

increases (Z), whereas the maximum of the disagreement slightly decreases ($D = D_3 = 29.2\text{--}28.55$). That is, by finding an agreement where the total disagreement increases, the extended GP method enables finding a new solution that decreases the disagreement of the more displaced group: the private sector. Scientists and NGOs and advocates continue being the stakeholder groups closest to the consensus agreement ($D_5 = 10.85$ and $D_4 = 6.25$, respectively). The minority consensus agreement is very similar to the majority consensus agreement, except for the option on information from mobile phone base stations having a weight that drops from 14.3% to 12.2%.

4.3 | Robustness tests

Three broad types of responses were identified to explain the nonparticipation in the survey by some respondents. First, the contacted individual did not want to contribute to opening another RF-EMF controversy that could hinder telecom rollout (type-1 individual). Second, the contacted individual did not participate because their organization had explicitly requested him not to do so (type-2 individual). Third, the contacted individual had lost faith in the policy process given the past experiences related to how exposure of humans to RF-EMF has been dealt with in the policy sphere. In addition, the individual considered that the EPRS (2021) report is very conservative, which reinforces the doubts about the usefulness of engaging in the survey. The (academic) individual is afraid of being involved to some extent in some controversy if their name is disclosed (type-3 individual). Most of the type-1 individuals belong to regulatory agencies, central administrations, and the private sector. Most of the type-2 individuals belong to the private sector. Most of the type-3 individuals belong to RF-EMF NGOs, advocates, and academics.

In order to take into account the potential effect associated with nonresponse bias, a set of scenarios is proposed. The scenarios are based on the potential for nonresponse bias (from low to large depending on the response rate of each stakeholder group), and the type of individual and hence most likely preferences (see Table A48). Scenarios 1, 1bis, and 2 favor the “no action” option, whereas scenario 3 favors some action on the topic. Scenario 4 integrates all identified nonresponse biases.

4.3.1 | Scenario 1

The private sector had a particularly low response rate and low intragroup consensus in the first phase of the AHP-GP approach. More precisely, the largest potential nonresponse bias is associated with this group, given the low response rate. It is possible that this stakeholder group would attribute a larger weight to the “no action” option (type-1 and type-2 respondents). Therefore, new AHP-GP results were

implemented taking into account only two private sector respondents giving a large weight to the “no action” option (Tables A49 and A50). In the first phase of the AHP-GP approach, the Shannon-entropy consensus rises from 44.3% to 98.9% for intragroup respondents from the private sector, as expected. No action is the preferred option (39.2%), and weights attributed to information on base station antennas and compliance assessments and prevention drop significantly (5.5% and 2.6%, respectively). The weights attributed to funding research and monitoring remain fairly similar (32.3% and 20.3%, respectively).

The second phase of the AHP-GP approach shows almost no difference when comparing majority consensus agreements including the five respondents from the private sector and the two selected respondents for this sector. However, there are noticeable differences when comparing the minority consensus: by decreasing the distance to this consensus of the two selected respondents from the private sector and increasing the distance for all the rest of the stakeholder groups, the weights attributed to the options “information on antenna base stations” and “compliance assessments and prevention” drop significantly (from 12.2% to 5.5% and from 19.9% to 9.4%, respectively). The weights attributed to the other options, including the “no action” option, remain relatively similar.

4.3.2 | Scenario 1bis

In order to integrate the nonresponse bias when the nonresponse rate is large, under scenario 1bis, the private sector would attribute a larger weight to the “no action” option than that fixed in scenario 1. Compared with scenario 1 where 20 points were to the “no action” weight associated with two private sector respondents, in scenario 1bis 30 points are added to this weight by hypothetical private sector respondents (Table A51). Like in scenario 1, “no action” is the preferred option of the private sector.

Like in scenario 1, in scenario 1bis, the second phase of the AHP-GP approach shows almost no difference when comparing majority consensus agreements including survey respondents from the private sector and the hypothetical respondents from this sector (Table A52). Again, there are noticeable differences when comparing the minority consensus: By decreasing the distance to this consensus of the hypothetical respondents from the private sector and increasing the distance for all the rest of the stakeholder groups, the weights attributed to the options “information on base station antennas” and “compliance assessments and prevention” drop significantly (from 12.2% to 4.2% and from 19.8% to 7.7%, respectively). The weight attributed to the “funding research” option also drops from 38.1% to 31.1%, but it remains by large the option with the largest weight. The weights attributed to the other options, including the “no action” option, remain relatively similar.

