Ecotoxicological Effects of Metal Mixtures from Offshore Wind Turbine Galvanic Anodes on Blue Mussels Mytilus edulis

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Offshore wind energy is a pivotal strategy for achieving carbon neutrality in electricity generation. Offshore locations offer the advantages of higher wind speeds and reduced spatial competition with human activities compared to onshore sites. However, the expansion of offshore wind farms to meet the 2050 carbon-neutral targets introduces potential pressures on marine ecosystems, particularly through trace metal emissions from galvanic anodes cathodic protection anti- corrosion systems. While zinc and aluminum are the primary metal ions emitted, other trace metals such as cadmium, lead, indium and gallium have also been reported as key components in these alloys. Despite well-documented toxic effects of zinc, aluminum, cadmium, and lead on marine organisms, such as oxidative stress, reduced growth potential, and DNA damage, little is known about the toxicity of gallium and indium, either alone or in combination with other metals. In a laboratory experiment, we are investigating ecotoxicological effects of a mixture of trace metal elements (Al, Zn, Cd, Pb, Ga, and In), emitted from galvanic anodes on the blue mussels *M. edulis.* Thereby the mussels will be exposed to increasing dissolved metal concentrations, achieved by dissolving pure chloride metal salts in relative proportions to the composition of aluminum based galvanic anodes. The lowest exposure concentrations will be comparable to those currently obtained around wind farms in the North Sea. Metal bioaccumulation, energy stores, oxidative stress enzyme activity, metallothionein induction, and expression of defense-related genes in gill and digestive tissues will be assessed after 1, 3, 7, and 14 days. Preliminary results after 7 days exposure show indication of some physiological effects of the exposed metals . This study will contribute to understanding the biological impacts of cumulative metal emissions from offshore wind farm anodes, enhancing environmental models and guiding sustainable planning to mitigate ecological effects while balancing offshore wind energy's socio-economic and environmental benefits.

Keywords
Offshore Wind Energy; Galvanic Anodes; Metal Emissions; Blue Mussel