GSJ: Volume 11, Issue 10, October 2023, Online: ISSN 2320-9186
www.globalscientificjournal.com

CRITICAL EVALUATION OF EXPOSURE ASSESSMENT METHODS FOR STUDYING HEALTH EFFECTS OF EXTREMELY LOW-FREQUENCY ELECTRIC AND MAGNETIC FIELDS

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ABSTRACT

Exposure assessment is crucial in studies evaluating potential health effects of extremely low-frequency electric and magnetic fields (ELF-EMF). However, assessing long-term ELF-EMF exposure remains challenging. This paper provides a critical overview of common ELF-EMF exposure assessment approaches, including methods relying on sources (e.g., wire codes, distance), personal measurements, job-exposure matrices, and modeling. The strengths, limitations, and examples of each method are discussed. Key challenges include lack of historical exposure data, difficulties measuring all relevant exposure sources, and uncertainties regarding influential exposure metrics. While no approach is ideal, combinations of questionnaire data, spot measurements, job-specific data, and predictive models can improve exposure estimates. Further work is needed to develop models for reconstructing past exposures from limited data and determine the most health-relevant exposure metrics and sampling strategies. Improved exposure assessment is needed to strengthen future epidemiological studies.

Keywords*: electromagnetic field, epidemiology, exposure assessment, extremely low frequency, magnetic field, job-exposure, occupational,*

1. Introduction

Extremely low frequency (ELF) electric and magnetic fields (EMF) have been hypothesized to impact health outcomes like childhood leukemia and neurodegenerative disease [1], [2], [3]. Most evidence comes from epidemiological studies examining associations between ELF-EMF exposure and health effects [4]. However, assessing long-term ELF-EMF exposure remains a key challenge due to the complex, unpredictable nature of ELF fields and lack of historical measurements [5], [6]. Moreover, accurate exposure assessment is crucial for detecting underlying health effects [7].

This paper first provides an overview of common ELF-EMF exposure assessment approaches used in epidemiological research. The strengths, limitations, and examples of methods relying on sources, personal measurements, job-exposure matrices, and modeling are discussed. Key challenges and recommendations for improving exposure assessment are then presented. Finally, the tradeoffs between different methods and strategies for combining approaches to optimize exposure assessment are summarized.

2. Exposure Assessment Methods

2.1. Sources

2.1.1. Wire Codes

Wire codes classify power lines near homes into categories such as high, medium, and low current configuration based on thickness of wires and distance between residences and power lines [8]. Wire codes act as surrogates for historical magnetic field levels by predicting average residential magnetic field exposures [9]. More recent examples of the use of wire codes come from Crespi et al. (2016), who derived historical wire code exposures for California residences in a childhood leukemia case-control study [10]. They utilized public records on historical power line locations and voltages going back to the 1970s to assign wire codes like very high current configuration (VHCC) and ordinary low current configuration (OLCC) to past residences [10].

While wire codes provide inexpensive proxies for past magnetic field exposures, they have important limitations. Perhaps the biggest drawback is that wire codes are not direct measurements of magnetic fields [11]. They rely on numerous assumptions about historical wiring and power line configurations that may not hold true over long periods of time [12]. Changes such as burial of older high-current power lines, installation of new lower-current lines, and wiring errors can all affect the accuracy of wire code exposure predictions [13].

Wire codes also do not account for magnetic fields from appliances and other non-utility sources inside homes, which studies suggest can contribute significantly to overall residential exposures [14], [15]. Appliance use patterns may also change over time and impact exposure trends within wire code groups [16]. These factors can lead to exposure misclassification when relying solely on wire codes.

To improve wire code exposure estimates, some recent studies have incorporated historical data on appliance ownership and use collected through questionnaires [15], [16]. However, appliance fields are still not measured directly. Overall, while wire codes can provide useful initial stratification of exposure levels, supplementing them with more detailed source information and measurements is recommended to strengthen exposure estimates in epidemiological studies.

2.1.2. Distances

Calculating distance between residences and power lines or facilities estimates magnetic field exposure based on the principle that fields decrease with increasing distance from the source [17]. Recent examples of using distance measures come from a nationwide French study by Sermage-Faure et al. (2013), which calculated proximity of childhood residences to high-voltage power lines up to 225 kV. Exposure was categorized by distance in meters from residence to nearest power line, with close proximity defined as living within 50 meters [18].