4.3.3 | Scenario 2

This is the most favorable scenario for “no action.” It integrates potential nonresponse biases from the private sector (type-1 and type-2 respondents), central administrations (type-1 respondents), and regulatory agencies (type-1 respondents). This scenario controls for the largest potential source of nonresponse bias, which is associated with the private sector given the low response rate of this group. Like scenario 1bis, about 30 points are added to the weight of the “no action” option by hypothetical private sector respondents (Table A51). “No action” is the preferred option of the private sector. Regarding central administrations, the potential nonresponse bias is considered from moderate to large, given the number of respondents. In this scenario, about 20 points are added to the weight of the “no action” option by hypothetical central administration respondents (Table A53). Lastly, the potential nonresponse bias is considered moderate for regulatory agencies, given their response rate. About 10 points are added to the weight of the “no action” option by hypothetical regulatory agencies’ respondents (Table A54). Under scenario 2, “funding research” remains the preferred option for central administrations and regulatory agencies.

In contrast with scenarios 1 and 1bis, in scenario 2 the second phase of the AHP-GP approach shows a significant difference when comparing majority consensus agreements for the survey respondents and the hypothetical respondents from the private sector, central administrations, and regulatory agencies (Table A55). The weight attributed to the “no action” option has increased from 5.5% to 16%. Yet, this option is the fourth choice across stakeholders. There are also noticeable differences when comparing the minority consensus: By decreasing the distance to this consensus of the hypothetical respondents from the private sector and increasing the distance for all the rest of the stakeholder groups, the weights attributed to all options decrease, except for the “no action” option, which remains with the same weight (16%). Even though the weight attributed to the “funding research” option drops from 38.1% to 31.1%, it remains by large the option with the largest weight. The weight attributed to the option on “information on base station antennas” drops from 12.2% to 4.2% under the minority consensus.

4.3.4 | Scenario 3

This is the most favorable scenario for some action on the topic. It integrates potential nonresponse biases from the NGOs and advocates (type-3 respondents) and academics (type-3 respondents). Concerning NGOs and advocates, the potential nonresponse bias is considered moderate, given the number of respondents. In this scenario, about 10 points are added to the weight of the “compliance assessments and prevention” option by hypothetical NGOs and advocate respondents (Table A56). Moreover, the potential nonresponse bias is also considered moderate for academics, given their response rate. About 10 points are added to

the weight of the “funding research” option by hypothetical academic respondents (Table A57). Under scenario 3, “funding research” remains the preferred option for NGOs and advocates and academics.

In scenario 3, the second phase of the AHP-GP approach shows no significant difference when comparing majority or minority consensus agreements for the survey respondents and the hypothetical respondents from the NGOs and advocates and academics (Table A58).

4.3.5 | Scenario 4

This scenario integrates all the potential nonresponse biases that have been considered in the analysis. It is a combination of scenarios 2 and 3 (see Table A51 for the private sector, Table A53 for central administrations, Table A54 for regulatory agencies, Table A56 for NGOs and advocates, and Table A57 for academics). Under scenario 4, “funding research” remains the preferred option for all stakeholders, except for the private sector, which attributed the largest weight to the “no action” option.

In scenario 4, the second phase of the AHP-GP approach shows a significant difference when comparing majority and minority consensus agreements for the survey respondents and the hypothetical respondents from the private sector, central administrations, regulatory agencies, NGOs and advocates, and academics (Table A59). The weight attributed to the “no action” option increases from 5.5% to 16%. There is also a noticeable difference when comparing the minority consensus: By decreasing the distance to this consensus of the hypothetical respondents from the private sector and increasing the distance for all the rest of the stakeholder groups, the weight attributed to the option on “information on base station antennas” drops from 12.2% to 4.2%. Even though the weight attributed to the “funding research” option drops from 38.5% to 35.5% (majority consensus) and from 38.1% to 31.1% (minority consensus), it remains by large the option with the largest weight.

5 | DISCUSSION

This paper assesses the views of key European stakeholder groups on the preferred policy options concerning the exposure of mobile communication emissions to nonhuman organisms. Even though there are some stakeholder groups with a low number of respondents, the results uncover differentiated preference patterns that can be useful for policy discussions. According to these results, there is a broad consensus on the extreme values: funding research on the topic being the first option, and no action being the last. This result holds true when implementing robustness tests. Monitoring RF-EMF exposure, and compliance assessments and prevention are the second preferred solutions, followed by funding research. Information on mobile phone base stations stands as the third policy option. When more weight is attributed to

selected respondents from the private sector and when seeking to reduce the distance of these selected private sector respondents to the consensus (minority agreement), funding research, followed by monitoring RF-EMF exposure, stands out as the preferred policy option.

