COSTS AND BENEFITS OF THE REDUCTION OF MAGNETIC FIELDS DUE TO OVERHEAD POWER LINES

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Abstract

The possibility of adverse health effects caused by electromagnetic fields around overhead power lines has been a topic of investigation, scientific and public debate over the past decades. Several surveys, including one by the Health Council of the Netherlands in 2000, have discussed the association between childhood leukaemia and living nearby overhead power lines found in epidemiological studies, although no plausible biological mechanism has been found. On the basis of the precautionary principle, the Dutch government has commissioned research into costs and benefits of measures to reduce the population's exposure to magnetic fields encircling power lines.

This research was carried out by KEMA (a technical consultancy specialising in the energy sector) in co-operation with RIVM (the National Institute for Public Health and the Environment in the Netherlands). KEMA digitised the overhead power lines and calculated the representative magnetic fields, while RIVM counted the number of dwellings in zones from 10 to 200 m (bilaterally). KEMA assessed the reduction of the magnetic field, applying technical measures such as changes in electrical characteristics, relocation of the line and undergounding.

Results indicate that approximately 45,000 of the 7 million dwellings in the Netherlands are situated within 100 m of a power line and 23,000 within the 0.4 µT magnetic field zone. The technical measures investigated can considerably reduce the number of dwellings exposed to magnetic fields above certain reference values, but reduction costs will rise sharply if large reductions are to be achieved.

Introduction

Generation, transport and use of electricity induce electric and magnetic fields with extreme low frequencies (ELF fields). Since the publication by Wertheimer and Leeper [i] in 1979 that showed an increased cancer risk for children living near electric wiring configurations, the possibility of adverse health effects induced by ELF fields has been a matter of scientific debate. In particular the relationship between the fields associated with electricity transport and distribution and childhood leukaemia has been a topic of investigation [ii, iii].

In 2000 a committee of the Health Council of the Netherlands – an advisory council to the Dutch government - evaluated the most recent scientific literature [iv]. The committee concluded that no clear-cut relationship could be established between the exposure to ELF fields and cancer, but that the aggregate of the epidemiological studies suggests a consistent association between the occurrence of childhood leukaemia and living nearby overhead power lines. However, the committee noted that no plausible mechanism for the induction of cancer by these fields has been reported, and that a causal connection between ELF and childhood leukaemia could therefore not be proven. In other words, the observed association between childhood leukaemia and ELF fields could not be explained and may still be attributable to other factors.

Two studies published after the Health Council's report (the pooled analyses by Ahlbom *et al.* [v] and by Greenland *et al.* [vi]) suggest an elevated leukaemia risk for children living close to overhead power lines. Based on these two studies – on the assumption that there is a causal connection between the magnetic field in the vicinity of power lines and childhood leukaemia – RIVM calculated the excess risks [vii]. There are approximately 3 million children aged between 0 and 15 years in the total Dutch population of 16 million. According to the RIVM study about 25,000 children in this group were exposed to magnetic field strengths above 0.2 μT originating from nearby power lines. In this 'exposed' group the number of extra cases of childhood leukaemia was estimated to be 0.2 to 1 per year. The background incidence of childhood leukaemia in the Dutch population is 110 new cases per year.

The inconclusive scientific evidence and the public concern on potential health effects of power lines pose a problem for policy makers. In the early 1990-s scientists in the United States advocated 'prudent avoidance' i.e. preventing exposure to magnetic fields as long as insight into health hazards is incomplete [viii, ix, x, xi]. In 1996 the Swedish authorities formulated a policy based on the precautionary principle [xii]. This principle implies that if a certain source may have as yet unproven adverse environmental or health effects, and that if measures to reduce the exposure can be implemented at reasonable costs and with acceptable consequences, these measures should indeed be effected.