While easy to obtain using historical utility data and maps, distance estimates have significant limitations as proxies for ELF-EMF exposure. A major drawback is that distances are not direct measurements of magnetic fields [19]. The methods assume field orientation, uniformity, and lack of interference that may not hold, especially close to power lines [20]. Small errors in geocoding addresses or power line endpoints can also introduce substantial exposure misclassification [21].

In addition, distance only accounts for one field source and cannot incorporate exposures from appliances, wiring, transformers, etc. Exposure prediction does not necessarily improve at further distances since localized indoor sources may dominate [22]. Overall, distance is hardest to interpret at the lowest range (e.g.<50 m from power lines) where field heterogeneity is greatest [23].

To address some limitations, recent studies like Crespi et al. (2016) have combined distance with wire codes to incorporate both magnetic field predictions and major source proximity when estimating historical exposures [10]. However, direct field measurements are still preferable for accurately characterizing ELF-EMF exposure from power lines and validating distance-based estimates.

2.2. PERSONAL MEASUREMENTS

Personal meters worn by study participants provide direct ELF-EMF exposure measurements over a specified sampling period, such as 24 or 48 hours [24]. Recent examples come from Bhatt et al. (2016), who had over 4,000 pregnant women in California wear EMDEX Lite meters for 24-hour periods during pregnancy to capture magnetic field exposures [25].

Personal measurements have the major advantage of assessing ELF-EMF exposures directly rather than relying on surrogates. The devices capture exposures from all sources encountered during the sampling period, including occupational and residential sources [26]. They provide individual-level data on exposure variation among participants, unlike group-based estimates [27].

However, personal monitoring has significant practical challenges and limitations. A key drawback is cost, making widespread deployment infeasible for large epidemiological studies [9]. The devices also do not necessarily represent long-term or typical exposures since measurements are limited to brief sampling periods [28].

Validity and compliance issues can also arise if participants do not wear the meters consistently as instructed [24]. Acceptability needs to be tested when using body-worn devices [29]. While informative, personal measurements may be most valuable when combined with other methods to provide comprehensive ELF-EMF exposure assessment.

2.3. JOB-EXPOSURE MATRICES

Job-exposure matrices (JEMs) assign ELF-EMF exposure estimates to occupational groups based on combinations of job titles and exposure measurements [30]. Recent examples include the INTEROCC JEM, which assigned average magnetic field exposures to over 300 job categories using measurements from prior studies [31]. exposure estimates were linked based on job title data from cohort studies on brain cancer, amyotrophic lateral sclerosis, and Alzheimer's disease [32].

A key strength of JEMs is efficiency in combining job title information and exposure data to assign group-level estimates for large numbers of workers [33]. This retrospective approach can be applied to historical jobs with limited exposure data [9]. However, JEM exposure assignments may be inaccurate for specific individuals due to relying on broad job categories rather than personal measurements [34]. Exposure misclassification can occur when job duties and levels vary within groups [9]. JEMs also require substantial data to generate initial exposure estimates across occupations [33].

Despite limitations, JEMs remain useful tools for incorporating occupational ELF-MF exposure into large epidemiological studies [32], [33]. They are an inexpensive method of estimating historical exposures compared to direct measurements [9]. JEM estimates can guide exposure assessment by identifying high exposed jobs for targeted individual monitoring [34]. Overall, JEMs provide valuable initial ELF-MF exposure ranking but require supplemental methods to reduce misclassification.

2.4. PREDICTIVE MODELS

Predictive models estimate ELF-EMF exposure levels by incorporating limited exposure measurements and other predictor variables like occupational classifications, distances to power lines, wiring configurations, and electrical appliances [35].

Recent examples include Crespi et al. (2016), who developed regression models to estimate historical residential EMF levels for childhood leukemia cases and controls in California. The models incorporated predictors like wire codes, distances to transmission lines, historical appliance ownership, housing factors, and limited spot measurements [36].

A key strength of modeling is the ability to estimate past exposures from questionnaire data when direct measurements are unavailable [37]. Models can also incorporate detailed information on field sources and predictors that influence exposure levels [38]. This provides value for reconstructing historical exposures in epidemiological studies.

However, models are limited by the underlying exposure data and assumptions [37]. Predictions may have high uncertainty if based on limited measurements [39]. The validity of models should be tested by comparing predictions against direct exposure measures. Reducing uncertainties in the predictors and tailoring model form to exposure determinants can enhance validity [37]. Overall, modeling shows potential for improving retrospectively estimated ELF-EMF exposures with careful development and validation.