As described in Table A43, the majority of respondents have a degree in engineering or physics (46). These respondents represent the majority group in regulatory agencies, central administrations, and the private sector. Respondents with a degree in life sciences (24) were the majority group in the NGOs and advocates, and academics stakeholder groups. This points to a critical limitation of key stakeholders who have the power to influence policymakers and whose expertise should reflect a larger extent the transdisciplinary nature of the topic. Current RF-EMF exposure limits, which were developed on the assumption that biological effects are due to excessive tissue heating and that no effects occur below the threshold, remain controversial. In addition, they ignore the health of other species.

The first main policy result that this work conveys is that despite very different points of view on this sensitive topic, and without any debate between the parties that would enable the reduction of some information asymmetries, there is a consensus on the preferred policy option, that is, funding research. There is already a trend underway, albeit small, which favors this. The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) is conducting a systematic map on whether EMFs have a negative effect on nonhuman organisms to inform environmental and radiation protection authorities (Karipidis et al., 2021). The WHO and BFS have recently organized seminars on the effects of EMFs on plants and animals (Pophof et al., 2022a; WHO, 2022). A Coordination Action under H2020 in Europe, EKLIPSE, recently identified the gaps in knowledge and the needs of research and has formulated recommendations on the impact of man-made radiofrequency EMFs on wildlife (Goudeseune et al., 2018; Malkemper et al., 2018).

The core message from these analyses and exchanges is the need to have more high-quality research on this issue. This transdisciplinary topic needs the integration of different expertise, as well as significant funding to provide the required quality output. Currently, no international organization exists with a mandate analogous to that of the WHO on human exposure to RF-EMF to evaluate the risks of exposure of RF-EMF to all nonhuman organisms. Existing organizations, such as the United Nations Environmental Program (UNEP) and the International Union for Conservation of Nature (IUCN), could adopt an agenda on this topic and propose research priorities to canalize international and national funds, like the WHO has done for human health (van Deventer et al., 2011).³⁰ It could also develop useful guidelines on quality frameworks for laboratory and field studies for non-

human organisms.³¹ The transdisciplinary nature of RF-EMF research on nonhuman organisms calls for such guidelines.

The question still remains: Who pays and by which means? We argue that policy options beyond funding research would require a more subtle analysis because the MCDM uncovers no clearly differentiated second-best option. According to oral and written feedback from survey respondents, we suggest that examinations based on better-informed respondents (e.g., through a deliberative process) may contribute to differentiating such a second-best option. For instance, deliberation between stakeholders would be useful on the use of monitoring networks versus simulations based on mobile phone base station data. Some respondents from central administrations (telecommunications sector) argued that monitoring networks are adequate for covering small areas for communication purposes, that is, to communicate and reassure the general public, but not to cover widespread areas for research. Simulations based on mobile phone base station information would be more accurate to deliver nationwide exposure maps (ANFR, 2022).

However, some academics argue that monitoring is better than simulations, as measured data display, in general, lower levels (and is, more broadly, more accurate) compared with the ones that are retrieved by simulation. At the same time, simulations are likely to be rapidly outdated given the continuous evolution of wireless network installations. Initiatives with software based on artificial intelligence and building over a combination of monitoring and base station data to enable updates could eventually provide large-scale solutions with accuracy (Chikha et al., 2023; Wang et al., 2022). Respondents from central administrations (health sector), monitoring past environmental contaminants, have shown limits when relevant indicators have not been previously identified.

Compliance assessment and prevention is the policy option subject to the most divergent views between stakeholder groups, with NGOs and advocates being very favorable, and central administrations and the private sector attributing less weight. Deliberation between stakeholders could eventually lead to converging views on “low-hanging fruit” aspects. Innovations associated with the colocation of mobile phone base stations and platforms to facilitate bird nesting could be devoted more attention in order to define the conditions under which such coexistence is possible when taking into account RF-EMF exposure. Reduced RF-EMF emissions and distance separation could be implemented, for instance, only in close vicinity to sensitive endangered species. Because these cases seem limited in number, correcting them would not be particularly costly from the operators’ point of view.

