical difficulties) in the *making* of biotechnological products, since they are made in vitro. Prediction of what will happen in natural surroundings requires an inference from the artificial to native conditions which often is all but trivial [40]. The logic of inference from artificial to native biological systems is little studied [13,41], and studies in the molecular life sciences are generally modest in their inferences.

With a novel GMO, there is obviously no direct evidence of environmental impact of that particular modification in that organism before the GMO is released, and little is known in general about phenomena such as gene flow and their ecological impact. Experimental studies combining molecular techniques with field methodology are now improving on this situation. The progress is also a consequence of the release of GM crops, which in reality work as “natural experiments”, and important “hard” data, e.g. on isolation distances, are being produced [42,43].

However, ecologists have conjectured that the really important problems with GMOs may arise only slowly, subtly, and through long chains of events. These effects include the formation of new agricultural pests, weediness in wild relatives, harm to non-target species and whole communities and ultimately extinctions and reduction in biodiversity [44,45]. The claims of ecological hazards are above all based upon natural history, i.e. zoological and botanical observation following past biological introductions. The particular problems of predicting or even discovering post hoc what is going on are nicely illustrated by the *Opuntia-Cactoblastis* story [46]. The prickly pear, *Opuntia*, was introduced as a hedge plant in Eastern Australia in 1839, but developed quickly into a pest which by 1925 occupied almost 250,000 km^2. The problem was solved by the introduction of *Cactoblastis cactorum*, an Argentinian moth which effectively diminished the cactus population and still keeps it down. Ecologist Daniel Simberloff continues: “Because the moth eggs are clumped, even in woodlands many plants are at least temporarily free of the moth, and some entire populations of the cactus may not contain the moth. It is possible that a clever researcher who did not know the history would be able to figure out that the moth controls the plant and is responsible for its absence from 250,000 km^2, but this deduction would not be trivial and would surely take detailed study and experiment” ([46], p. 6).

Ecological impacts can obviously not be reliably predicted today [30]. Will they ever be? That depends upon the complexity and uniqueness of the involved systems: whether there in fact are undiscovered patterns that are simple and similar enough to allow ecological causal laws, or ecology is more to be likened with the butterfly-hurricane system. *This is unknown*, and disputed [42,46,47] (see Section 6.1).

To summarise, biology faces an inevitable trade-off between quantitative reliability and validity, i.e. relevance to real nature. The opinion of the EU Scientific Committee on Plants on the above mentioned Monsanto insect-resistant maize illustrates the problem. Austria invoked the so-called safeguard clause in 1999 on grounds of new evidence (a letter to Nature entitled “Transgenic pollen harms monarch larvae” [48], a non-target species). The committee concluded that the design of the laboratory study (including some plain methodological weaknesses, such as the absence of a dose-response curve) failed to support inferences about natural systems, and maintained that their previous assessment that “no evidence to indicate that the (product) is likely to cause adverse effects (. . .) on the environment” [49], “stands unchanged” [50]. However, this conclusion seems imprecise and/or unreasonable. The Nature letter is indeed evidence to indicate adverse effects. It may be indirect and unconvincing evidence regarding the overall decision as to the order of size of the involved risks, but one would be wrong to claim that nothing was learnt from it; hence it is a form of knowledge.

Likewise, ecological theory may generate relevant *questions* for an assessment, lists of things to look for [31]; and one may incorporate descriptive knowledge from natural histories that more or less directly relate to the species and habitats involved. The answer to the question “Can and should other types of biological knowledge than causal laws be included in the risk assessment?” is accordingly positive. I propose the following, broader, normative definition: a risk assessment should be *an investigation as to whether specific adverse effects can be identified and an evaluation of their likelihood on the basis of the content, reliability and validity of current knowledge.*

Regarding the alleged dramatic high-order impacts on the ecology, they are generally not specified. Indeed, the only evidence for such impacts comes from largely unrelated natural histories, which cannot be directly utilised into any risk assessment that is conceived as an evaluation of specific, determinate impacts. Rather, these insights seem to strengthen a certain *evaluation* of such risk assessments, namely that they are inadequate tools to manage long-term, higher-order ecological effects.

