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*Perspective*

# Risk Governance for Mobile Phones, Power Lines, and Other EMF Technologies

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Power-frequency electric and magnetic fields (EMFs) have been present in industrialized countries since the late 19th century and a considerable amount of knowledge has been accumulated as to potential health effects. The mainstream scientific view is that even if there is a risk, it is unlikely to be of major public-health significance. EMFs from cellular communications and other radio-frequency technologies have increased rapidly in the last decade. This technology is constantly changing, which makes continued research both more urgent and more challenging. While there are no persuasive data suggesting a health risk, research and particularly exposure assessment is still immature. The principal risk-governance issue with power frequencies is how to respond to weak and uncertain scientific evidence that nonetheless causes public concern. For radio-frequency electromagnetic fields, the issue is how to respond to large potential consequences and large public concern where only limited scientific evidence exists. We survey these issues and identify deficits in risk governance. Deficits in problem framing include both overstatement and understatement of the scientific evidence and of the consequences of taking protective measures, limited ability to detect early warnings of risk, and attempted reassurance that has sometimes been counterproductive. Other deficits relate to the limited public involvement mechanisms, and flaws in the identification and evaluation of tradeoffs in the selection of appropriate management strategies. We conclude that risk management of EMFs has certainly not been perfect, but for power frequencies it has evolved and now displays many successful features. Lessons from the power-frequency experience can benefit risk governance of the radio-frequency EMFs and other emerging technologies.

**KEY WORDS:** Mobile phones; policy; power lines; risk analysis; risk governance

## 1. INTRODUCTION

In today's world, technological developments bring social and economic benefits to large sections of society; however, the health consequences of these developments can be difficult to predict and manage. The scientific evidence on electric and magnetic fields (EMFs) and their possible health effects has been reviewed many times (most authoritatively by the World Health Organization (WHO)[(1)]). Similarly, there are many publications discussing possible policy responses or advocating one particular policy. The purpose of this article is to consider, not the scientific evidence or the policies that have been adopted, but the process by which the science has been addressed in the course of policy making and the risk management tools that have emerged; that is, to consider EMFs as a risk-governance issue, and to identify any risk-governance deficits.

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We provide first an overview of the issue to set the context, including a chronology to illustrate the development of risk-governance approaches to EMFs. We then discuss both the stakeholders involved in risk governance and the processes that have been followed, before identifying suggested deficits and drawing conclusions. The objective of identifying deficits from the past is to allow better practice in the future, both for EMFs and for other issues sharing pertinent characteristics.

## 2. SCIENTIFIC CONTEXT OF THE RISK ISSUE

In this article, we focus on power-frequency or extremely low-frequency (ELF) (50 and 60 Hz) fields and radio-frequency (RF) (3 kHz to 300 GHz) fields. Both are part of the electromagnetic spectrum, but the frequencies are a factor of, often, 10 million times different, so their physical properties and interactions are very different. Both have acute effects at high-enough levels, which form the basis of exposure guidelines.

ELF EMFs are unavoidably produced wherever electricity is used, and are thus inherent in modern societies. This exposure has been present in industrialized countries since public electricity supplies appeared in the late 19th century. RF EMFs from broadcast radio and TV have also been present for decades, but with recent advances in EMF technologies (including base stations, other cellular communication infrastructures, and residential exposures such as wireless monitors used in children's cribs, cordless phones, and Wi-Fi), people are increasingly exposed to a range of different signals in the RF range. The increase is especially dramatic for handheld mobile phones, which have been available only since the later part of the 1980s and have become widely used by the general population only during the last decade. Currently, there are 4 billion mobile phone users worldwide, with a penetration in some countries over 90%.[2] Therefore, even if only a small health effect were occurring, this widespread exposure could have large public-health consequences.

For ELF EMFs, the scientific evidence essentially dates from 1979 with the publication of the first epidemiological study of childhood cancer and power lines (Table I).[3] Originally regarded with scepticism by much of the scientific community, ELF magnetic fields are classified by the International Agency for Research on Cancer (IARC) and the World Health Organization (WHO) as "possibly carcinogenic," based on reasonably epidemiological data for childhood leukemia, but with lack of support from laboratory studies in animals and cells.[4] There are also hypotheses that the etiological factor is not magnetic fields but something related to it such as contact currents in homes or corona ions produced by power lines, or mobility and socioeconomic status. The conventional scientific view is that the evidence really only implicates one relatively rare disease, childhood leukemia, and the exposures that are implicated are at the top end of the normal range of residential exposure and are therefore also relatively rare. If there is a risk at all, it would therefore be unlikely to be of major public-health significance. Estimates are of just a few percent of cases of childhood leukemia being attributable to magnetic fields if there is an effect.[1,5] However, from the perspective of the individual, any risk could be of order 1 in 20,000 per year for those few children exposed, which is approaching levels that can trigger regulatory action for other agents.[6–9]

