

MARE-WINT

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Editors

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New Materials and Reliability in Offshore
Wind Turbine Technology



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About MSCA

The Marie Skłodowska-Curie actions (MSCA) provide grants at all stages of researchers’ careers, from doctoral candidates to highly experienced researchers, and encourage transnational, intersectoral and interdisciplinary mobility. For research institutions (universities, research centres and companies), MSCA offer the possibility to host talented foreign researchers and create strategic partnerships with leading institutions. The idea is to equip researchers with the necessary skills for a successful career, be it in the public or the private sector.

The MSCA are open to all domains of research and innovation, from basic research up to market take-up and innovation services. Research and innovation fields are chosen freely by the applicants (individuals and/or organisations) in a fully bottom-up manner. International mobility is prerequisite under all Marie Skłodowska-Curie actions. There are no restrictions in terms of research field, nationality or age.

Endowing researchers with new skills and a wider range of competencies, while offering them attractive working conditions, is a crucial aspect of the MSCA. In addition to mobility between countries, the MSCA also seek to break the real and perceived barriers between academic and other sectors, especially business.

About ITN

The doctoral training is covered under the action Innovative Training Networks (ITN). This high-quality joint research and doctoral training is delivered by international networks that bring together universities, research centres and non-academic organisations (companies, NGOs, charities, etc.) across Europe and beyond.

ITN can take one of three forms:

- European Training Networks (ETN): Joint research training, involving a minimum of three partners from in and outside academia (business, museum, NGO, etc.).
- European Industrial Doctorates (EID): Joint doctoral training delivered by at least one academic partner entitled to award doctoral degrees and at least one partner from outside academia, primarily enterprise. Each participating researcher is enrolled in a doctoral programme and is jointly supervised by supervisors from the academic and non-academic sector, where they spend at least 50% of their time. The aim is to broaden the career perspective of the PhD candidate upon completion of the training.
- European Joint Doctorates (EJD): A minimum of three academic organisations form a network with the aim of delivering joint, double or multiple degrees. Joint supervision of the research fellow and a joint governance structure are mandatory. The participation of additional organisations from anywhere in the world, including from the non-academic sector, is encouraged.

During their ITN training, researchers will develop key transferable skills common to all fields, such as entrepreneurship, management and financing of research activities and programmes, management of intellectual property rights, ethical aspects and communication.

In all cases, the recruited researchers are fully funded by the Marie Skłodowska-Curie actions, with an attractive living and mobility allowance. The host organisations receive a contribution to the research and training costs of the recruited researcher and apply good employment practices in line with the European Charter for Researchers and the European Code of Conduct for the Recruitment of Researchers (European Commission 2016a).

The Marie Skłodowska-Curie actions support PhD candidates by financing organisations which subsequently recruit candidates to the training programmes. Therefore PhD candidates do not apply to the commission for the funding of their posts. Instead, they apply directly on the European Researchers Mobility portal EURAXESS (European Commission 2016b).

The External Contributors

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References

European Commission (2016a) The European Charter for Researchers. <http://ec.europa.eu/euraxess/index.cfm/rights/europeanCharter>. Accessed 06 Apr 2016

European Commission (2016b) EURAXESS Researchers in Motion. <http://ec.europa.eu/euraxess/index.cfm/jobs/index>. Accessed 06 Apr 2016

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