In the Netherlands there is no compulsory policy with respect to possible health effects of power lines. From the maintenance and general safety perspective, the advice is not to build dwellings in a zone of approximately 35 metres on each side of the line [xiii]. In 2001, in the framework of the Fourth National Environmental Policy Plan (NMP4) the Dutch government commissioned further research into measures to reduce possible health effects of power lines. The government states that: 'On the basis of the precautionary principle the present evidence forms sufficient reason for further research and for taking appropriate measures in relation to the social costs and benefits' [xiv]. From this starting point, VROM (the Dutch Ministry of Housing, Spatial Planning and the Environment) commissioned research into the costs and benefits of a further policy on overhead power lines. Part of this research is presented in this paper.

Aim

The present investigation focuses on the costs and the effects of technical measures to reduce the exposure of the Dutch population to magnetic fields in the vicinity of overhead power lines. It takes five reference values for this magnetic field: 0.2, 0.3, 0.4, 0.5 and 100 μT. The values of 0.2, 0.3, 0.4 and 0.5 μT were based upon the epidemiological studies [v, vi]. The 100 μT value is the ICNIRP reference level [xv] and the reference level advised by the European Union [xvi] for exposure of the general public to magnetic fields.

The principal goal of this investigation is to examine on the national level how to reduce the number of dwellings located in zones where these magnetic field reference values are exceeded. The following four measures to achieve a possible reduction have been evaluated: vector-sequence rearrangement, phase conductor splitting, relocation of the power line, and undergrounding of the line. Relocation of dwellings has not been evaluated in this study.

Overhead power lines

In the framework of this investigation KEMA digitised the Dutch network of overhead power lines. There are five voltage levels: 50, 110, 150, 220 and 380 kilovolts. The combination lines are treated separately. For these combi-lines circuits of different voltages (380 and 220 kV circuits, 380 and 110 kV circuits, 220 and 110 kV circuits) are attached to the same towers. For every voltage level the network consists of lines that start and end at a substation. Each line was subdivided into straight sections, going from one angle tower to another. Lines and sections were scanned from topographic maps (scale 1:25,000). Each line was characterised by the voltage level and a unique geographic designation for start and endpoint. Visual checks were performed to identify the most common tower type for each power line. Table 1 summarises the quantitative data for the overhead power lines. Figure 1 maps the lines.

Table 1 Summary of the overhead power lines in the Netherlands

voltage level (kV)	number of lines	total line length (km)
50	15	164
110	76	778
150	165	1781
220	9	249
380	23	840
combi	15	159
total	303	3971

