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Assumptions in quantitative analyses of health risks of overhead power lines

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Abstract

One of the major issues hampering the formulation of uncontested policy decisions on contemporary risks is the presence of uncertainties in various stages of the policy cycle. In literature, different lines are suggested to address the problem of provisional and uncertain evidence. Reflective approaches such as pedigree analysis can be used to explore the quality of evidence when quantification of uncertainties is at stake. One of the issues where the quality of evidence impedes policy making, is the case of electromagnetic fields. In this case, a (statistical) association was suggested with an increased risk on childhood leukaemia in the vicinity of overhead power lines. A biophysical mechanism that could support this association was not found till date however. The Dutch government bases its policy concerning overhead power lines on the precautionary principle. For the Netherlands, previous studies have assessed the potential number of extra cases of childhood leukaemia due to the presence over overhead power lines. However, such a quantification of the health risk of EMF entails a (large) number of assumptions, both prior to and in the calculation chain. In this study, these assumptions were prioritized and critically appraised in an expert elicitation workshop, using a pedigree matrix for characterization of assumptions in assessments. It appeared that assumptions that were regarded to be important in quantifying the health risks show a high value-ladenness. The results show that, given the present state of knowledge, quantification of the health risks of EMF is premature. We consider the current implementation of the precautionary principle by the Dutch government to be adequate.

1. Introduction

Policy decisions on issues where inconclusive evidence is involved are complex and often contested. Uncertainties of different nature and level can be present in various stages of the policy cycle, which means, among other things, that the available evidence on either background and causes of a problem or approaches to solve an issue can be insufficient to come to a straight and undisputed policy (Funtowicz & Ravetz, 1990; Junnti *et al*., 2009). Besides, institutions of science and policy show different behavior and interests, which hampers transforming scientific knowledge into policy decisions even more. In terms of uncertainty, policy makers seek certain and deterministic solutions, whereas scientists are more familiar with uncertainty and complexity (Adger and Vincent, 2004; Bradshaw & Borchers, 2000). Provisional and uncertain evidence, institution change, and uncertainty communication are major issues when it comes to improving the science-policy interface (Cortner, 2000; Kinzig and Starrett, 2003; Oreskes, 2004; Van den Hove, 2007; Wardekker *et al.*, 2008). Several research fields on the science-policy interface can be distinguished, including complexity (Chu *et al.*, 2003), post-normal science (Funtowicz and Ravetz, 1993), trans-disciplinarity (Thompson Klein *et al*., 2001; Pohl, 2008), Bayesian belief networks (Aguilera *et al.*, in press) and deliberative risk governance (Jasanoff and Wynne, 1998).

Different lines are suggested to address the problems of inconclusive and uncertain evidence in science-for-policy (Van der Sluijs *et al*, 2008), and intend scientific uncertainty to be incorporated in the whole decision-theoretic framework (Bradshaw and Borchers, 2000). Uncertainties in the evidence might be disclosed by formal methods for sensitivity and uncertainty analysis (Saltelli *et al.*, 2008). When quantification of uncertainties appears to be impossible, the quality of the evidence can be explored through reflective approaches such as pedigree analysis.

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One of the issues where the scientific evidence does not provide for undisputed policy decisions is the case of electromagnetic fields of overhead power lines. In a study by Wertheimer and Leeper (1979), it was suggested that children living in the vicinity of overhead power lines have an increased risk at cancer. Since then, a large number of epidemiological studies have been published, investigating the suggested association between extremely low frequency (ELF) EMF and childhood leukaemia (see Kheifets & Shimkhada (2005) for an extensive review). In three pooled analyses (Ahlbom *et al.* 2000, Greenland *et al.* 2000, Kheifets et al, 2010) on previously published case-control studies, an increased relative risk at higher magnetic field strength was found. A biophysical mechanism that could support and verify this suggested association has not been found in ongoing scientific research, although several mechanisms have been hypothesised (see Gee, 2009). The lack of both experimental evidence and a plausible biophysical mechanism that could support the statistical association found in the pooled analyses hampered the policy formulation on electromagnetic fields considerably. In 1998, Guidelines for EMF between 1 Hz and 100 kHz were issued by the International Commission on non-Ionizing Radation Protection (INIRP). In 2002, the World Health Organization's International Agency for Research on Cancer (IARC) changed his official position and considered ELF-EMF to be possibly carcinogenic to humans.