Although safety limits on exposures to high-power RF sources (which can cause serious injury) have always been necessary, and there were reports of health effects at lower levels in the 1960s and 1970s (Table II), serious scientific inquiry about possible health effects to the public is relatively recent. Laboratory evidence, broadly, does not support health effects of RF EMFs at environmental levels encountered by the public. In particular, animal toxicology experiments have not identified effects. Epidemiological evidence from broadcast RF EMF or from cellular communications infrastructure is sparse and uninformative.[10] Epidemiological evidence concerning cell phones themselves is, so far, mainly reassuring, but only few diseases have been studied and there is little to no data on children. Additional uncertainty is due to inadequate latency and exposure assessment and suggestions of effects in some analyses.[11]

Uses of both ELF and RF EMFs brings enormous benefits to societies and thus appropriate risk governance includes consideration of a large number of tradeoffs, including the potential for risk offset, risk substitution, risk transfer, and risk transformation, as well as benefits and costs.

The invisible and largely involuntary nature of EMF exposure, its production by infrastructure that may be unwelcome for other reasons, its presence within the sanctity of the home, and its association with radiation, at least in name, and the putative health outcome of cancer among children have all

**Table I.** Development of Key Events for ELF EMFs

| | Research Results | Reviews and Assessments of Scientific Evidence | Policy |
|---|---|---|---|
| 1960s | Occupational reports from Russia[14] | | Largely discounted |
| 1970s | 1979: first residential epidemiologic study[2] | | |
| 1980s | 1982: first occupational epidemiologic study[15]<br>Other studies published but still fairly weak.<br>Numerous laboratory studies but without robust results. | | First major research program in New York.[16]<br>1989: first recommendation for "prudent avoidance" in United States.[17] |
| 1990s | 1993: first Scandinavian epidemiological studies published, higher quality but still small.[18] | Succession of official reviews in United Kingdom and United States use language of "no firm/established/conclusive effects."[22,23] | Australia, California, Sweden, and others adopt precautionary policies.[25–28] |
| | Succession of occupational epidemiological studies in utilities<br>More laboratory results but including failed replications of earlier positive results<br>1997–1999: results of major epidemiological studies from United States, Canada, and United Kingdom; uncertainty remains[20–22] | 1998: NIEHS (USA) classify magnetic fields as "possibly carcinogenic."[24] | 1992: major U.S. research program (RAPID).[29]<br>1998: ICNIRP publish exposure limits based on established effects only (now adopted by 30 countries).[30]<br>1999: official recommendation for "passive regulation" in United States.[19] |
| 2000s | 2000: pooled analyses of childhood leukemia epidemiology establish association but not causation[31,32] | 2001: IARC classify magnetic fields as "possibly carcinogenic."[3] | 2002: WHO starts consideration of precautionary measures.[44] Italy, Switzerland, and Netherlands adopt precautionary limits.[36] |
| | | 2002: Report in California sees strong evidence for several health effects but is not adopted by state authorities.[35]<br>WHO confirms IARC classification but says evidence for disease other than childhood leukemia is "much weaker."[1] Other official bodies reach similar conclusions (e.g., SCENIHR).[37]<br>2007: Bioinitiative Report published to counter "official" views, claiming stronger evidence for more effects.[38] | 2004: United Kingdom starts detailed process to consider precautionary measures.[40]<br>WHO report includes detailed consideration of possible appropriate precautionary measures.[1] |

heightened public anxiety. Consequently, media coverage has sometimes been intense and the issue has been brought to a wide public awareness.[12,13]

In risk-governance terms, therefore, the principal issue with power frequencies is how to respond to a considerable body of scientific evidence that, except for the uncertainty about childhood leukemia issues, is otherwise largely reassuring, but that nonetheless causes public concern. For RF EMFs, particularly from cellular communications, it is the combination of rapid growth of exposures over a relatively short time, little scientific evidence, but large potential consequences and large public concern that presents the risk-governance challenge.