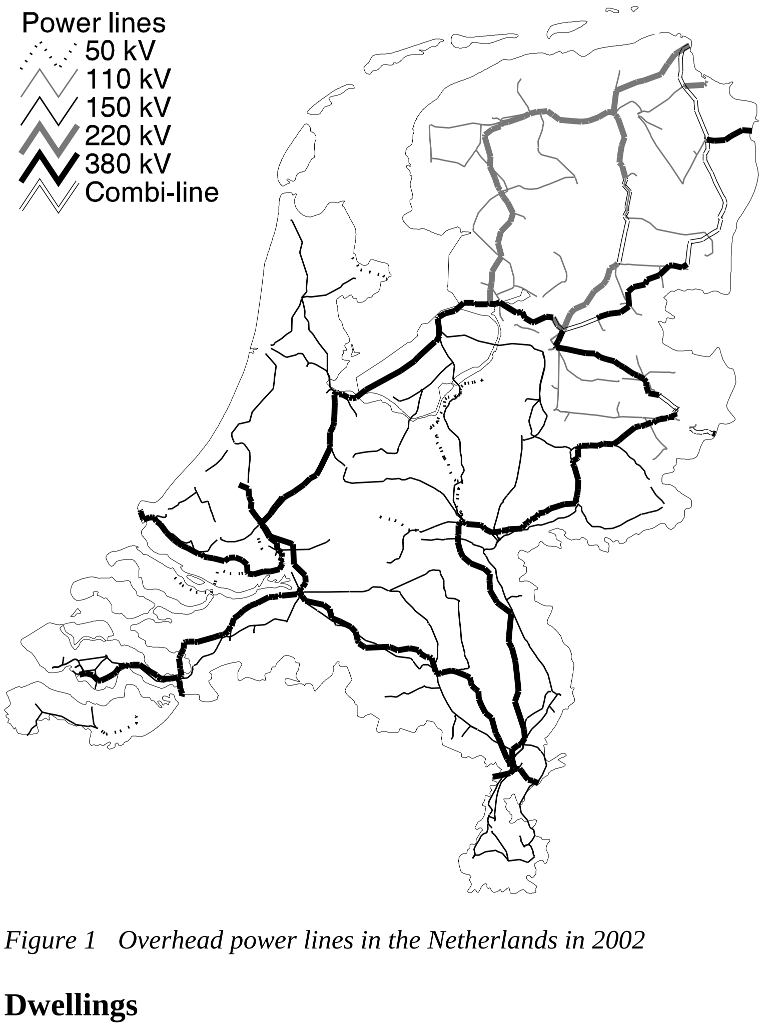

Figure 1 Overhead power lines in the Netherlands in 2002

Dwellings

Calculations are based on the Address Coordinate File Netherlands (ACN) of the Dutch Land Registry, reference date November 1, 2000. For each address the ACN-file contains: the Dutch standard co-ordinates, name of the municipality, house number and area code. The database contains a total of 6.85 million addresses registered for housing purposes.

The dwellings were counted in a Geographical Information System (GIS), combining the ACN file for dwelling locations with the digitised power lines at the level of the straight sections. Around each section 20 zones were constructed with borders at 10 m, 20 m, 30 m, … , 200 m from the centre line of the power line. In this way the number of dwellings as a function of the distance to the centre line was calculated.

Figure 2 shows an example for the dwellings within the 100 m zone (bilaterally) around a 150 kV power line in an urban area. The number of dwellings along a straight section strongly depends on the length of the section. We therefore calculated also the dwelling density defined as the number of dwellings in the zone divided by the surface area of the zone. In rural areas the dwelling density in the 200 m zone varies between 0 and 2 dwellings per hectare; in urban areas densities as high as 100 dwellings per hectare can occur.

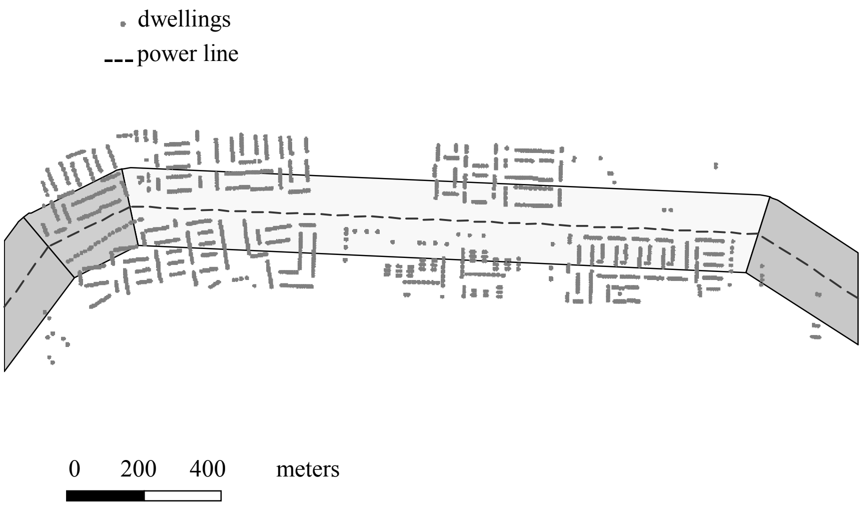

Figure 2 Straight section of a 150 kV power line in an urban area. The 100 m zone is marked. Dwellings are depicted up to 200 m on each side of the power line.

Magnetic field

KEMA calculated the magnetic field strengths around the power lines with an arithmetic model that was developed and validated in-house. Ideally all individual power lines should be dealt with on their specific individual properties. However, this information is not available. Therefore, a few crucial parameters for the magnetic field were used at the level of the individual lines. These parameters are: representative current, dominant tower type, number of circuits, phase conductor geometry and the earthing method.