In literature, different strategies were proposed to deal with the uncertain risks of EMF: 1) take no action unless the health effects data become more consistent; 2) allow individuals to make personal choices to limit exposure; or 3) regulate power lines and appliances (Jamieson and Wartenberg, 2001). In 1999, the Council of the European Union published a Recommendation on the limitation of exposure to EMF. Since the Recommendation is not legally binding, member states follow different approaches in succeeding this Recommendation, ranging from implementing no regulation at all to stricter basic restrictions and/or reference levels based on the precautionary principle (Stam, 2011). The same applies to countries outside Europe.

Rationale behind the use of the precautionary principle is that uncertain scientific evidence can not deter from taking anticipatory preventive action, when there is a threat of serious or irreversible damage (Weed, 2004). The precautionary principle is often linked with the prevention principle, but the latter is adopted in cases where sufficient knowledge is available of causes of adverse impacts, and associated risks easily can be quantified (UNESCO COMEST, 2005).

Based on among others the then available pooled analyses, the Health Council of The Netherlands -an advisory council to the Dutch government- concluded that "a reasonably consistent association, that is, a statistically significant relation, between residence in the vicinity of overhead power lines and an, otherwise slight, increase in the incidence of childhood leukaemia existed" (Health Council of the Netherlands, 2000). Using estimated numbers of dwellings in different (magnetic) zones close to overhead power lines, the National Institute for Public Health and the Environment (RIVM) translated the relative risks from the pooled analyses into an annual number of extra cases of childhood leukaemia for The Netherlands (Van der Plas *et al.*, 2001; Pruppers, 2003). Assuming a causal relationship between exposure to ELF EMF and childhood leukaemia, the study concluded that overhead power lines would add 0.4-0.5 extra cases leukaemia annually (to a total of then 110 cases – note that it is nowadays 135 cases per year (Smale and Van der Sluijs, 2010)). Comparable studies in other countries using a calculation chain with estimations for dwellings near overhead power lines are not known. Studies for the United Kingdom and Ireland for instance use the calculated increase of the absolute risk from the pooled analyses and compare this with the annual total of cases, to get an estimation of the additional childhood leukaemia caused by exposure to fields greater than 0.4 μT (NRPB, 2004).

Partly based on the results of RIVM, the Dutch government founds its policy concerning high voltage overhead power lines on the precautionary principle. The Ministry of Housing, Spatial Planning and the Environment (VROM) recommends municipalities to avoid that new situations occur in which children stay for extended periods of time in areas near overhead power lines with an annual average magnetic field over 0.4 μT (VROM, 2005). In

its advice, clarified by an addition in 2008 (VROM, 2008), VROM specifies the kind of new situations that should be avoided (e.g. nurseries and schools) as well as details on the maximum residence time. Legally, this advice is not binding, but municipalities only can deviate from it in exceptional cases. For existing situations, the ICNIRP 1998 guideline of 100 μT remains as reference value. To improve the knowledge base for policy making, in 2008, VROM established the Knowledge Platform Electromagnetic Fields and Health, in which both institutions with knowledge on electromagnetic fields and organisations that are dealing with health issues are represented. The Knowledge Platforms task is to assist citizens and professionals in understanding and valuing scientific research on electromagnetic fields and health.
Despite these efforts, the policy of the Dutch government has led to debate and social unrest in several municipalities recently. Electromagnetic fields, including those related to GSM and UMTS transmitters, account for a great deal of the complaints VROM obtains regarding the spatial environment. Citizens are not convinced that the government's policy will be effective in addressing the risk of electromagnetic fields. Among others, they tried to prevent the construction of a new overhead power line in a relatively densely populated area; in other cases they protested against the existence of overhead power lines in a new residential area.

Concerned citizens call upon the same scientific publications to underpin their complaints the Dutch government is using to base its policy. The scientific uncertainty on the explanation of the demonstrated statistical association motivated the Dutch government to apply the precautionairy principle for their policy on the electromagnetic fields of overhead power lines. Citizens focus on the statistical association itself to request much stricter guidelines then applied at this moment. This ambiguity of the available scientific knowledge give rise to a more thorough exploration of the evidence, by reviewing the most important assumptions that underpin the methodology and conclusions of the scientific publications that induced a value for the relative risk for children in the vicinity of overhead power lines, as well as the calculation chain developed by RIVM. The aim of this study is to prioritize the key assumptions in the existing risk studies, and to critically evaluate the ones which are most important regarding the final result (a quantified risk indicator) of the calculation chain.

