MEMETRE – from processes to modelling of methane emissions from trees

The atmospheric concentrations of CH_4 (methane), a powerful greenhouse gas, have been increasing since the beginning of industrial times, mainly due to anthropogenic activities such as agriculture, waste management and the production and use of fossil fuels. Methane is also released into the atmosphere from natural sources, for example, geological activity, permafrost thawing and wetlands.

Since the beginning of the new millennium, the atmospheric methane concentration has shown an increasing trend that is not explained by known anthropogenic or natural sources. Moreover, large differences exist between the emission estimates based on source-specific surface-level measurements and those provided by satellites that observe the Earth's greenhouse gas emissions from space.

Plants and forests are crucial elements in the global cycles of carbon, not only for their capability to remove carbon dioxide from the atmosphere but also as platforms for numerous other processes of interaction between terrestrial ecosystems and the atmosphere by which they regulate the global climate. While many of these interactions are well-known and thoroughly studied and thus serve as the premise of climate action and mitigation of global warming, others still remain to be resolved. One of the missing pieces to the puzzle is the role of forests and trees in the cycles of methane. MEMETRE, a European Research Council-funded project, sheds light to the processes through which trees contribute on the methane exchange of forests and provides the understanding necessary for building regional emission models and further expanding them to global scales.

Plants and vegetation are recognised as important components of global methane cycles due to their capability to transport methane from deeper, methane-producing layers of waterlogged soils into the atmosphere through their roots and stems. In areas where the methane production in the soils is high, such as tropical wetlands and rice paddies, this transport significantly increases the amount of methane emitted to the atmosphere because the vegetation serves as conduits for methane to pass through the aerated top layers of soil, where methane moving towards the surface from the deeper soil layers could otherwise be consumed.

Recently, methane emissions have also been reported from the trees of temperate and boreal forests. As opposed to wetlands, where the methane production dominates the methane budget, the net ecosystem fluxes of methane in upland ecosystems consist of several smaller but overlapping consumption or production processes taking place in the soil and in trees. These poorly known methane-related processes may change our view of methane cycling in upland forests, which are generally perceived as sinks of methane due to the methane-oxidising nature of the topsoils. MEMETRE revises this view by bringing new insight into how trees mediate the methane cycling of the forests in cooler climates by presenting findings based on gas flux measurements and modelling of methane cycling in trees.

MEMETRE identifies, partitions and quantifies methane fluxes of boreal trees and determines the environmental and physiological drivers of tree-mediated methane emissions. The overall aim is to increase the process-level understanding of the origin of these emissions, determine their contribution to the forest ecosystem's methane flux and scale up the emissions of boreal forests into regional and global scales.

The fundamentals of the empirical methods of MEMETRE are chamber-based gas-exchange measurements conducted on living, intact trees and tree saplings in field conditions, semi-controlled environments such as the greenhouse and garden, and a controlled growth chamber. With the technical challenges related to the measurements done with such methods also comes one of MEMETRE's objectives: to further develop and improve chamber measurement methods for plant gas exchange (Kohl *et al.*, 2021). Measurements in controlled laboratory and greenhouse conditions allow us to define key environmental drivers of the fluxes at tree stem and canopy levels. MEMETRE also evaluates the involvement of methane-producing or consuming microbes in the methane exchange of boreal trees (Putkinen *et al.*, 2021).

In detailed laboratory measurements with blocks of tree stems, we quantified methane transport capacity within xylem sap flow (Anttila *et al.*, 2023). This empirical data was further used to parametrise a dynamic model originally developed for carbon dioxide (CO_2) (Hölttä and Kolari, 2009). The methane transport model was further tested against field flux measurements and then used to study the spatial and diurnal dynamics of stem methane transport and fluxes. To our knowledge, the methane transport model is the first model that enables us to estimate the importance of the transpiration stream (sap flow) as a driver of methane emissions from tree stems. The model can have multiple future applications and can also be used to estimate methane fluxes in temperate