For the representative continuous current the (n-1) criterion is used: for a two-circuit line this current amounts to half of the technical maximum in each circuit. For a three-circuit line the representative current is two-third of the technical maximum and so on. The actual current at a given moment will usually be substantially lower. In the Netherlands three types of phase conductor geometries are used: triangular, horizontal and vertical. For other parameters like vector-sequence arrangement, tower resistance, number and location of lightning wires, soil resistance, distance between the phase wires and tower height, KEMA used the most common, typical values in the calculations. These typical values depend on the voltage level, the geographical location of the line and the phase conductor geometry.

Typical values are adequate for the calculations at the national scale. For an individual power line, however, the specific values for that line may differ from the typical values, and substantial additional effort would be needed to obtain reliable line-specific results.

For each magnetic field reference value the distance on either side of the power line where the magnetic field equals the reference value was calculated. These reference zones form the basis for the evaluation of the actual situation and for analysing the effect of measures to reduce the magnetic field. The 100 µT reference value is not exceeded anywhere in the vicinity of the Dutch overhead power lines.

Four measures for the reducing magnetic fields were evaluated in detail:

1. vector-sequence rearrangement;
2. phase conductor splitting which is only possible in towers with triangular phase conductor geometry (50-60% of the power lines);
3. relocation of the power line;
4. undergrounding of the power line.

The remaining numbers of dwellings for the reduced width of the reference zones were calculated for these measures.

Costs

For a number of lines there are no dwellings in the vicinity of the overhead power line. Since measures to reduce magnetic fields are not necessary here, these lines were excluded from the cost analysis. Optimising vector-sequence arrangement requires phase-change towers at the beginning and the end of the line and related supplies. For this reduction costs do not depend on the line length. For the other three measures costs do depend on the length of the section of the power line. Further costs for relocation of the power line and undergrounding depend on the degree of urbanisation in the vicinity of the power line. Costs data have been corrected for these regional differences. Finally, costs do strongly depend on the voltage level of the power line. Specific costs for the combi-lines are four to seven times higher than for a 50 kV line. Table 2 summarises the specific cost data used in this study.

Table 2 Specific costs for magnetic field reduction

measure		costs (x 1,000 €)
vector-sequence rearrangement	per power line	350-1,300
phase conductor splitting (triangle geometry)	per km section	70-300
line relocation	per km section	320-1,200
undergrounding	per km section	1,100-8,000

Please note that costs were computed for typical power lines at the national scale, irrespective of the local circumstances. For an individual line, the real costs may fall outside the ranges presented.

Results

Figure 3 shows the relationship between the magnetic field and the corresponding distance to the centre of the power line for the six different voltage levels. The plotted lines represent the 90 percentile for all lines with the same voltage, meaning that at a given reference value for 90% of the lines this reference value is reached at a shorter distance and for 10% of the lines at a longer distance.