2. Method

The RIVM studies used a calculation chain to assess the potential number of annual extra cases of childhood leukaemia due to overhead power lines. The distinct steps in this calculation chain are:

- Estimation magnetic field strength zones in the vicinity of overhead power lines
- Determining the number of dwellings in each zone
- Converting to the number of inhabitants in each zone
- Converting to the number of children in each zone
- Adapting 'Relative Risk' on calculated number exposed children for each distinct magnetic field strength zone

In the final step of the calculation chain, relative risks and three dose-response curves from Ahlbom *et al.* (2000) and Greenland *et al.* (2000) were used to calculate the potential number of additional cases of childhood leukaemia.

The assumptions both prior to and in each of the distinct steps of the calculation chain developed by RIVM were systematically inventoried by analyzing the relevant (risk) studies and by conducting interviews with 4 experts. One interviewee was a radiation expert of the RIVM who was involved in the above mentioned RIVM studies, two experts interviewed worked at KEMA (a major energy testing & certification institute) and were questioned on technical aspects of the national network of overhead power lines; the fourth interviewee was an epidemiologist. The calculation chain contains many assumptions prior to it, for instance (hidden) in the distinct studies that were used in the pooled analyses of Ahlbom *et al.* and Greenland *et al.* Those assumptions for instance concerned country specific parameters or were derived from cases with specific national circumstances that might not be the same for the Dutch situation. The RIVM calculation chain itself contained assumptions that are specific for the Dutch situation.

To create a prioritized list of assumptions, of which the most import ones could be characterized, an expert elicitation workshop was held. Expert elicitation is a structured approach to systematically consult experts on uncertain issues. Experts are consulted on a subject for which insufficient knowledge is available in scientific literature; both published and unpublished knowledge are intended to be made explicit, supplemented with the personal experience of the experts (Knol *et al*., 2010).
6 experts participated in the workshop, which is in line which the guidelines for expert elicitation research (Cooke and Probst, 2006, Knol *et al*., 2010). The expert community on electromagnetic fields in the Netherlands is rather small; names for workshop members were inventoried at the Knowledge Platform Electromagnetic Fields and Health; via snowball sampling, the persons named were asked to add further names to the list. Among the participants were two radiation experts (one with expertise on physical aspects of radiation, one radiobiologist), two experts on the technical aspects of the national network of overhead power lines, an engineer specialized in risk inventories of EMF, and an normative expert on uncertainty.

The aim of the expert workshop was three-fold:

- to discuss and validate the initial list of assumptions
- to prioritize the assumptions on their impact regarding the end result of the calculation chain
- to discuss and characterize the value-ladenness of the most important assumptions, and estimate their influence on the end result of the calculation chain

As input for the workshop, among others an initial list of assumptions was sent to the participants. This initial list is available in de Supplementary Material. Literature was available during the workshop, to provide participants the opportunity to find information they might need. Each of the participants individually selected and ranked nine assumptions from the initial list that they judged to be the most important towards the end result of the calculation chain. The individually ranked assumptions then were combined into a group ranking. The maximum score an assumption could obtain was 54 (when all six participants would have assigned it the highest rank). The top-ranked assumptions were subsequently discussed and critically appraised using a 'pedigree matrix' adapted from Craye *et al.* (2009) (see Supplementary Material) (see Van der Sluijs *et al.,* 2008 and Maxim and Van der Sluijs, 2010, 2011 for similar approaches to critical appraisal of scientific assessments). The pedigree matrix is based on the method of Kloprogge *et al.* (2005, 2011) for characterization of assumptions in assessments. In this method, a set of criteria is used to evaluate the potential value-ladenness of assumptions, and estimate their influence on the end result of the calculation chain. All criteria were scored on a level 0 – 4, where 0 means high value-ladenness/high influence on results and 4 means low value-ladenness/influence on results. The criteria used were:

- Influence of situational limitations: the degree to which the assumption made can be influenced by factors such as (lack of) data, money, human resources
- Plausibility: the degree of correspondence to 'reality' by the assumption
- Choice space: the degree to which tenable alternatives for the assumption are available
- Agreement among peers: the degree to which fellow experts would agree with the assumption made in the calculation chain
- Agreement among stakeholders: the degree to which stakeholders would agree with the assumption made in the calculation chain
- Sensitivity to views and interests of analyst: the degree to which de choice for the assumption by the analyst, could be influenced by his/her vision and interests (consciously or unconsciously)
- Influence on results: the influence of the assumption on the end result of the calculation chain

For each of the top-ranked assumptions, first the assumption was clarified among all participants (does everyone interpret the assumption in the same way) and strong and weak points of the assumptions were evaluated. After a plenary discussion on the criteria from the pedigree matrix, the participants scored the assumption individually. There was only time to do this plenary for the top 5 assumptions. Participants took the remaining 3 assumptions home, from which 4 participants returned their evaluation on the remaining assumptions.

