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Towards a quantification of the social and economic impacts of the upper atmosphere effects in Europe

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The PITHIA Network of Research Facilities (PITHIA-NRF) is a research infrastructure funded by the European Union's Horizon 2020 research and innovation program under grant agreement No. 101007599 that aims at building a European network integrating observing facilities, data collections, data processing tools, and prediction models for the study of the Earth's Ionosphere, Plamasphere, and Thermosphere.

The project is expected to lead to research advances in data access and analysis and to the development of models with improved predictive power of those upper atmosphere phenomena (ionospheric variation, ionospheric irregularities, polar cap absorption, thermospheric drag, among others) which pose not only scientific but also societal challenges. For example, Space Weather effects in the Ionosphere and Thermosphere affect the performance and reliability of several essential space-borne and ground-based technological infrastructures such as earth observations systems (e.g., low-frequency SAR), satellites (e.g., GNSS satellites), electricity grids, ground-based augmentation systems, astronomical observation systems (e.g., LOFAR), and terrestrial radio systems using HF and VHF communications. In turn, failures in any of these infrastructures may disrupt or render unavailable services of exceptional importance to society such as power or those (nowadays ubiquitous) relying on accurate positioning, navigation, and timing information such as transport, surveying, or banking.

Beyond supporting the design of technologies mitigating the mentioned upper atmosphere effects, PITHIA-NRF, through this paper, wishes to contribute to the ongoing effort of estimating the socioeconomic impacts of space weather, focusing on continental Europe. While no consensus has yet been reached among practitioners on the most suitable approach for tackling this challenging task [1], in recent years, a few studies have indeed advanced our understandings of the nature of impacts and put forth frameworks defining socioeconomic impacts indicators [1] and quantitative methodologies [2,3]. Our paper will start by assessing how the upper atmosphere phenomena act on technological infrastructures and inhibit them, totally or partially, from providing their services. Then, a literature review on previous space weather socioeconomic impacts ensues and will present the consequences of "moderate" and "extreme" space weather events over Europe. Here, we will follow the approach in [1] to quantify the impacts of the upper atmosphere phenomena on power grids, satellites, GNSS use, aviation, and rail. In our view, the Abt Associates report [1] presents the most suitable framework for our work, for it is overarching in nature, computing lower and upper bound estimates for several economic sectors, and it relies on stakeholders' perspectives on impacts. Looking ahead, for instance, we could refine our effort by eliciting stakeholders' inputs during the three Innovation Days that will be organized during the PITHIA-NRF project.

1. Abt Associates, "Social and Economic Impacts of Space Weather in the United States," October 2017, retrieved from https://www.weather.gov/media/news/SpaceWeatherEconomicImpactsReportOct-2017.pdf

2. E. J. Oughton, M. Hapgood, G.S. Richardson, C.D. Beggan, A.W.P. Thomson, M. Gibbs, et al., "A Risk Assessment Framework for the Socioeconomic Impacts of Electricity Transmission Infrastructure Failure Due to Space Weather: An Application to the United Kingdom," *Risk Analysis*, **39,** 5, 2019, pp 1022–1043, doi: 10.1111/risa.13229.

3. J.P. Eastwood, M.A. Hapgood, E. Biffis, D. Benedetti, M.M. Bisi, L. Green, et al. "Quantifying the Economic Value of Space Weather Forecasting for Power Grids: An Exploratory Study," *Space Weather*, **16**, 12, 2018, pp 2052–2067, doi: 10.1029/2018SW02003