5.3. Nature versus Society

Most of the discussion in Section 5.2 also applies to socio-economic, cultural or otherwise human impacts of the release of GMOs. Today, aspects of human health are included mainly through deliberations of nutrition and medicine; however, applying the positive health definition (health as well-being), one should include a broader spectrum of effects. Because the beneficial or harmful character of such effects is not always obvious, the use of *impact* rather than risk assessments has been proposed [25] and is in fact implemented in at least one country (Norway) [51].

The idea of including societal effects into risk assessments of GMOs is somewhat unconventional, and deserves a few comments. Firstly, a division into "natural" and "societal/cultural" effects is in general simplistic. For instance, effects on nature may appear by causal mechanisms that go through social systems, and vice versa. A clear example is civil nuclear energy, in which the technical challenges to human precision have been so great that the inevitable human error now and then results in environmental harm. Probably, most such scenarios will have to be omitted from the risk assessment because they are not specific and determinate; however, this will not always be the case. Indeed, the overall economic impact of biotechnology is continuously being forecasted, and one should think that effects on agricultural practice, ownership structures and equity are no more difficult to understand. For instance, Albert Gore (then Senator) worried strongly that GMOs would imply economical imbalance in the US due to an even larger over-production of food (see [52]).

Secondly, it should be stressed that social facts are both man-made and *real*, without there being a contradiction [53,54]. For instance, if studies show that the introduction of genetically modified foodstuffs will result in substantial anxiety or disgust in the population, this amounts to an adverse effect to human health which ought to be included in the assessment. In order to ignore such effects, one will have to justify the belief that the anxiety or disgust will disappear, for instance by planned actions directed at the public. If so, public participation is a good idea, since experts are in general not representative of the general population and may look differently at the ethical aspects of plans of public persuasion. For instance, the disgust many people experience by the thought of human cloning is an adverse effect that hardly can be eliminated without interfering with basic religious feelings.

Finally, when dealing with social and cultural entities, the inclusion of non-causal knowledge of distal outcomes is at least as important as in the case of "pure" ecology, implying that the broader definition of risk assessment (Section 5.2) ought to be preferred. For instance, risk assessments ought to include a rich set of scenarios of human error and malfeasance. Above all, erroneous or malevolent transport of seeds to undesirable locations should be expected, because the history of man presents rich evidence that specimen of common articles tend to end up anywhere people go. To some extent, this is already current practice in risk assessments.

5.4. What are the uses of risk assessments?

It was noted above (Section 5.1) that risk or impact assessments in general cannot answer the question of what will happen when a given GMO is released. What it can do, is to evaluate current bodies of evidence for and against effects that have been thought of and formulated as specific and determinate events. Besides, it can provide useful ideas for monitoring and future research. Indeed, statements of EU Scientific Committees have included instructions for specific monitoring.

Accordingly, a fruitful way to understand a risk assessment is to see it as a basis for action rather than a forecast of the future. Thus, by compiling scenarios of undesired chains of events and keeping them mentally alive by a regulatory body, they may be avoided through the mechanism of self-refuting prophecy.

In addition, risk assessments can work well as forecasts when the involved systems are of low complexity. However, if we are interested in long-term, high-order environmental or societal effects, the value of a risk assessment is unclear at best, or zero or even negative at worst, since it may contribute to a false sense of control and safety. In conclusion, the perceived utility of risk assessments depends on our theoretical beliefs about complexity and our value commitments with regard to long-term effects.

6. Complexity, values and policies

Instruments of governance should not exclude policy options by their very design. In particular, scientific advice should not obstruct rational arguments from legitimate ideological and scientific perspectives. In Sections 6.1 and 6.2 the contested cognitive issues will be narrowed down. From the range of legitimate positions to these issues, a minimum range of rational policy options on the regulation of the release of GMOs will be formulated (Section 6.2). The final question is how to accommodate this range in the production and formulation of scientific advice (Section 6.3).