3. Results

In this section, results from the group ranking are shown, as well as scores for characterization of the prioritized ranking during the workshop.

Table 1 shows the assumptions that participants considered most important in determining the end result of the calculation of health impacts of overhead power lines. The group ranking originally contained one more assumption (i.e.: The incidence of childhood leukaemia between countries where epidemiological studies have been done, is comparable). The workshop participants considered themselves to lack expertise to evaluate this assumption; in an interview with an epidemiologist after the workshop, it appeared that incidence itself is not important towards the end result of the calculation chain, due to the fact that the pooled analyses only use case-control studies. Where individual studies yield a risk of the case relative to its control, the pooled analysis yields the incidence in the pooled cases relative to the incidence in the pooled controls. Therefore, this assumption was removed from the final list.

Rank	**Assumption**
1	A causal relationship exists between exposure to electromagnetic fields of overhead power lines and the occurrence of childhood leukaemia
2	Overhead power lines are the main differentiating source of exposure to electromagnetic fields for children
3	The height of the (prolonged) average of exposure causes the effect
4	A threshold value exists
5	The current in the year prior to determining the incidence of childhood leukaemia is representative for the average current during the development of childhood leukaemia
6a	The combination of the magnetic field strength and the residence time of the child determine the biological relevant dose
6b	The zone width of the individual lines has been estimated correctly
7	No confounding variables for the observed association exist, or their effect is very limited

Table 1: top 7 list of assumptions, ranked by workshop participants

The pedigree scores for the pedigree criteria for the 8 assumptions from the prioritized list are shown in Table 2. Likewise, total median pedigree scores, and median scores for Influence on Results are shown. The number of votes for each of the assumptions can be found in the Supplementary Material.

Assumption	**1**	**2**	**3**	**4**	**5**	**6a**	**6b**	**7**
Situational limitation	1	4	0	0	3	0	1	1.5
Plausibility	2	0.5	0	0	3	0.5	2	1.5
Choice space	2	3	0	3	3	1	1	1
Agreement peers	0	3	1	1	3	1	3	3
Agreement stakeholders	2	2	2	2	3	2.5	3	3
Sensitivity views analyst	0	3	3	0	3.5	2	0	1
Total pedigree score	*1.5*	*3*	*0.5*	*0.5*	*3*	*1*	*1.5*	*1.5*
Influence on results	*0*	*0.5*	*0*	*0*	*3.5*	*0*	*0*	*1*

Table 2: Median pedigree scores

Scale 0 – 4 → 0 = high value-ladenness/high influence on results; 4 = low value-ladenness/influence on results.

Combining the total median pedigree scores with the median scores for Influence on results can be presented in a diagram showing 4 quadrants. This diagram is presented in Figure 1.