## 3. STAKEHOLDERS INVOLVED

### 3.1. Scientists

The most influential group over the years of risk management has been what might be called "establishment" scientists—the type of scientist who becomes eminent and generally respected by his or her peers and accordingly tends to populate groups (e.g., IARC, WHO, AGNIR, NAS) and bodies that recommend exposure limits or other policies (e.g., ICNIRP), with those bodies then adopting the characteristics of their members. Such scientists tend to be cautious in accepting new results. This could be seen, negatively, as innate conservatism reinforced

**Table II.** Development of Key Events for RF EMFs

| Year/Technology Introduction | Research Results | Reviews and Assessments of Scientific Evidence | Policy |
|---|---|---|---|
| 1970s and before. | Sporadic reports of laboratory findings[41–43]<br>Ambiguous epidemiological results linking RF exposures with various health effects | | |
| 1980s First and second generation mobile telecommunications networks established. | Animal studies show effects due to heating.[44] | National and international reports conclude the only established health effect is the thermal effect.[25,30] | Several organizations published guidelines based on established thermal effects.[45]<br>1984: Establishment of CTIA—International Wireless Association |
| 1990s Widespread siting of first and second generation base stations. Base stations and facilities become more visible and numerous evoking public concern. | Some positive animal studies on effects on brain,[46] and cancer. Other studies fail to find health effects. | | 1992: First lawsuits. None successful but raised profile of issue globally and resulted in adverse publicity for industry.[47] |
| High penetration rate of mobile phones into the market. | 1993: Industry established Wireless Technology Research Program (WTR). | | Anti-tower campaigns emerge in different countries. |
| | 1996: Studies reporting increased cancer incidence with proximity to radio and TV transmitters. | | More guidelines published in different countries based on heating effects,[23,30,48,49] including Europe.[50]<br>1998: Establishment of International Mobile Manufacturer's Forum (MMF). |
| 2000s Introduction of third generation and other technologies (UMTS, TETRA, DECT, WIFI, WIMAX WILAN). | 2001: Funding for WTR ceased with claims of coverup.[51] | 2000: European Commission communication on the precautionary principle.[53] | Public suspicion of the relationship between industry and scientific research grows. |
| | 2000–2004: Major international epidemiological study (INTERPHONE)[52] launched but publication of final results delayed. | 2000: U.K. report recommends adoption of precautionary approach and addressing public concern.[54] | Numerous new facility sittings and media reports raise public concern.<br>2001: Industry agrees to publicize SAR levels of mobile phones. |
| | Further mixed results. | Reviews by different authors, teams, and institutions have reached different conclusions.[38,40,42,53,54,56,57] | 2002: WHO starts considering precautionary approaches.[44] |
| | | | More countries adopt ICNIRP exposure limits; a few countries develop stricter levels or precautionary policies.[36] |

by a like-minded peer group, possibly including an element of conscious or unconscious selection of scientists to ensure preservation of the status quo, or, positively, as the appropriate exercise of judgment informed by maturity and experience. The major and influential reviews throughout EMF history have tended to be produced by such people, but usually involving an extended and intensive process of examining the evidence. The best-organized review groups have structured their examination of the evidence in such a way as to discourage casual dismissal and to force justified decisions, an example being the IARC Monographs classification scheme, which requires classification of component strands of evidence against defined criteria before reaching an overall conclusion.

Other scientists have taken positions to both sides of the mainstream. On the one hand, there are senior scientists who feel confident enough to declare that the evidence does not justify concern; that there are no effects, or that effects are exceedingly unlikely at exposure levels to which the public is exposed; and that research should cease, or other public-health issues should receive higher priority. On the other hand, some scientists have viewed the evidence for health effects as considerably stronger than the conventional assessment. With regard to childhood leukemia, they suggest different exposure-response relationships leading to a higher attributable fraction, and that this association is sufficiently strong to justify setting exposure limits. They also say that the scientific evidence on other, more prevalent, diseases, regarded by WHO as "much weaker," is being underestimated.[35,38] These different views indicate that individual evaluations are influenced not just by the evidence but by wider factors, possibly including differing priors and dispositions to weight evidence differently.

The divergence of views between scientists has been most evident in legal or quasi-legal settings, such as litigation, siting or permitting hearings for new facilities. The adversarial legal system employed in the United States, the United Kingdom, and elsewhere encourages the polarization of views, and many of the scientists most represented on review groups have declined to become involved in this activity, leaving the field clear for people willing to espouse less nuanced views. This effect also occurs in the media, and it is there that scientists willing to take an unambiguous stance have had the most influence.[58]

Although best practice often promotes risk assessment and risk management as separate activities, in EMFs, they have often been performed by the same people. For example, the same body of scientists who make up the International Commission on Non-Ionizing Radiation Protection (ICNIRP) both evaluate the evidence and make recommendations for exposure limits (but are not necessarily involved in the policy-making process). The WHO Environmental Health Criteria in 2005 contained science chapters and a policy chapter, both approved by the same scientifically constituted Task Group. In principle, there should be a separate stage where officials and, ultimately, politicians decide on the risk management measures to be adopted. In practice, this has often amounted to rubber-stamping of recommendations from scientists, as, for example, when the EU initially simply adopted the ICNIRP recommendations on occupational exposure limits. Only in recent years with the more explicit thinking about precautionary measures has an identifiably political step in risk management, separate from the scientific risk assessment, been apparent.[63]