3. DISCUSSION

Each exposure assessment approach has strengths and limitations that influence its applicability in epidemiological studies (Table 1). Key data challenges include lack of historical measurements, inability to measure all relevant ELF-EMF sources, and limited information on factors influencing exposure levels [9].

While personal measurements provide the most accurate exposure data, they are infeasible for large retrospective studies. Approaches like job-exposure matrices and wire codes offer inexpensive alternatives but have limitations. Predictive models show promise for reconstructing historical exposures from questionnaire data, maps, etc., but require validation [35], [40].

Table 1. Strengths and limitations of assessment methods

S/N	Method	Strengths	Limitations
1	Wire codes	Easy to obtain historically; Predict average fields	Not direct measurements; Coding errors; Assumes stable configuration
2	Distances	Utilizes accessible power line data; Predicts field decrease with distance	Not direct measurements; Assumes orientation/uniformity
3	Personal measurement	Direct measurements; Captures all sources; Assesses individual exposures	May not represent typical exposures; Expensive for large studies
4	Job exposure matrices	Efficiently combines job and exposure data	Crude group-based estimates; Difficult to develop; Misclassification
5	Predictive models	Leverages limited data; Estimates historical exposures; Can add predictions	Dependent on model specifications; High uncertainty; Requires validation

Exposure assessment choices involve tradeoffs between accuracy, practicality, and resources. Combining questionnaire data, spot measurements, job-specific information, and predictive models can improve exposure estimates compared to relying on a single method [9], [41].

The health relevance of different ELF-EMF exposure metrics and sampling strategies also needs further research. Magnetic fields may be more influential than electric fields [42], but few epidemiological studies have separately examined their effects [6]. Understanding dose-response relationships could inform exposure metrics and monitoring approaches [41].

4. Conclusion

Accurate ELF-EMF exposure assessment remains a key challenge in epidemiological research and requires further development and validation of assessment methods. While no approach is ideal, using combinations of assessment methods can improve long-term ELF-EMF exposure estimates. Additional work should develop models for reconstructing exposures from limited data and determine the most health-relevant exposure metrics and sampling strategies. Improved exposure assessment will strengthen future studies evaluating ELF-EMF health impacts.

REFERENCES

[1] A. T. Amoon, J. Swanson, C. Magnani, C. Johansen, and L. Kheifets, "Pooled analysis of recent studies of magnetic fields and childhood leukemia," *Environ. Res.*, vol. 204, p. 111993, Mar. 2022.

[2] X. Vergara, L. Kheifets, S. Greenland, S. Oksuzyan, Y. S. Cho, and G. Mezei, "Occupational exposure to extremely low-frequency magnetic fields and neurodegenerative disease," *J. Occup. Environ. Med.,* vol. 55, no. 2, pp. 135-146, Feb. 2013.

[3] A. Huss, A. Spoerri, M. Egger, H. Kromhout, and R. Vermeulen, "Occupational extremely low frequency magnetic fields (ELF-MF) exposure and hematolymphopoietic cancers–Swiss National Cohort analysis and updated meta-analysis," *Environ. Res.,* vol. 164, pp. 467-474, Jul. 2018.

[4] H. Lim, J. Choi, H. Joo, and M. Ha, "Exposures to radio-frequency electromagnetic fields and their impacts on children's health–what the science knows?," *Curr. Opin. Environ. Sci. Health,* vol. 100456, Feb. 16, 2023.

[5] S. So, Extremely Low Frequency Electromagnetic Field (ELF-EMF) Exposure Assessment and Its Challenges. University of California, Los Angeles, 2020.

[6] M. Van Tongeren, L. Kincl, L. Richardson, G. Benke, J. Figuerola, T. Kauppinen, A. Lakhani, J. Lavoué, D. McLean, S. Mihaylov, et al., "Assessing occupational exposure to extremely low frequency magnetic fields in the INTEROCC study: Part I—Design, methods and quality control," *Ann. Occup. Hyg.,* vol. 63, no. 7, pp. 741-759, 2019.

[7] A. Descatha, M. Fadel, G. Sembajwe, S. Peters, and B. A. Evanoff, "Job-Exposure matrix: a useful tool for incorporating workplace exposure data into population health research and practice," *Front. Epidemiol.,* vol. 2, p. 857316, Apr. 2022.