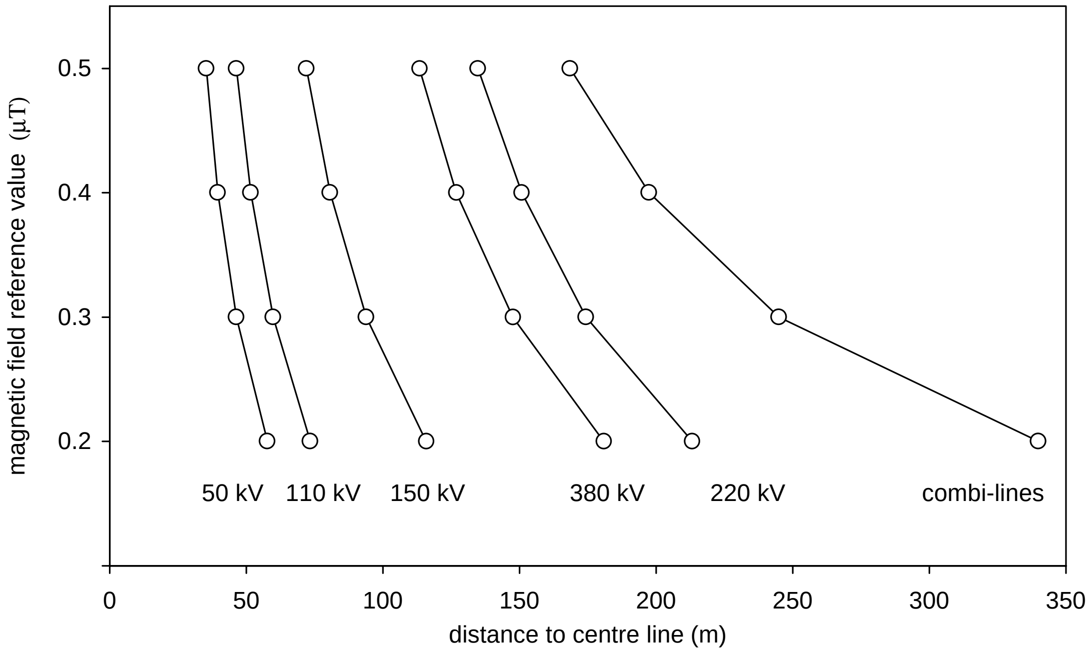

Figure 3 The decrease of the magnetic field with increasing distance to the centre of the power line

Magnetic field reducing measures are only taken along straight sections where dwellings are present. Therefore, the reduction of the number of dwellings is supposed to be a good indicator of the reduction of the width of the zone where magnetic field reference values are exceeded.

Figure 4 depicts the number of dwellings – for all voltage levels together and for the 150 kV level separately – as a function of distance to the centre of the power line, and the number of dwellings within the magnetic field reference zones.

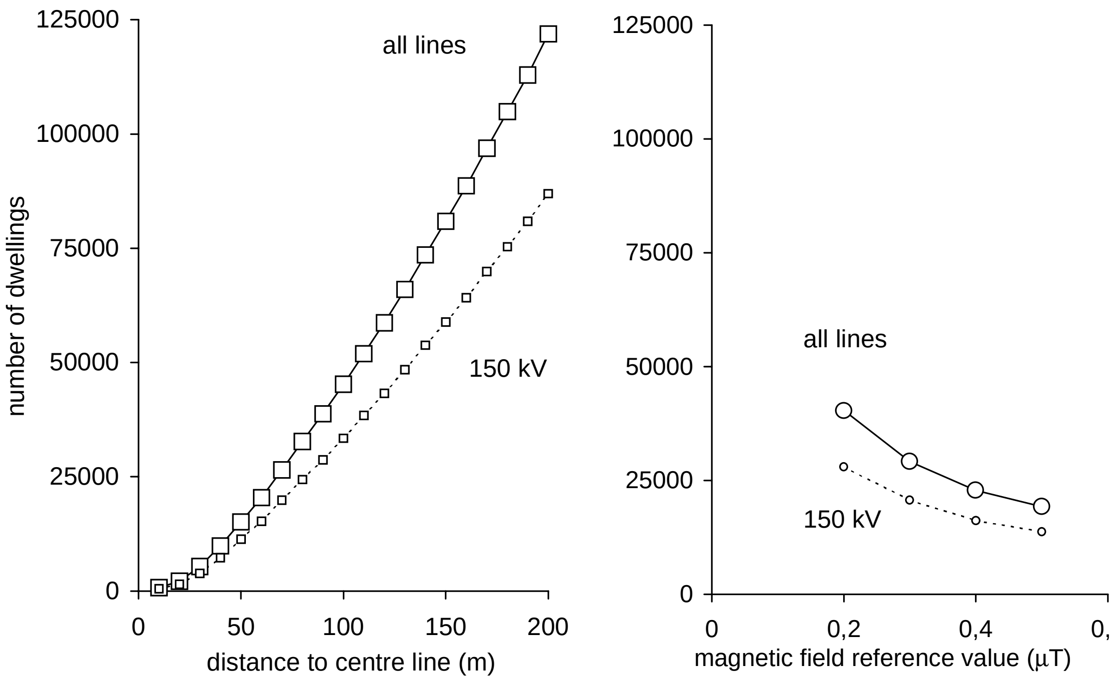

Figure 4 Increase of the number of dwellings within the zone with increasing distance to the centreline (left) and decrease with increasing strength of the magnetic field (right).