### 3.2. Activists

Alongside scientists, the issue has been driven by activists, who have often first engaged with the issues through opposition to a local infrastructure project. For some, EMFs may have only been another weapon in the armory of opposition. However, for others, EMFs have become a matter of genuine conviction, sometimes to be pursued once the immediate trigger is no longer an issue. Some activists become engaged as a consequence of their own illness or that of a friend or relative, which they attribute to EMFs. The extent of public concern about EMFs, like many other issues, is clearly influenced by whether they are perceived as voluntary, controllable, and bringing a benefit to the individual.[33,34]

### 3.3. Public Authorities

Other important parties involved in the risk management process are government and public authorities. They integrate societal, economic, and political considerations into the decision-making process and are influenced by accountability for their decisions. Charged with the health protection of their population they often look at other decisionmakers (e.g., government officials in other countries) to benchmark their policy. This has resulted in some convergence of EMF policies around the world (e.g., adoption of ICNIRP guidelines by most countries in Europe and a legitimization of EMF precautionary policies in recent years).

### 3.4. Industry

Industries, as proponents of EMF technology, are also influential actors. Industry's relation to scientific research on health effects has been controversial. On one hand corporations are attacked for not providing sufficient funds for research, suggesting a lack of concern as to the safety of their technology. On the other hand, when they do sponsor studies, they are accused of having done so only to influence the findings. Industry also sometimes faces competing pressures: a short-term need to build the next power line or base station, but a longer-term pressure (which is increasingly seen as the more important) to run a sustainable and responsible business in a context where public goodwill, or at least toleration, is essential for success.

Motivations for all actors—scientists, regulators, industry, or activists—are undoubtedly mixed, with conviction and altruistic motives juxtaposed with unavoidable pragmatic and personal motives. Many activists feel an obligation to society to promote the view they hold and the actions that should stem from it; many scientists feel an obligation incumbent on being a professional scientist to play their part in uncovering truth. Equally, some scientists have found EMFs a welcome source of research funding, while some activists have found EMFs a platform from which to have national influence or to generate a living.

## 4. EVOLUTION OF THE RISK-HANDLING PROCESS

As with many other agents, international guidance or exposure limits on occupational and public exposure to EMFs is based on avoiding risks to health that are well understood and for which there is good scientific evidence.[3] Once that basis is adopted, setting the actual guidance is relatively uncontroversial, but because it addresses effects at much higher levels of exposure (principally experienced occupationally) than the public generally experiences, it is often viewed by the public as not addressing its concerns, and may be opposed for that reason.[35,38]

For these and other reasons precautionary approaches for EMF have been introduced. Initially different interpretations of the principle led to different precautionary based approaches as policy tools.[36,38,77,78] In the last few years, the World Health Organization and the European Commission's communication have put forth the considerations needed to apply this principle in a manner that will benefit society as a whole.[1,39,54,55]

The attitude toward public involvement in the risk handling process for both ELF and RF EMFs has evolved from no involvement and a defensive approach to public concern, to recognition of the need to communicate to the public, and finally to being open to public input.

### 4.1. ELF EMFs

Since the issue first emerged in 1979, there have always been the twin drivers of scientific and public concern, but the balance between these has changed over time. At the start, there was less sensitivity in official circles to the need for public engagement or communication than today. Early responses were partly driven by a sense that this issue could be managed by conventional scientific expertise. The scientific evidence in the early stages was, by any objective standards, fairly weak (Table I). Thus, many early official responses had a large element of attempted reassurance about the weakness of the evidence, which at times could sound like dismissal of the concerns. Further research was commissioned, but in part as a response to public demand or as an issue-management tool, rather than solely as a scientific endeavour in its own right. Many official reports recognized evidence of possible effects at low levels, but used terminology such as "no conclusive evidence," "no reliable evidence," or "no established effects." This terminology was factually correct, and accurately reflected the concern of those organizations to focus on identifying any effects where the evidence would be strong enough to warrant, in their estimation, regulatory action. Nonetheless it contributed to a sense of the evidence being downplayed or even ignored.

This response evolved over time through the 1980s and 1990s. Some better quality research, suggestive of effects though still far from conclusive, emerged, together with a staggering quantity of other research of variable quality, some frankly poor. This contributed to a sense that this issue was not going to disappear, and that perhaps the way to deal with it was for good-quality research groups to perform studies as close to definitive as possible. For many of the health outcomes studied, the issue could legitimately be largely dismissed; however, the newer and better epidemiological studies served to strengthen the evidence that there is an association between childhood leukemia and unusually high exposures to magnetic fields in the home, although the cause of that association is far from certain.