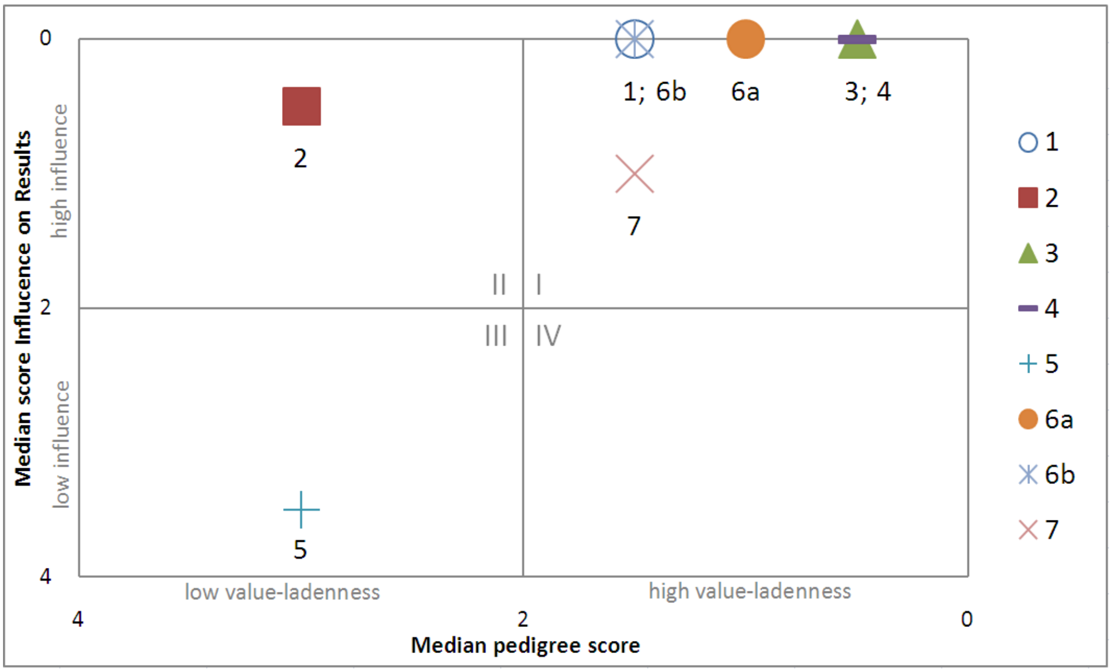

Figure 1: Scores for characterization of the prioritized ranking.
Numbers of the assumptions refer to the numbers in *Table 1.*

The four quadrants in which this figure can be divided are *high influence | high value-ladenness, high influence | low value-ladenness, low influence | low value-ladenness* and *low influence | high value-ladenness.* Given both their influence on the end result of the calculation chain as well as their value-ladenness, the assumptions in the *high influence | high value-ladenness*-quadrant are most problematic.
There are no results for the fourth quadrant, the other quadrants will be discussed; hereby, the most striking results from the workshop for each of the assumptions will be presented.

Quadrant I: High influence | High value-ladenness
Assumptions 1, 3, 4, 6a, 6b and 7 share a high value-ladenness, and a high influence on the end result of the calculation chain.
The high final score for the 1st assumption depends mainly on the influence of situational limitations (there is a need for more clear epidemiological data about the different countries from the pooled analyses of Ahlbom *et al.* (2000) and Greenland *et al.* (2000), and more toxicological data on biophysical mechanisms), limited agreement among peers and the sensitivity of views and interests of the analyst, combined with a high score concerning the influence of this assumption on the end result of the calculation chain.
The final score of the 3rd assumption is mainly determined by the lack of differentiated data on the strength of the magnetic field (for the first criterion), the lack of confidence in the plausibility of this assumption due to the absence of a proofing biophysical mechanism, and the fact that in practice it is difficult, if not impossible, to test alternatives for the assumption. Calculated risk zones could change drastically, if it would be feasible to use such alternatives in the calculation chain. Measurements of these alternatives are not available however.
The criteria with the highest scores for the 4th assumption, concerned the influence of situational limitations, due to a lack of cases in the groups with higher exposure; furthermore, participants considered the agreement among experts as low, due to the lack of data that support the presence of a threshold. Participants consider the assumption as (very) highly sensitive tot the views and interest of the analyst; it was stated that for instance assuming a continuous exposure-response relationship would have considerable consequences for policy. Overall, the assumption is deemed fictive/speculative; it is considered to be made for practical reasons.

The high score for the value-ladenness of assumption 6a mainly is due to a high score on three criteria; workshop participants deem the assumption completely influenced by situational limitations, because no detailed data exist on different parameters other than this one. Again, this assumption was considered not to be plausible, because no biophysical mechanism that could indicate this assumption to be correct is known. Excluding any influences from peak values for instance is considered to be speculative. Therefore, among experts there is a low degree of agreement on this assumption. Agreement among stakeholders is considered to be higher, but it was noted that they generally paid little attention to this assumption. Its influence on the end result of the calculation chain is high: an alternative assumption will change the calculation chain itself, and other sources of magnetic field strength will become relevant.
Assumption 7 scores high on value-ladenness, mainly due to a high score on three criteria. Workshop participants consider the assumption influenced by situational limitations, because in the calculation of the zone widths for the Dutch situation, a worst-case scenario for the current load has been used. Furthermore, it was mentioned that the performed sensitivity analysis could be extended to investigate more parameter alternatives in order to create zones that are more precise than the standard zone widths. Workshop participants deemed that some alternatives remain to be investigated. Lastly, it was commented that the assumption is (very) highly sensitive to the views and interests of the analyst, because analysts don't agree on the magnetic field strength as cause of childhood leukaemia. However, it was admitted that, if 'magnetic field strength' was chosen as cause of childhood leukaemia, different analysts will get the same results for zone widths.