Approximately 122,000 dwellings are found within 200 m from the centre line, and 45,000 within 100 m. The 35 m zone - where building is discouraged – contains about 6,000 dwellings. Approximately 19,000 dwellings are situated within the 0.5 µT reference zone, 23,000 within the 0.4 µT zone and 40,000 within the 0.2 µT reference zone.

From Figure 4, for every reference zone we calculated an equivalent distance that contains the same number of dwellings as the magnetic field reference zone. Table 3 shows these equivalent distances for each magnetic field reference value. For instance, the 23,000 dwellings exposed to magnetic field strengths above 0.4 µT are on the average situated within 65 m on both sides of the power lines.

Table 3 Equivalent distance to the centre of the power line, calculated on the condition that the number of dwellings within this distance equals the number of dwellings within the magnetic field reference zone (situation without measures)

magnetic field zone (µT)	number of dwellings	equivalent distance to centre of the line (m)
0.2	40,000	90
0.3	29,000	75
0.4	23,000	65
0.5	19,000	60

The effects of the measures to reduce the magnetic field are shown in Figure 5. The four measures evaluated in detail in this study can substantially reduce the number of dwellings where reference values are exceeded. In the 0.4 µT reference zone the actual number of 23,000 dwellings is reduced to about 15,000 for vector-sequence rearrangement, 15,000 for phase conductor splitting, 2,500 for line relocation and 1,000 for undergrounding. The costs to achieve these reductions are approximately € 140 million for vector-sequence rearrangement, € 450 million for phase conductor splitting, € 2.5 billion for line relocation and € 15 billion for undergrounding. However, total undergrounding on a national scale will even lead to higher costs, because the network structure will change substantially. Comparison of Figure 5 and Figure 6 demonstrates a clear correlation between the effectiveness and costs of a measure.

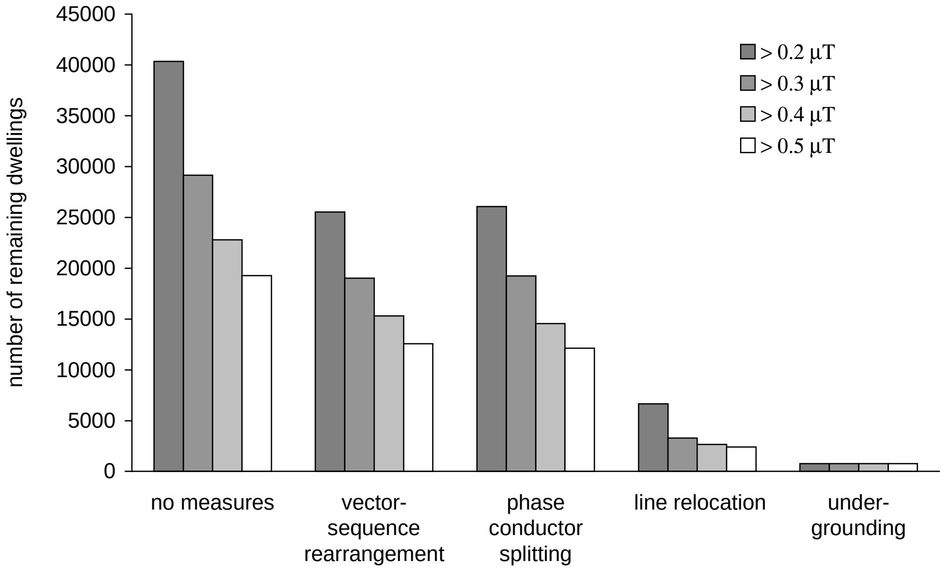

Figure 5 Number of dwellings remaining in the reference zones after taking measures to reduce the magnetic field