Concern over the issue fluctuated over time, being most prominent in the United States during the

1980s and early 1990s, but probably more prominent in Europe since then. It has also been an issue in more affluent communities in several of the Central and Latin American countries as well as in Japan, Korea, Taiwan, Australia, and New Zealand.[64] The controversy over EMFs has led to some opposition and delays in building new power lines. But most industrialized countries have undertaken relatively little building of new power lines in recent years compared to the existing networks, so such delays are probably not a major cost to society. This situation is changing, as the old infrastructure is aging and there is a growing need to connect new green sources of power. In some jurisdictions, new power lines have become more expensive as a result of EMF mitigation measures, and there are suggestions that some buildings are built or retrofitted with EMF mitigation measures at significant increased cost.[65]

Over the same period, most jurisdictions continued a policy of being prepared to base protective or public-health measures only on fairly robust evidence, and therefore not being prepared to take action over the EMF concerns. A few jurisdictions, however, started taking action. Notably, some Scandinavian countries adopted precautionary approaches, albeit not terribly specific in their requirements, and Australia and California (and some other U.S. states) adopted precautionary policies (then known under the label "prudent avoidance") where modest amounts of money should be spent to reduce exposures where practicable.[28] It is arguable that some of these measures were more motivated by issue management than by genuine public-health concerns; and it is arguable they were partially successful in that, for example, in California it may be that the measures adopted for mitigating EMFs in building new power lines did contribute to reduced public opposition.

The trends in the management of the issue accelerated with something of a step change around the turn of the millennium. First, the U.S. NIEHS officially classified ELF EMFs as "possibly carcinogenic" in 1998. Then two influential pooled analyses of the epidemiological studies on childhood leukemia were published in 2000, and in 2001 IARC classified ELF magnetic fields as possibly carcinogenic. None of these, of course, actually changed the evidence, but between them, they contributed to a sense that EMFs were now a legitimate unresolved scientific issue; it had become "mainstream" and had shed something of its "fringe" reputation in scientific circles. At the same time, particularly in Europe, the precautionary principle was becoming more discussed and accepted, for reasons amply explored elsewhere.[31,37,56–62,66]

Some scientific bodies, such as ICNIRP and the U.K. HPA, felt and still feel that they should act only on established science; but in other scientific circles, and certainly in political circles, there was an increased willingness to consider what measures would be appropriate when dealing with uncertain scientific evidence. Following the IARC classification, the WHO International EMF Project started considering possible precautionary measures,[39] and this was influential.

Thus, since about 2001, there has been a change in the tone of the debate on risk management: less of "how can we keep the lid on this" or "how can we educate people to understand why it shouldn't be of concern," and more of "how can we do something measured and reasonable that is a correct response to the scientific evidence and associated uncertainty, as well as to public concern."

### 4.2. RF EMFs

For radio-frequency EMFs, the risk management landscape has been different. Most notably, the debate has been conducted with less scientific evidence. This has allowed players in risk management to take divergent views, some saying that as there is no good evidence of harm there is no justification for any protective measures, and that the emphasis should be on managing (or, often, simply resisting) what is seen as unreasonable public concern. Others have argued that given the absence of positive reassurance and the potential scale of the impact if there were to be an effect, there is every reason to take protective measures now.

Another difference with RF EMFs is that the technology is new and developing continually in a competitive environment; the infrastructure is being rolled out at impressive speed and with considerable visibility within communities, and there are strong pressures, both commercial and social, not to brook any unnecessary delay. This combination of a much wider set of scientific viewpoints and more focused pressures gives the RF risk-management debate a sharper edge.

## 5. RISK-GOVERNANCE DEFICITS

Risk governance refers to the social, legal, and institutional decision-making processes used in

**Table III.** Components of Effective Risk Governance

| Operational Component | Elements of Component |
|---|---|
| Framing | Monitoring and early warning to systematically search for new risks<br>Define problem: articulate risk, goals, implications of current knowledge<br>Selection of decision rules and identification of risk managers and stakeholders<br>Effective involvement of all stakeholders |
| Assessment/evaluation | Risk assessment (quantitative and/or qualitative)<br>Concern assessment: systematic analysis of the risks and benefits as perceived by relevant stakeholders and of the social or cultural aspects of the problem<br>Effective involvement of all stakeholders |
| Evaluation/management | Evaluation: identify and evaluate potential options, including no action, risk management, and risk prevention options, against specific criteria such as effectiveness; efficiency; equity; potential side effects; social, political, legal, and cultural considerations, etc.<br>Option selection and implementation<br>Monitoring and evaluation of outcomes<br>Effective involvement of all stakeholders |

identifying and responding to risks facing society. These processes occur at multiple levels ranging from the local through the global. Clearly, in practice the nature of risk governance will vary depending upon a variety of factors. For example, risk governance at the national level typically involves a superior authority in the form of the national government, while risk governance at the global level rarely involves a single superior authority. Nonetheless, leading models of risk governance share certain common principles and operational components applicable across a variety of applications, which are set out in Table III.[63,71,72]

A risk-governance deficit is the failure of a governance approach to effectively implement one of the central operational components.[72] This section provides a survey of the risk-governance deficits reflected in policy development in this area. As EMFs involve risk governance at the local, national, and global levels, this survey extracts general themes from all levels in an effort to learn from the experience.