Quadrant II: High influence | Low value-ladenness
Although assumption 2 is judged as hardly plausible by workshop participants, its total median score is relatively high. Its impact on the end result is estimated to be high, probably due to the fact that high voltage cables are an important part of the available research and the calculation chain. Studies that would investigate the share of home installations to the total magnetic field strength in dwellings, could confirm or reject this assumption. Also, scenario studies might be used to explore the consequences of the uncertainty regarding the share of high voltage cables within the total of sources. This however is not of first priority, since the value-ladenness is low.

Quadrant III: Low influence | Low value-ladenness
This quadrant contains assumption 5. The assumption is judged as plausible, due to the fact that most cases of childhood leukaemia concern Acute Lymphatic Leukaemia, which would correspond with a short exposure time. The total median pedigree score is 3, the median for Influence on results is 3.5. Both the score for influence on the end result of the calculation chain, as well as the value-ladenness indicate that there is no need to investigate alternatives for this assumption.

4. Discussion
We will reflect upon method and results from this study. In section 4.1 strengths and weaknesses of the used method are elaborated. Striking points from the results are reflected upon in section 4.2. More general remarks are made in section 4.3.

4.1 Method
The pedigree matrix for assumption-analysis used appeared to be a useful tool to thoroughly discuss and evaluate the assumptions. It regularly evoked discussions between experts from different disciplines, allowing them to learn from each others' expertise. The matrix allows for a structured and in-depth discussion of the assumptions, including on issues which the participants indicated not to have considered explicitly before. As such, it provides value-added to generic, non-structured discussion. The criteria in the matrix are however for some experts difficult to interpret. Unfamiliarity with the concepts led to initial difficulties in the scoring and discussion, but this was remediated by a limited amount of further clarification. This problem has also been reported by Krayer von Krauss *et al.* (2005) in the application of a similar method. They found that experience with the many of the concepts put forward are relatively unfamiliar - and perhaps somewhat controversial - to experts practising decision support. Thus, efforts are required to communicate such concepts to experts in such a way that their knowledge of uncertainty is elicited adequately, without them being overly intimidated or confused by the novelty of the concepts presented to them. In our workshop participants suggested to start future

workshops with a short example and exercise preceding scoring the assumptions of interest.

Like any form of expert elicitation, some care should be taken in the interpretation and use of the results. Panels are always of limited size and another group of experts, in another context, will not necessarily give the same scores. Nonetheless, such elicitations yield useful insights into the topic studied; in the case of this study into the background and relative value-ladenness of the various assumptions, which would otherwise have remained opaque. It is essential that participants are selected such that they well represent both the relevant fields/disciplines and the various opinions that are present among those involved in the subject.

Expert elicitations can be performed through a workshop, questionnaire, and/or interviews. Each method has its advantages and drawbacks (see Knol et al. 2010 for discussion). This study relied mostly on a workshop, supplemented with interviews. An important advantage of a workshop is that it allows for interaction and thorough discussion among participating experts. On a complex issue in a multidisciplinary field such as EMF and health, this has considerable value-added for the quality and robustness of the analysis. A disadvantage is that the number of assumptions analysed is limited (compared with e.g. a questionnaire). To prevent from missing any key assumptions, the workshop started with making a prioritisation. Our aim was to assess the seven most important assumptions with regard to influence on the outcome of the calculation. Respondents were asked to select and rank the top-9 (see section 2. Methods). In the group ranking, the four most important assumptions received a score of over 20 points each (of max. 54); the fifth most important received 12 points. All other assumptions received less than 10 points. Sixteen assumptions (of 35 in total) received no points at all, indicating that these were seen as of minor importance. The available time during the workshop allowed for assessment of only five assumptions. Assumptions 6a, 6b and 7 were taken home by the workshop participants; four participants returned their characterization. As these were not discussed extensively within the group, their scores should be considered less robust than those of assumptions 1-5 (see section 4.2).