6.1. Complexity and values

The functions and worth of risk assessments strongly depend on the complexity of the involved system(s) (Section 5.4). However, there is no consensus on how to define [55] or measure [56] complexity. We may define *system complexity* in terms of objective qualitative features such as hierarchical structure, richness of feedback loops, self-organisation and adaptation. In that case, the Earth and a lot of its subsystems are obviously very complex. Furthermore, we may define *epistemologically* (“knowledge-theoretically”) *complex* systems as systems that evade precise description and prediction so that our knowledge of them always will be partial or qualitative. The relationship between system complexity and epistemological complexity is not trivial. Traditional reductionist philosophy claims that epistemological complexity can be eliminated, so that everything in principle can be known and predicted. Full-fledged reductionism is, however, philosophically flawed [57–59] and contrary to empirical fact, since even small Newtonian systems can be shown to be epistemologically complex, at least in the long run [60].

On the other hand, many systems can be predicted well enough for all practical purposes. A more relevant notion is that of *problem complexity*, a problem being a specification of the involved system, our plans, what actions we are willing to take, and what types of outcome we worry about, in other words, choice of perspective and value commitments. For instance, the problem of release of insect-resistant GM maize is probably of low complexity with respect to agricultural production in France over a 10-year period, but (given our general ecological knowledge) of high complexity with regard to the population dynamics of butterflies for the next 100 years.

Adding to the trouble, value commitments can be interwoven with the factual matters to be determined. For instance, there is a growing insight that “equilibrium”, “homeostasis” and “balance” are man-made concepts that might not describe real, ever-changing nature too well [61]. This constitutes a challenge to deep ecologists who insist that humans should be seen as part of nature [11]. If there is no “authentic” landscape to “restore”, why claim an essential difference between domestic and wild species? Indeed, Europe has changed from “wilderness” because of the competitive efficiency of species like wheat and the domestic cow in their symbiosis with man [52]. Could it not be argued that the transgenic maize also has a right to live [62] and blossom? Likewise, one may hold that system complexity in Nature primarily is a nuisance, and that wilderness should be tamed. If Commoner’s (disputed) laws of ecology are correct, however, overzealous attempts to control and reduce ecological complexity will fail [63].

Science since Galileo has focused on (and made) systems of relatively low complexity in order to produce knowledge sufficiently robust to “make things work”. A world-view constituted by current scientific knowledge is accordingly biased towards low complexity. Consequently, our current understanding of complexity comes from the margins of science: lessons when things do *not* work; folk knowledge; philosophy; natural history and recently, the science of complexity (e.g. the Santa Fe Institute). This understanding is sufficient to conclude that the environment possesses both system and epistemological complexity. It is insufficient to draw strong conclusions on epistemological problem complexity.

6.2. Values, ideology and rational policy options

We are now ready to identify legitimate sources of pluralism in the construction of rational options for policy on the regulation of release of GMOs.

Firstly, there is the issue of human equity across spatial and temporal boundaries. Secondly, views differ on the rights of other species. Above we argued that a refusal of anthropocentrism cannot be founded in the endorsement of unchanging, authentic nature, since this does not exist. Instead, it may turn to a *gradualism* in moral intuitions, either combined with a partial anthropocentrism (less rights for organisms that try to kill us, or that we feed on) or biological criteria (mental capacity, biodiversity, keystone species [46]). Or, it may focus on the unprecedented *speed* in which nature now changes as a result of deliberated human action. In either case, a modified and slightly slackened version of deep ecology will be the result.

Thirdly, value commitments regarding the acceptability of courses of *action* may differ. This is true of technological action itself (consider the “sheepgoat”) but also plans for action in case of emergency. On suspicion of nuclear terror it seems likely that the State will have to use authoritative means to protect its citizens [64], and I see no relevant difference to bioterrorism (say, GMOs with anthrax traits). This insight seems to undermine extreme versions of technological optimism or liberalism.

Finally, we are largely ignorant about the level of complexity of specific novel problems.