### 5.1. Framing Deficits

Problem identification is a central component of framing in every leading risk-governance model. The main framing deficits relate to the limited scientific knowledge. Lack of knowledge itself is not necessarily a risk-governance deficit; the deficit arose from how the relevant parties and institutions responded to that lack of knowledge. The responses to ELF risk and RF risk reflect different types of deficits related to inadequate knowledge.

In the early period of ELF risk management, there was a failure of the mainstream, "establishment" scientific community, and the institutions and policymakers who relied upon their views, to acknowledge sufficiently the limited nature of the available scientific knowledge. In particular, they tended to privilege their assessment of the science, and to exhibit limited regard for alternative scientific views. Consequently, they gave the impression of dismissing concerns prematurely, prior to the initiation and completion of a body of quality epidemiological and laboratory studies sufficient to support legitimate consensus. That dismissal was contrary to an important element of proper framing in risk governance: the relevant actors should seek consensus in terms of characterizing the problem, including identification of potential adverse effects.[63,72]

To be fair, this should be seen in the context of the times. The initial scientific evidence was, objectively, weak, perhaps not as weak as sometimes painted at the time, but still legitimately regarded by conventional scientific assessment as likely to amount to little in the long run. It was not, perhaps, until the late 1990s that the evidence started firming up (though still amounting to only a "possible" risk), and around that time, the mainstream scientific community did change so as to recognize that (Table I). In more recent years, while there are still circles where the evidence and the legitimacy of the issue tend to be minimized or even dismissed, such views are noticeably rarer. There is still debate over the scope and nature of the risks, with recent reports and pronouncements challenging the conventional view that power-frequency EMFs risks are limited to possible leukemia effects on a subpopulation of children,[35,38] but the main issue now is selecting the appropriate policy.

RF EMFs associated with the cellular-telephone industry raise a different type of knowledge-related deficit due to the astonishingly rapid rate of technological change in this sector. By contrast to power-transmission practices and technologies, which are deeply imbedded in society and have been fairly stable over the last decades, wireless technologies, and the manner in which they are deployed and used, change frequently, making it extremely difficult to characterize and study exposures over time. However, the constant change also offers windows for intervention, if appropriate, to deflect the adoption of unreasonably hazardous new technologies or practices. In risk-governance terms, the dynamic nature of this technology makes detection of early warnings of risk extremely difficult. This problem is exacerbated by two factors, society's apparently insatiable appetite for the latest in wireless equipment and services and the potentially long latency periods for chronic effects.[66,69] In addition, a clear distinction should be made between evidence of the absence of an effect and the absence of evidence of an effect—for RF this distinction is sometimes intentionally or unintentionally blurred. For example, while studies of children, who might be more sensitive, are largely lacking (the absence of evidence of an effect), it is sometimes stated that children are not affected or are no more sensitive (evidence of the absence of an effect).

Policymakers do recognize the need to search systematically for emerging risks in new technology, and appear to be making some efforts in that direction. Whether those efforts will be effective is unclear. The Federal Communications Commission is a case in point. In 1985, the Commission first established guidelines for human exposure to RF radiation from various transmitters it regulated. Since then, it has only revised its standards when other agencies and organizations with greater expertise concluded that changes were necessary.[10] In response to a lawsuit challenging this policy, the court approved the Commission's strategy of "watchful waiting."[74] By casting the decision as a purely scientific exercise, the Commission skirted the difficult issues raised when a new technology cannot be expected to manifest any early warnings until years after it is introduced. Relevant factors include whether it is appropriate to forego the enormous benefits cellular communications have brought to societies, both developed and developing, on the basis of rather little scientific evidence; how robust an early warning has to be under these circumstances; whether a proactive surveillance, if it existed, would provide reassurance that early warnings would be detected; and how the debate changes if precautionary measures are available that have no or low cost. The absence of a widely agreed upon answer to this problem underlies much of the disagreement on appropriate risk management and can be seen as a deficit; the disagreements are not so much over the facts as over the appropriate values and normative framework to be applied to those facts. Disagreement over values also extends to the role of economic considerations when dealing with health issues, particularly emotive health issues involving childhood cancer.