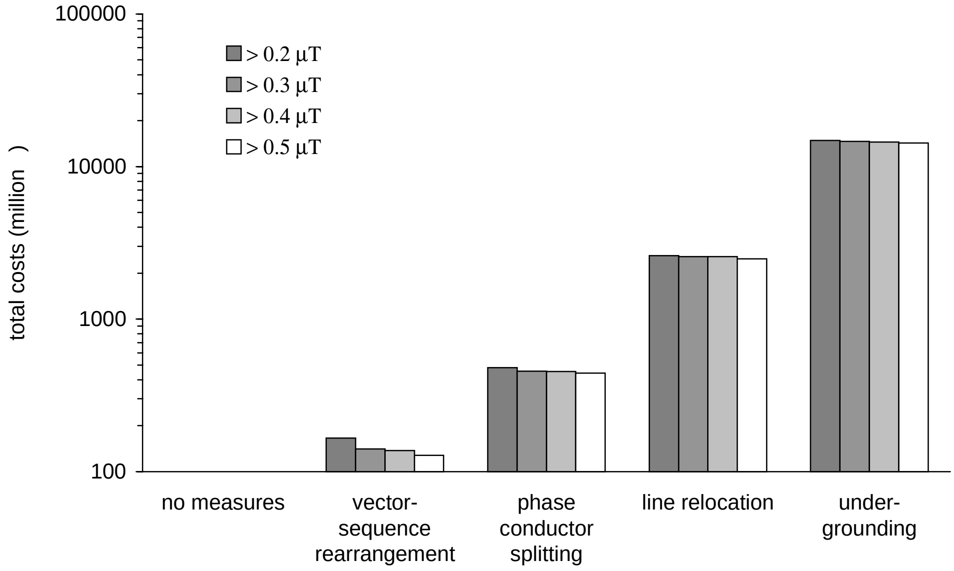

Figure 6 Total costs of measures taken to reduce the number of dwellings in the reference zones

Discussion

The aim of this investigation was to underpin a future policy with respect to potential health effects of power lines. In designing such a policy it is essential to be able to compare technical measures with other options, for instance relocation of a dwelling. A quantitative indicator to establish the cost-effectiveness of a technical measure is the ‘average cost per dwelling gained’. For a given reference zone this indicator is defined as the total costs divided by the reduction in the number of dwellings. For the 0.4 µT reference zone the costs per dwelling for vector-sequence rearrangement, phase conductor splitting, line relocation and undergrounding are respectively € 18,000, € 55,000, € 128,000 and € 655,000.

A future policy may consist of a mix of technical measures on the lines and spatial measures with respect to the dwellings. If the dwelling density around the power line is high, action on the line will be cost-effective. For sections with only a few dwellings in the vicinity, relocation of these dwellings will be more cost-effective. For example, when considering the measure ‘relocation of the power line’ to reduce the number of dwellings within the 100 m zone around the 150 kV lines, the costs per dwelling gained range from € 50 per dwelling for the section with the highest dwelling density to € 3 million per dwelling for the section with the lowest density.

Summary

The extremely low frequency fields surrounding power lines may have adverse health effects. Consequently, as a precaution, the Dutch government investigates how the population’s exposure to these ELF fields could be reduced. This study evaluates technical measures to the power lines, the associated costs and the benefits in terms of a reduction in the number of dwellings where people are exposed above certain magnetic field reference values.

Initially information on location and characteristics of the power lines was updated. For every power line, the number of dwellings within a variable distance and within five magnetic field reference zones was then calculated. Of the approximately 7 million dwellings, 45,000 are situated within a distance of 100 m from a power line. A total of 23,000 dwellings are situated within a zone where the magnetic field exceeds 0.4 µT.

The ‘average cost per dwelling gained’ was calculated from the reduction in the number of dwellings and the associated costs. For the 0.4 µT reference zone these costs for vector-sequence rearrangement, phase conductor

splitting, line relocation and undergrounding amount to respectively € 18,000, € 55,000, € 128,000 and € 655,000 per dwelling.

This study focussed on existing dwellings. In an additional investigation RIVM is currently surveying new development plans and the number of dwellings projected near power lines. Adjustment of the plans may reduce the future number of dwellings near the lines.

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