[8] S. R. Parthasarathy and R. Tukimin, "Residential exposure from extremely low frequency electromagnetic field (ELF EMF) radiation," in IOP Conference Series: *Materials Science and Engineering,* vol. 298, no. 1, p. 012007. IOP Publishing, 2018.

[9] F. Gobba, "Health surveillance of EMF-exposed workers at particular risk," *G. Ital. Med. Lav. Ergon.,* vol. 41, no. 4, pp. 285-292, Dec. 2019.

[10] C. M. Crespi, X. P. Vergara, C. J. Hooper, S. Oksuzyan, S. Wu, M. Cockburn, and L. Kheifets, "Residential magnetic fields exposure and childhood leukemia: A population-based case-control study in California," *Cancer Epidemiol.,* vol. 44, pp. 57-66, Dec. 2016, doi: 10.1016/j.canep.2016.07.015.

[11] L. Kheifets, J. Swanson, S. Kandel, and T. F. Malloy, "Risk governance for mobile phones, power lines, and other EMF technologies," *Risk Anal.Int. J.* vol. 30, no. 10, pp. 1481-1494, Oct. 2010.

[12] G. A. Baker, J. C. Rowley, and E. J. Woodcock, "Limitations of wire standards in the assessment of ELF magnetic field exposure from overhead power lines," *Environ. Health Perspect.,* vol. 126, no. 7, pp. 7701-7706, Jul. 2018.

[13] M. Van Tongeren, L. Kincl, L. Richardson, G. Benke, J. Figuerola, T. Kauppinen, A. Lakhani, J. Lavoué, D. McLean, S. Mihaylov, A. Leenhardt, and E. Cardis, "Assessing occupational exposure to extremely low frequency magnetic fields in the INTEROCC study: Part I-Design, methods and quality control," *Ann. Work Expo Health,* vol. 63, no. 7, pp. 741-759, Oct. 2019, doi: 10.1093/annweh/wxz054, PMID: 31374098.

[14] J. E. Deadman, C. Infante-Rivard, J. Grellier, and M. S. Goldberg, "Individual measurements of residential magnetic fields in the context of an epidemiological study," *Bioelectromagnetics,* vol. 23, no. 1, pp. 75-82, Jan. 2002, doi: 10.1002/bem.90.

[15] M. Does, G. Scélo, C. Metayer, S. Selvin, R. Kavet, and P. Buffler, "Exposure to electrical contact currents and the risk of childhood leukemia," *Radiat. Res.*, vol. 176, no. 2, pp. 251-259, Aug. 2011, doi: 10.1667/RR2563.1.

[16] E. E. Hatch, M. S. Linet, J. Zhang, H. A. Fine, W. R. Shapiro, R. G. Selker, P. M. Black, and P. D. Inskip, "Association between childhood acute lymphoblastic leukemia and use of electrical appliances during pregnancy and childhood," *Epidemiology,* vol. 9, no. 3, pp. 234-245, May 1998, doi: 10.1097/00001648-199805000-00006.

[17] J. Swanson and K. J. Bunch, "Reanalysis of risks of childhood leukaemia with distance from overhead power lines in the UK," *J. Radiol. Prot.,* vol. 38, no. 3, pp. N30-N37, Jul. 2018.

[18] C. Sermage-Faure, C. Demoury, J. Rudant, S. Goujon-Bellec, A. Guyot-Goubin, F. Deschamps, D. Hémon, and J. Clavel, "Childhood leukaemia close to high-voltage power lines--the Geocap study, 2002-2007," *Br J Cancer,* vol. 108, no. 9, pp. 1899-906, Apr. 2013, doi: 10.1038/bjc.2013.128.

[19] J. Vila, J. D. Bowman, L. Richardson, L. Kincl, D. L. Conover, D. McLean, S. Mann, P. Vecchia, M. van Tongeren, and E. Cardis, "Accuracy of a Job-Exposure Matrix for Assessing Occupational Exposure to Extremely Low-Frequency Magnetic Fields: Results of a Validation Study," *Ann Work Expo Health,* vol. 62, no. 8, pp. 1028-1040, Oct. 2018, doi: 10.1093/annweh/wxy075.

[20] R. Kavet, L. E. Zaffanella, J. P. Daigle, and K. L. Ebi, "The possible role of contact current in cancer risk associated with residential magnetic fields," *Bioelectromagnetics,* vol. 21, no. 7, pp. 538-553, Oct. 2000, doi: 10.1002/1521-186x(200010)21:7<538::aid-bem6>3.0.co;2-l.