These degrees of freedom translate into ideologies and policies as follows:

Liberalism and *laissez-faire*, i.e. no regulation of release of GMOs, cannot be supported unless one denies basic rights of even of coexisting humans, and is to my knowledge not supported by any country.

Technological optimism may be combined with any view on sustainability and the rights of other species into a policy of regulation based upon scientific risk assessment and case-by-case regulation as understood in Section 5. This choice of ideology and resulting policy is seen to depend strongly on *either* a priori beliefs of low epistemological problem complexity, *or* the normative standpoint that the ontological and accordingly the epistemological complexity of nature can be reduced without loss of value, *or* granting larger value to present than future needs (principles of discounting), *or* that there seem to be no serious normative problems involved in the ways of action that may be necessary to control adverse effects.

Policy based upon shallow ecology may overlap with technological optimism only by making the assumptions on complexity explained in the former paragraph. Furthermore, shallow ecology dictates the inclusion of socio-economic risk (of non-sustainability), since it does not assume that technological development is a good per se [12]. Shallow ecology combined with anticipations of irreducible problem complexity, however, will at least lead into a policy of *impact assessments* since it will not assume that the desirability of effects can be known in their initial manifestations. Such a policy is reminiscent of the Norwegian Gene Act [65], which prescribes a full assessment of possible environmental, ethical and socio-economic impacts, and instructs the Ministry to lay emphasis on the prospects of GMO *contributions* to sustainability. However, in Norway, permission must be denied unless full safety is proven (§10), which in effect contradicts the principle of case-by-case evaluation. In practice it has implied something close to a total ban.

Anticipations of significantly large and irreducible problem complexity may even find impact assessments unsatisfactory. In such cases one may resort to the solutions prescribed by Funtowicz and Ravetz in their conception of post-normal science [66] in which a primary role of the expert is to identify and communicate the irreducible uncertainty and ignorance.

Deep ecology justifies prohibitions of release of GMOs by recourse to the unethical character of the practice of modern biotechnology (playing with the integrity of other life-forms) or the high complexity and thus the unpredictability of release. This is so because a non-anthropocentric conception of the problem includes more complex features (like the fate of the monarch butterfly). This justification is also strong enough for unilateral prohibition, since it may be argued that unilateral action is a necessary first step out of an unwanted global practice. However, deep ecology would also be consistent with impact assessment-based case-to-case regulation in no-win situations (for instance when we see no other way of cleaning up pollution) or intermediate, "post-normal" solutions as described above.

6.3. Form and function of scientific advice in governance

The norm of objectivity should govern the production and formulation of expert scientific advice. However, "objectivity" can have at least four different meanings, relating to (a) the "scientific method", (b) not being a stakeholder, (c) intellectual honesty and (d) lack of value bias.

(a) There are several legitimate research perspectives to the issue of release of GMOs, and the norm of objectivity demands proper data without subjective bias from each perspective. However, the *choice* of problem definition and research perspectives cannot be resolved with resort to objectivity, or by reference to one's own limits of expertise. If other perspectives are needed in a scientific committee, the individual expert should feel responsible for seeing that need and doing something about it. This insight is elaborated in the theory of post-normal science, in which it corresponds to the shift from a curiosity-driven to an issue-driven mode of scientific practice [66].

(b–c) A desire for experts not being stakeholders is naive in the present world. However, this does not mean that the norm of objectivity as *intellectual honesty* has no function as an ideal. Indeed, without a certain level of mutual trust in truth-telling ambitions, there is no point in talking and discussing at all, and scientific research would be futile. In this respect, recent proposals, including the participation of people of different interests as well as lay people to promote a broad, open-minded and transparent debate [25] are in some ways quite reminiscent of Merton's ethos of science [67].