4.2 Results

Five assumptions from the group ranking received the highest-possible score for Influence on results. The median score for assumption 2, concerning overhead power lines as main differentiating source of exposure to electromagnetic fields for children, was 0.5, mainly due to one participant who considered it less influential. It is surprising that the assumptions 6a and 6b received such a high result on Influence on results, because during the group ranking, their relative influence compared to assumption 2 and 5 was lower. This might be due to the fact that those assumptions were not discussed within the group, but sent in after the workshop. This could have impeded a nuanced comparison with the individual group members' characterization of previous assumptions.

Assumptions 3, 4 and 6a received a (very) low score on both Plausibility and Agreement among experts. These assumptions are in the upper right corner of the Pedigree figure as well. This indicates that alternatives for these assumptions might be worth considering. Participants indicated that for assumptions 6a and 3 respectively, an average or even very ample choice of alternatives is available. For assumption 4, the number of alternatives is very limited however.

The scores for the assumptions that were discussed during the workshop only show limited spread between different participants. The only exception is the characterization of the Influence on Results for the 2nd assumption. For the assumptions that were taken home and sent in later, characterization is more often further apart (see Supplementary Material). Participants for instance did not agree on the choice space for the assumption concerning the zone width of individual lines (6b). A participant who scored high (very limited number of alternatives available) mentioned that a sensitivity analysis was carried out during the development of the calculation chain; a participant who scored low (very ample choice of alternatives available) mentioned that many more parameters could be investigated by performing more sensitivity analyses, although it might be not feasible to do this countrywide. Another example on which the characterization differs, is the Influence on Results for Confounding Variables (assumption 7). Overall, this might be due to the fact that no group discussion was held on those assumptions, which could have made the opinions of individual group members better informed.

4.3 Concluding remarks

As in other risk assessments, the use of assumptions cannot be avoided when quantifying the risk of childhood leukaemia due to living in the vicinity of overhead power lines. Specific assumptions distinguish themselves however by their value-ladenness. Our study shows that many of these assumptions are difficult to underpin and highly value-laden with the state of current knowledge: assumptions that were regarded to be important in quantifying the risk appeared to show a high value-ladenness. Moreover, it is shown that the assumptions which are regarded to be most problematic are prior to calculation chain used by the RIVM.

It is unlikely however that for many of these assumptions less value-laden assumptions can be adopted in future studies. Except for assumptions 2 and 5, situational limitations are considered to be an important factor for selecting the chosen assumptions; in many cases (assumptions 3, 6a, 6b and 7) a lack of alternatives in measurements, or a lack of cases in higher exposure groups (assumption 4) force researchers to take an assumption. The value-ladenness of most of the assumptions will decrease when a biophysical mechanism would be found that confirms the statistical association to be causal. Much research on this is already done however, without significant results.

National policies range from having no regulation at all to the implementation of the precautionary principle with reference values even below those advised by ICNIRP. This study shows that quantification of the risk of electromagnetic fields of overhead power lines is premature. The outcome of the RIVM's quantitative analysis was meant to obtain an indication of the magnitude of this risk for the Netherlands. It rather has to be considered as a very preliminary indication of the magnitude of the risk, with a low reliability, due to the high value-ladenness of important assumptions that are used. The outcome has to be interpreted as an indicative result for a scenario in which the preliminary assumptions appear to be valid, rather than a factual representation of the magnitude of the risk. Applying the prevention principle, which in the past has been suggested by concerned citizens and might have been triggered by the possibility of quantification the risk of overhead power lines, is not recommended.

A reasonably consistent association between the occurrence of leukaemia in children and residence near overhead power lines has been found in several previous studies however. The fact that this association has been confirmed repeatedly requires a policy based on the precautionary principle. Adopting this principle requires to take action proportionally to the seriousness of the potential harm (UNESCO COMEST, 2005). The Recommendation of the Council of the European Union has, as in many other European countries, not been implemented in the national legislation of the Netherlands, but only has been advised. We recommend to transpose the limitations on exposure from the Recommendation into national binding legislation, as consequence of adopting the precautionary principle. We consider the implementation of the precautionary principle by the Dutch government (i.e. avoiding new situations in which children stay for extended periods of time in areas near overhead power lines with an annual average magnetic field over 0.4 μT) as adequate. It can be debated however whether new developments in the Dutch policy, such as buying out residents that live under or in the close vicinity of overhead power lines to prevent from social unrest, are proportional to the potential harm, as enormous costs are involved.

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