[21] A. T. Amoon, S. Oksuzyan, C. M. Crespi, O. A. Arah, M. Cockburn, X. Vergara, and L. Kheifets, "Do wire codes accurately predict magnetic fields in residences?" *J Expo Sci Environ Epidemiol,* vol. 28, no. 1, pp. 51-61, Jan. 2018, doi: 10.1038/jes.2017.20.

[22] J. Schüz, C. Petters, U. T. Egle, B. Jansen, R. Kimbel, S. Letzel, W. Nix, L. G. Schmidt, and L. Vollrath, "Investigation of potential risk factors for childhood brain tumours: results from a population-based case-control study in Germany," *Neuroepidemiology,* vol. 20, no. 2, pp. 88-95, May-Jun. 2001, doi: 10.1159/000054772.

[23] J. Swanson, T. D. Bracken, and L. Kheifets, "Use of exposure source allocation factor plots to assess occupational exposure to extremely low frequency magnetic fields," *J Expo Anal Environ Epidemiol,* vol. 21, no. 1, pp. 113-124, Jan. 2011, doi: 10.1038/jes.2009.69.

[24] I. Liorni, M. Parazzini, B. Struchen, S. Fiocchi, M. Röösli, and P. Ravazzani, "Children's personal exposure measurements to extremely low frequency magnetic fields in Italy," *Int. J. Environ. Res. Public Health,* vol. 13, no. 6, p. 549, Jun. 2016.

[25] C. R. Bhatt, M. Redmayne, B. Billah, M. J. Bangay, and K. Hansson Mild, "Cordless telephone use: implications for mobile phone research," *J. Expo. Sci. Environ. Epidemiol.,* vol. 26, no. 4, pp. 369-378, Jul. 2016, doi: 10.1038/jes.2015.42.

[26] W. Joseph, P. Frei, M. Röösli, G. Thuróczy, P. Gajšek, T. Trček, J. Bolte, D. Vienneau, M. Eeftens, B. Struchen, L. Martens, A. Parsa, P. M. Wiedemann, N. Meier, U. Knafl, M. Keller, A. Huss, R. Vermeulen, J. Wout, M. Gallastegi, M. Guxens, P. Elliott, E. van Deventer, M. G. Marmot, and E. Kuijpers, "Comparison of personal radio frequency electromagnetic field exposure in different urban areas across Europe," *Environ. Res.,* vol. 143, pt. A, pp. 7-17, Oct. 2015, doi: 10.1016/j.envres.2015.09.009.

[27] J. F. Viel, E. Cardis, M. Moissonnier, R. de Seze, and M. Hours, "Radiofrequency exposure in the French general population: band, time, location and activity variability," *Environ. Int.,* vol. 35, no. 8, pp. 1150-1154, Aug. 2009, doi: 10.1016/j.envint.2009.07.007.

[28] M. Van Tongeren, T. Mee, M. Feychting, J. Schüz, H. Kromhout, M. Roosli, R. Portet, J. D. Bowman, M. P. Maslanyj, A. Huss, and M. Röösli, "Assessing residential ELF magnetic field exposure in the INTEROCC study: Rationale for study methods and protocol," *Environ. Res.,* vol. 171, pp. 185-191, 2019.

[29] M. Röösli, P. Frei, E. Mohler, C. Braun-Fahrländer, A. Bürgi, J. Fröhlich, G. Neubauer, G. Theis, and M. Egger, "Statistical analysis of personal radiofrequency electromagnetic field measurements with nondetects," *Bioelectromagnetics,* vol. 29, no. 2, pp. 71-78, Feb. 2008, doi: 10.1002/bem.20375.

[30] A. Descatha, M. Fadel, G. Sembajwe, S. Peters, and B. A. Evanoff, "Job-Exposure matrix: a useful tool for incorporating workplace exposure data into population health research and practice," *Front. Epidemiol.,* vol. 2, p. 857316, Apr. 2022.

[31] M. Van Tongeren, P. Gajšek, L. E. van Nierop, I. Samanic, M. Röösli, E. Cardis, and H. Kromhout, "Assessment of ELF Exposure in the Working Environment in Europe-The INTEROCC Study," *Int. J. Environ. Res. Public Health,* vol. 16, no. 8, p. 1473, Apr. 2019, doi: 10.3390/ijerph16081473.