(d) I have shown that different legitimate value commitments may imply different demands of scientific advice (Section 6.2). A governance process with an underlying consensus on technological optimism needs no more than a narrowly construed risk assessment. On the other hand, from the point of view of shallow or deep ecology, there is a need for impact assessments that also include socio-economic effects and the interplay between technology, society and the environment. Expert scientific advice which does not take such demands into account, de facto constitutes a value bias to the process of governance, even when objectivity in the three other senses is satisfied. In particular, one should distinguish between the role of the scientific expert in a public process of governance, and the professional consultant [66]. The consultant is expected to show loyalty and coherence to the interests and value commitments of his client. In a process of governance where values are disputed, the expert should be loyal to the process rather than, say, the particular ideology of the government. Thus, advice should be produced and formulated in a way so as to satisfy the least common multiple of the ideologies present in the public process. This can be done without contradiction, however, since a narrow risk assessment simply can be a part of a broader impact assessment, which again can be a part of a broader, post-normal approach of characterising the inherent uncertainties and sources of ignorance.

To summarise, if technological optimism, shallow and deep ecology are all found to be significantly present in the public discourse on the release of GMOs, a regulatory body that asks a scientific panel to report in the form of a risk assessment, enforces a *value* *bias*. If they ask for a broader report with an impact assessment and a scientific opinion on inherent uncertainties and sources of ignorance, they *avoid* this particular value bias.

7. Conclusion and practical implications

7.1. Step one: from risk to impact assessment

To accommodate the legitimate demands of shallow ecology for scientific advice in cases of anticipated irreducible complexity, a shift should be made towards broader impact assessments, defined as follows:

An impact assessment should investigate whether specific effects (beneficial or harmful) can be identified and evaluate their likelihood on the basis of the content, reliability and validity of current knowledge. This includes impacts of possible measures that may be taken in the case of acute and chronic adverse effects. The relevant body of knowledge should include any discipline necessary for evaluating environmental, medical and socio-economic effects as well as their interplay.

7.2. Step two: focus on uncertainty, ignorance and reflexivity

To accommodate the legitimate demands of deep ecology for scientific advice, as well as shallow ecology in cases of anticipated large and irreducible complexity, a characterisation of sources of qualitative uncertainty and ignorance should be included (see e.g. [14,68,69]). They should ask questions like (a) What do we not know? (b) What is the quality of current knowledge? (c) If evidence is missing, what should be done, and when?

This also implies that the panel should be familiar with critiques of modernity (Sections 3 and 5.1), in particular risk sociology, to be sensitive to their own role in the governance process. Finally, the panel should reflect on unspecified threats from the current understanding of system complexity, including ecology. It follows that panels need technical expertise in biotechnology, agriculture, and ecology, including natural history, but also medicine, sociology and/or economics. Of the economicist sub-disciplines, interdisciplinary ones like environmental economics and ecological economics [70] would be particularly helpful. Multi-competent individuals may accommodate the need for knowledge of theoretical critiques of modernity; otherwise, the services of a sociologist or a philosopher may be required.

7.3. The training of scientists

Communication across scientific disciplines can be difficult and time-consuming. It seems therefore a good idea to train students to master more than one discipline and be able to communicate across boundaries, especially across the natural and social sciences. Above all, natural scientists familiar with critical theories of science are needed. The University of Linköping is a fine example of educational programmes which combine these demanding objectives [71]. The compulsory inclusion of philosophy of science into every Norwegian university degree is another suggestive example.

7.4. Governance of science

The proposal of broad impact assessments raises a particular challenge with respect to basic research projects involving the release of GMOs: How can one assess the socio-economic impact of basic research? In Norway, this problem has been evaded by disregarding the sustainability aspect in such cases [6]. Especially from the perspective of deep ecology the question of "forbidden knowledge" is actualised. Outside the scope of this paper, the problem is difficult but important.

7.5. The need for research

Along the line of argument, needs for research have been noted. Above all we are in want of an adequate understanding of ecological, societal and global complexity, including the role of technological development in the history of man. Thus, various theoretical approaches to complexity should be encouraged, above all research that is self-conscious on its relationship to or resonance with ideology. Furthermore, there is a need for long-term natural history studies beyond what funding they can get in times of product-oriented research policies [22].

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