1. PUBLISHABLE SUMMARY

Summary of the context and overall objectives of the project (For the final period, include the conclusions of the action)

Airborne wind energy (AWE) is a class of emerging renewable energy technologies that are based on tethered flying devices replacing the foundation and rigid tower of conventional wind turbines. AWE systems can potentially achieve lower energy costs at a reduced environmental footprint and with access to wind at higher altitudes. Current predictions confirm the potential impact on the energy situation in Europe and the world. However, apart from the common feature of using tethered flying devices, the technical details and designs of AWE systems can be quite different. The currently pursued conversion concepts use combinations of flexible membrane wings or rigid aircraft-like kites, single or multiple tethers with various ways to control the flying devices and airborne or ground-based electricity generation. While the concept is highly promising, major academic and industrial research is still needed to achieve the performance required for industrial deployment. Following a decade of systematic technical development, several commercial prototype platforms have reached power levels between 50 and 600 Kilowatts. None of these has however been operated long-term under real-world conditions. Typical scientific and technical challenges include operational reliability and robustness of the system, computational tools for the design and engineering phases as well as for the operation of the systems.

Addressing these challenges was the shared objective of the doctoral training network AWESCO (Airborne Wind Energy System Modelling, Control and Optimisation), which was launched in January 2015 and was funded by the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 642682. The network aimed at (1) training a new generation of world class AWE researchers highly valuable to the industry, (2) expanding the training, scientific and technical knowledge base for AWE, and (3) establishing the framework for long-term cooperation between universities and industry. Technical and scientific breakthroughs were expected for (1) modelling and computational simulation of flexible as well as rigid wing systems, (2) system design and optimisation of reliable launching, power generation and landing operation, and (3) developing new sensors, estimation and control algorithms. At finalisation of the project, the AWESCO consortium consisted of 6 academic and 3 industry beneficiaries as well as 2 fully-integrated Swiss partners with own national funding. In total 16 Early Stage Researchers (ESR) worked on 4 ambitious work packages that were aligned with the technical and scientific aims of the project. The AWESCO consortium was complemented by 9 partner organisations. Actively involved in AWE, these had joined the training network to provide secondment opportunities for ESRs, but also to send own staff or researchers to the AWESCO network trainings.

The systematic multi-disciplinary research of the AWESCO network has substantially increased the knowledge base for AWE, especially in the targetted areas of system modelling, control and optimization. The collaboration between the AWESCO network and 4 parallel EU-projects at industrial consortium partners, REACH, EK200-AWESOME, AMPYXAP3 and NEXTWIND, has created an effective research ecosystem of high value to all parties involved and the AWE community in general. The innovation potential of this ecosystem is also demonstrated by the fact that the academic beneficiaries spun-off 4 new AWE companies during the runtime of the network: Enevate (TUD), Aenarete (TUD), Kiteswarms (ALU-FR) and Kitekraft (TUM).

Work performed from the beginning of the project to the end of the period covered by the report and main results achieved so far (For the final period please include an overview of the results and their exploitation and dissemination)

During the runtime of AWESCO, 6 project meetings and 10 teleconferences were held, 25 technical milestones were achieved and 18 individual training events organised at 8 different partner locations. At finalisation, the AWESCO project had generated more than 140 scientific publications in either green or gold open access. The 16 Early Stage Researchers were involved as co-authors in 70 of these publications, not counting manuscripts that are still under review. In April 2018, a comprehensive textbook was published by Springer, edited by the project coordinator and covering the field of AWE with 30 contributed chapters, several also from consortium members. With a total of 752 pages this book is to date the largest single work about the emerging technology.

Two international conferences were organised during the runtime of AWESCO. The 6th Airborne Wind Energy Conference (AWEC) was held on 15-16 June 2015 in Delft, the Netherlands, attracting more than 200 participants from all over the world to attend the 54 oral presentations arranged in 10 different sessions and 17 poster presentations in a special poster session. The 7th AWEC was held on 5-6 October 2017 in Freiburg, Germany, organized jointly by ALU-FR and TU Delft and attracting a similar number of participants. The conference functioned also as a central networking event of AWESCO, providing ample opportunities for the Early Stage Researchers to present and discuss their work as well as future prospects. Both conferences have been preserved as online events by making the video recorded presentations and posters freely available to the public on the conference websites http://www.awec2015.com and http://www.awec2017.com. The two books of abstracts were published in open access and comprehensively document the state-of-development of airborne wind energy in 2015 and 2017. The generously illustrated booklets perfectly complement the scientific publication output in terms of dissemination of the technology.

Progress beyond the state of the art, expected results until the end of the project and potential impacts (including the socio-economic impact and the wider societal implications of the project so far)

The available knowledge base for the emerging technology has been enlarged substantially. The key contributions of AWESCO are especially in the targetted areas of system modelling, control and optimization. These areas are crucial for and efficient development of larger-scale commercial systems and quantitative assessment of new AWE concepts, such as multi-kite configurations. The achieved progress was reported to the AWE community and the interested public at the AWEC 2017. The continued research progress of the consortium will be reported at the Wind Energy Science Conference (WESC) Airborne Wind Energy Conference 2019 in Cork and the AWEC 2019 in Glasgow. Journal editors are by now well aware of the innovation potential of airborne wind energy and are actively seeking contributions from the AWE community.

The networked research activities in AWESCO also had an impact on the parallel study that consultancy company Ecorys conducted for the European Commission, assessing the challenges of the commercialisation of airborne wind energy systems (http://doi.org/10.2777/87591). AWESCO consortium members attended the final workshop on 4th July 2018 in Brussels and used this opportunity to provide feedback to the commission. Further, the International Renewable Energy Agency IRENA is covering Airborne Wind Energy in their “Innovation Outlook: Offshore Wind 2016” report (http://www.irena.org/DocumentDownloads/Publications/IRENA_Innovation_Outlook_Offshore_Wind_2016.pdf). Another excellent indicator for the steady

development of AWE technology towards utility scale is the announcement of Shell and Makani to partner and begin testing of the 600 kW system offshore Norway in June 2019 (https://spectrum.ieee.org/energywise/energy/renewables/alphabets-moonshot-wind-kites-to-fly-offshore).

Address (URL) of the project's public website

www.awesco.eu