According to oral and written feedback from some survey respondents, there is a trade-off between focusing exclusively on funding research as a long-term policy and taking into

³⁰ ICNIRP’s publication on the proceedings of the international seminar on effects of electromagnetic fields on the living environment held in Ismaning, Germany, on October 4–5 was partly financed by the UNEP (ICNIRP, 2000).

³¹ During a WHO workshop in the Bioelectromagnetics annual conference in Oxford on June 18–23, 2023, best practices were described on how to develop high-quality research work on RF-EMF effects on human and nonhuman health. Such best practices are needed to ensure that research is included in international assessments.

account, to some extent, certain actions on plants and animals and other living organisms in the short term according to a precautionary principle (through monitoring exposure, simulations based on antenna base station information, and compliance assessments and prevention). Concerning the short term, there is, first, well-established evidence of thermal effects on all living organisms. Second, there is a lack of information on the effects of RF-EMF on nonhuman organisms, particularly for high frequencies (> 6 gigahertz) and for plants, fungi, and invertebrates. As a consequence, the risk of exposure has not been evaluated or updated with the arrival of new technologies.

Although the ICNIRP has worked under the general assumption that nonhuman organisms are protected from harmful Rf-EMF radiations as long as humans are protected (ICNIRP, 2000), the organization set up a new project group on Environment and EMFs in November 2021 to “draft a statement on the environmental effects of electromagnetic fields on the basis of qualitatively reliable scientific papers. And, if possible, to analyse whether the current human exposure guidelines are also sufficiently protective for non-human organisms in their natural environment.” It is possible that this project group may deliver some broad statements because thermal thresholds are species-dependent and research is still lacking. Nevertheless, ecosystem and ALARA (as low as reasonably achievable) approaches could be developed, inspired by ionizing radiation frameworks developed for the environment (ARPANSA, 2015; ICRP, 2014).

According to ARPANSA (2015), environmental exposure is defined as “... the exposure of wildlife to all additional radiation sources resulting from human activities. Wildlife may require protection in order to maintain biological diversity, conservation of species, or the health and status of natural habitats, communities or ecosystems, or anything that may be otherwise required from a conservation point of view in accordance with relevant legislation.” Their framework integrates with assessments and/or in decisions on the protection of wildlife the dosimetric quantity, reference organisms and representative organisms, and environmental reference levels (Fig. A.3, ARPANSA, 2015).

According to the International Commission on Radiological Protection (ICRP), steps taken to protect the environment from ionizing radiation should fall within the concept of optimization, the latter understood as the process of determining the level of protection and safety that makes exposures, and the probability and magnitude of potential exposures, as low as reasonably achievable, economic and societal factors being taken into account. Reference levels were derived by the ICRP to relate the effects of ionizing radiation to doses to nonhuman organisms, but the institution states that these values are not limited and are not intended to be used in that manner. Potential synergies between ICNIRP and ICRP approaches were already subject to discussion in the past for human health, in particular, whether ALARA approaches developed by the ICRP could be meaningfully applied to nonionizing radiation (ICNIRP/WHO/ICRP/IRPA/ILO, 2014).

To conclude, humans have so far chosen not to address the effects of RF-EMF on nonhuman organisms even if there is evidence of thermal effects on all living organisms. The controversial debates on RF-EMF effects on human health have probably hampered early attempts to address the effects on nonhuman organisms. Our results show that, for the consulted stakeholders, this topic calls for some action. It is not a matter of hindering progress, but understanding the optimal conditions for technological proliferation, given the current state of knowledge.

ACKNOWLEDGMENTS

We are extremely grateful to the respondents of the survey for their contributions. We would also like to thank two anonymous reviewers for their insightful comments, as well as Jacques Lochard and Jacqueline Garnier-Laplace for their comments and suggestions. Jérémy Froidevaux was supported by the Leverhulme Trust through an early-career fellowship (award reference ECF-2020-571).

DECLARATION OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article. Arno Thielens declares that he authored the EPRS study (EPRS, 2021) and has formulated the recommendations listed in the study.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Recuero Virto, L., Thielens, A., Czerwiński, M., & Froidevaux, J. (2024). The exposure of nonhuman living organisms to mobile communication emissions: A survey to establish European stakeholders' policy option preferences. *Risk Analysis*, 1–15.
<https://doi.org/10.1111/risa.14322>