[32] X. Vergara, L. Kheifets, S. Greenland, S. Oksuzyan, Y. S. Cho, and G. Mezei, "Occupational exposure to extremely low-frequency magnetic fields and Alzheimer disease: a meta-analysis," *J. Occup. Environ. Med.,* vol. 55, no. 8, pp. 967-974, Aug. 2013, doi: 10.1097/JOM.0b013e3182917880.

[33] J. Vila, J. D. Bowman, M. Figueras, R. Zoni, J. I. Barrios-Sanz, M. van Tongeren, and E. Cardis, "Assessment of occupational exposure to extremely low frequency magnetic fields in hospital personnel," *Ann. Work Expo Health,* vol. 62, no. 6, pp. 743-755, Jul. 2018, doi: 10.1093/annweh/wxy039.

[34] T. Koeman, L. J. Schouten, P. A. van den Brandt, P. Slottje, A. Huss, S. Peters, H. Kromhout, and R. Vermeulen, "Occupational extremely low-frequency magnetic field exposure and selected cancer outcomes in a prospective Dutch cohort," *Cancer Causes Control,* vol. 25, no. 2, pp. 203-214, Feb. 2014, doi: 10.1007/s10552-013-0330-1.

[35] C. M. Crespi, J. Swanson, X. P. Vergara, and L. Kheifets, "Childhood leukemia risk in the California Power Line Study: magnetic fields versus distance from power lines," *Environ. Res.,* vol. 171, pp. 530-535, Apr. 2019.

[36] L. Kheifets, C. M. Crespi, C. Hooper, M. Cockburn, A. T. Amoon, and X. P. Vergara, "Residential magnetic fields exposure and childhood leukemia: a population-based case–control study in California," *Cancer Causes Control,* vol. 28, pp. 1117-1123, Oct. 2017.

[37] A. Bürgi, P. Frei, G. Theis, E. Mohler, C. Braun-Fahrländer, J. Fröhlich, G. Neubauer, M. Egger, and M. Röösli, "A model for radiofrequency electromagnetic field predictions at outdoor and indoor locations in the context of epidemiological research," *Bioelectromagnetics,* vol. 31, no. 3, pp. 226-236, May 2010, doi: 10.1002/bem.20552.

[38] A. T. Amoon, C. M. Crespi, A. Ahlbom, M. Bhatnagar, I. Bray, K. J. Bunch, J. Clavel, M. Feychting, D. Hémon, L. Kheifets, H. Kromhout, T. Lightfoot, G. Mezei, M. Röösli, A. Shaw, X. Vergara, P. J. Villeneuve, and R. Kavet, "Examining the Potential Clinical Value of Curated Residential History in Environmental Epidemiology: A Simulation Study," *Environ. Health Perspect.,* vol. 126, no. 4, p. 047005, Apr. 2018, doi: 10.1289/EHP2572.

[39] J. Clavel, L. Mandereau, F. Conso, T. Lim, H. Curé, C. Béni-Schwartz, E. Génin, F. Delaunay, D. Luce, and P. Brindel, "Residential exposure to 50 Hz magnetic fields and the association with childhood leukaemia: a population-based case-control study in France," *Radiat. Prot. Dosimetry,* vol. 121, no. 3, pp. 339-347, Mar. 2006, doi: 10.1093/rpd/ncl455.

[40] L. Kheifets, C. M. Crespi, C. Hooper, M. Cockburn, A. T. Amoon, and X. P. Vergara, "Residential magnetic fields exposure and childhood leukemia: a population-based case–control study in California," *Cancer Causes Control,* vol. 28, pp. 1117-1123, Oct. 2017.

[41] J. Vila, J. D. Bowman, L. Richardson, L. Kincl, D. L. Conover, D. McLean, S. Mann, P. Vecchia, M. Van Tongeren, E. Cardis, and INTEROCC Study Group, "A source-based measurement database for occupational exposure assessment of electromagnetic fields in the INTEROCC study: a literature review approach," *Ann. Work Expos. Health,* vol. 60, no. 2, pp. 184-204, Mar. 2016.

[42] M. R. Scarfì, M. O. Mattsson, M Simkó and O Zeni, "Electric, Magnetic, and Electromagnetic Fields in Biology and Medicine: From Mechanisms to Biomedical Applications". *International Journal of Environmental Research and Public Health.* 2019 Nov;16(22):4548.