The Presidential/Congressional Commission on Risk Assessment and Risk Management's framework in particular stresses the need for putting the problem in context; that is, focusing on whether the relevant population is exposed to a particular pollutant from other sources or multiple pollutants from one or more sources.[63] Risk governance of both ELF and RF EMFs, however, has focused on addressing individual sources, with more emphasis on some than others, and little attention paid to mixed exposures. More policies focus on power lines, and particularly transmission lines, than on other sources such as distribution lines and appliances, which, depending on the aspect of exposure considered, can constitute a more significant source.[10] In RF, policies focus more on base-station siting whereas other sources such as mobile phones can (again depending on the aspect of exposure considered) contribute much more to individual exposure. This differential treatment stems from the reactive nature of policy formulation in this area, including reacting to public concern; a pragmatic recognition of where it is easiest to effect change; and the dispersed responsibility between institutions.[74]

### 5.2. Assessment/Evaluation Deficits

Although rigorous, careful risk assessment is central to risk appraisal, so too is assessment of the concerns held by the public, including stakeholders' perceptions of risks and benefits, and the social and cultural aspects of the problem. Indeed, most formulations of effective risk governance expressly acknowledge the importance of public involvement, broadly defined, in problem framing and in evaluation/management as well.[63,71] This focus on public concerns and public involvement rests on three justifications. It is grounded in normative views about the right of the public to be engaged, in instrumental desires to secure political legitimacy for the ultimate policy, and in substantive beliefs that knowledgeable lay engagement can improve the assessment and evaluation of risk.[69,70,74]

In practice, public involvement can range from simple unilateral *communication* by public authorities or other decisionmakers to the public, to *consultation* in which comments are sought from citizens or specified stakeholders, to more robust substantive *participation* in which the interested parties engage directly in dialogue with the policymakers or even share in decision-making authority.[75,76] From a normative standpoint, the appropriate level of public involvement and the specific mechanisms for securing such involvement depend on a number of factors, including the complexity, certainty, and urgency of the problem, the goals of stakeholder involvement, the available resources, and the nature of stakeholder groups.[63,71,74] Moreover, other factors such as legal requirements of administrative law, bureaucratic norms, or political pressures may limit the scope or effectiveness of public involvement, for example, by restricting the process to risk communication, or engaging in "tokenism" to evoke the false impression of an engaged citizenry.[76]

In the earlier stages of EMF risk governance (both for ELF and RF), members of the scientific establishment undervalued the importance of lay public perceptions of scientific issues and made insufficient use of public involvement mechanisms. To some degree, this separation of the science-based policy development from social perceptions and values reflected the legal regime in which risk decisions were often formulated. Siting decisions were governed by legalistic procedures, largely adopting an adversarial framework in which both sides had strong incentives to state the evidence as strongly as possible. An example of an inappropriate statement by activists would be the highlighting of a single, seemingly positive, experimental study, without considering the weight of evidence from the totality of relevant studies, which may often present a consistently negative picture that casts doubt on or outweighs the single positive study. The evidence has in fact often been overstated by conventional standards, a deficit in itself, but also contributing perhaps to a minimization of the risk as presented by the establishment through a desire to counter the exaggerated claims. An example of an inappropriate statement by industry would be references to numerous negative studies when many of them may not be especially relevant to human health or may not have had a resolving power to detect an effect (due to limited size or relevance of the biologic model). Similarly, oversimplistic arguments, based on crude energy considerations, of the impossibility of any effects have been used. This desire by the establishment to counter alarmism coming from elsewhere by slanting its own presentation of the facts is seen in other issues as well (e.g., the BSE issue in the United Kingdom[67]).

A closely related risk-governance deficit concerns the means by which stakeholders are engaged in the process. Policymakers for both power-frequency and radio-frequency EMFs face challenges in integrating wide varieties of interests and groups within the risk-governance process, particularly with respect to small but vocal groups or groups with largely local concerns. For example, in the United States, the federalization of cellular tower siting has minimized opportunities for advocates to raise concerns before local, regional, or even state decisionmakers. Section 332 of the Federal Communications Act prohibits local authorities from considering environmental effects of RF EMFs so long as the tower complies with the FCC's radio frequency emission regulations.[73] Similarly, the Energy Policy Act of 2005 partially federalizes the siting of transmission lines before the Federal Energy Regulatory Commission (FERC). While stakeholders in federal permitting proceedings are guaranteed a "reasonable opportunity to present their views and recommendations with respect to the need for and impact of a facility covered by the permit,"[79] FERC's permitting processes meld prefiling outreach mechanisms with highly formalized, adversarial proceedings.[80] It is unclear whether those procedures will engage stakeholders in a meaningful way.[81]

Setting policy at a national level may expedite the approvals process and bring clarity of policy, desirable outcomes in themselves, but clearly limits local and lay participation and funnels stakeholders into a traditional administrative proceeding rather than encouraging proactive consensus-building process. Despite progress (for the best example, see the SAGE process in the United Kingdom[82]) a fully satisfactory process for involving stakeholders has yet to be found.

### 5.3. Evaluation/Management Deficits

The evaluation/management process calls for balancing a variety of factors in selecting an appropriate management strategy. One important factor is consideration of the consequences, positive and negative, that are likely to flow from the options under review. This includes attention to direct and indirect social, economic, and legal consequences as well as anticipated health and environmental impacts. Two issues of risk governance are implicated. First, in some instances, limitations of the administrative process—whether they be resource or time limitations, the vertical or horizontal fragmentation of governmental authority, or flawed stakeholder involvement—may prevent decisionmakers from considering the full range of tradeoffs. Second, in contrast, parties seeking particular outcomes may overstate the possible consequences of alternatives that they disfavor, with exaggeration of the adverse consequences of taking protective measures or exaggeration of the scientific evidence. The EMF debates provide examples of both.

For ELF EMFs, where one major source is the high-voltage power line, there are a set of interrelated issues about land use and land values adjacent to such lines, the different economic interests of nearby residents from society as a whole, the availability of land to meet broader societal objectives, and other concerns. The consequences of any EMF mitigation measures for these wider issues have to be considered. This may not be appreciated by the proponents, but equally, may be overstated by the opponents of such measures. Further, pragmatic policy decisions, such as the California Public Utilities Commission heuristic rule requiring mitigation measures so long as their cost is below 4% of the total project cost,[83] can obscure consideration of tradeoffs associated with particular mitigation measures.

Similar issues apply with RF technologies. Importantly, there are issues of equity between those experiencing the exposure and receiving some benefit, those experiencing the exposure and not receiving direct benefit, and society as a whole. Those technologies, in particular cellular communications, have an undeniably enormous impact on societies. They have a downside (e.g., contributing to collisions if used when driving, the environmental consequences of manufacture and disposal, and, perhaps, some adverse social effects of changing communication patterns), but there is broad agreement that the overall effect is overwhelmingly positive, through improved communication generally as well as specifics such as expediting help in medical emergencies. It would be hard to justify restricting those benefits, but some precautionary measures would not in fact limit the use of or benefit from these technologies.

## 6. CONCLUSIONS

Introducing new and widespread technologies, technologies that require visible infrastructure dispersed throughout society and that trigger many public "fright factors," will inevitably create public concern and opposition, at a time when trust in conventional science and risk management is declining.[68] Thus, we should not see the current public concern as a failure of risk governance *per se*; the question being is the position worse than it could have been if we had managed the issues better? In some ways, that question will only be answered definitively at some point in the future when hindsight is complete. If health risks turn out to be real, we will be criticized for not recognizing early warnings sooner and acting so as to protect public health. If there turn out to be no health risks, we will be criticized for not managing the issue more robustly so as to reduce its impact.

Against that backdrop, we conclude that risk governance of EMFs has certainly not been perfect. Deficits can be easily identified, most obviously, attempts by the "scientific establishment" to manage the issue purely as a scientific issue without fully recognizing the many facets of the social dimension to risk management, coupled sometimes with a disinclination to accept the possibility of any risk from a popular technology that undoubtedly brings vast public benefit.

These deficits apply principally to the earlier years for ELF EMFs; risk governance in that issue has evolved and now displays many successful features. Scientific uncertainty has been greatly reduced by limiting potential health consequences (narrowed to fewer health outcomes and limited health impact). For the remaining uncertainty, we increasingly see openness to new scientific ideas and to lay perspectives while retaining scientific integrity and insisting on a valid scientific basis for policy; willingness to face up to the implications of an absence of evidence; moves to avoid prejudice and bias in both reviews of the evidence and in research priorities; understanding of both the nature and validity of the social dimensions of a scientific risk issue; thought put in to understanding communication strategies; and stakeholder engagement in each component of the decision-making process.

These deficits are perhaps still seen, to varying extents in varying countries, in the RF issue, which is a more recent issue and where the pressures, commercial and other, are stronger. It remains to be seen how well lessons from the ELF experience will be applied to RF risk management. The main lessons to be learned from ELF are that an open and proactive approach to research greatly assisted successful governance of a potentially volatile issue that could have had tremendous societal costs; that exaggerated reassurance, even when well meant, is counterproductive; and while there are still disputes, particularly at the local level, continued research, public involvement, and adoption of low and no-cost exposure reduction measures allow for a manageable process of building and upgrading power-line infrastructure.

We suggest that these examples have lessons that can be applied when introducing other new technologies into society, which may be prone to the same or similar deficits.

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