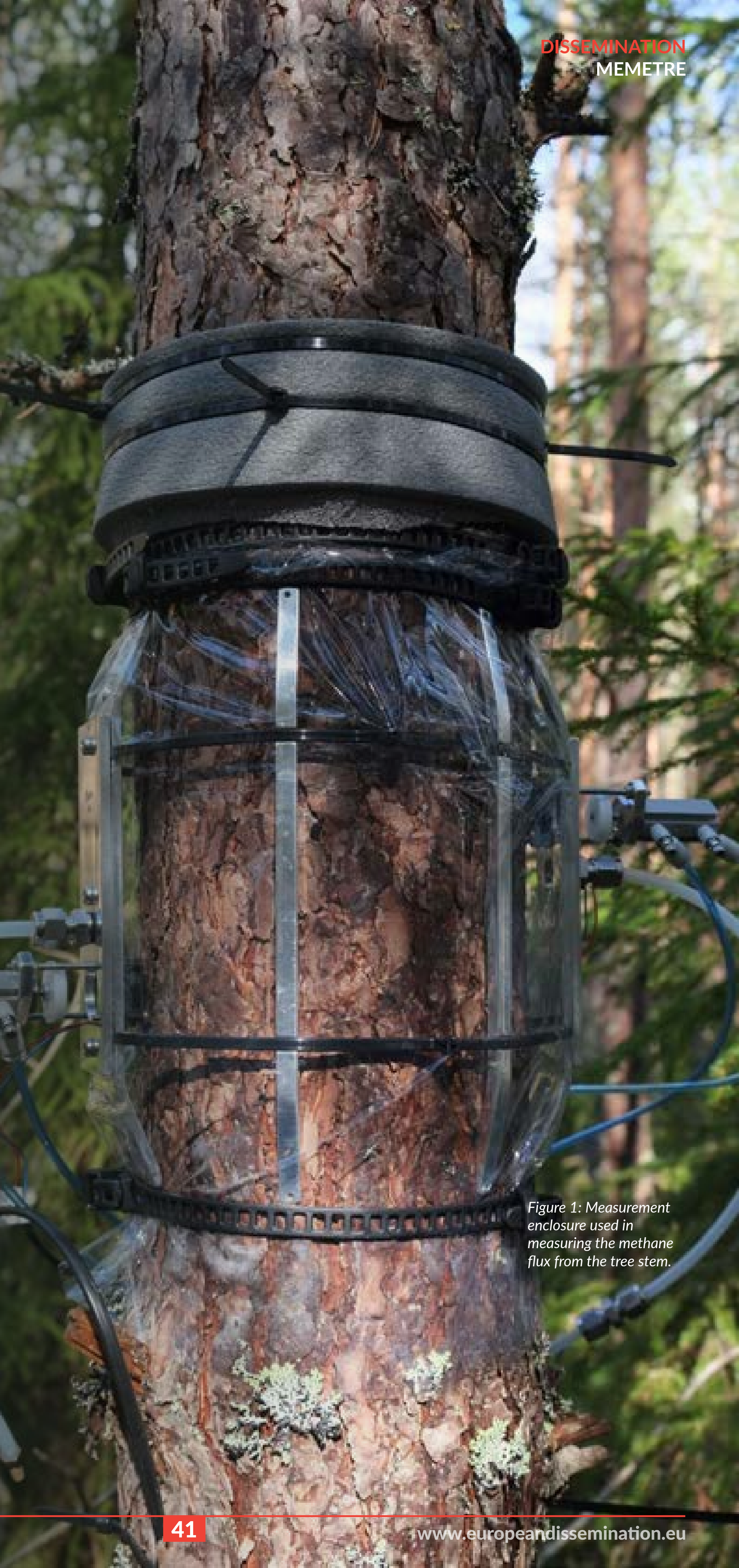

Figure 1: Measurement enclosure used in measuring the methane flux from the tree stem.

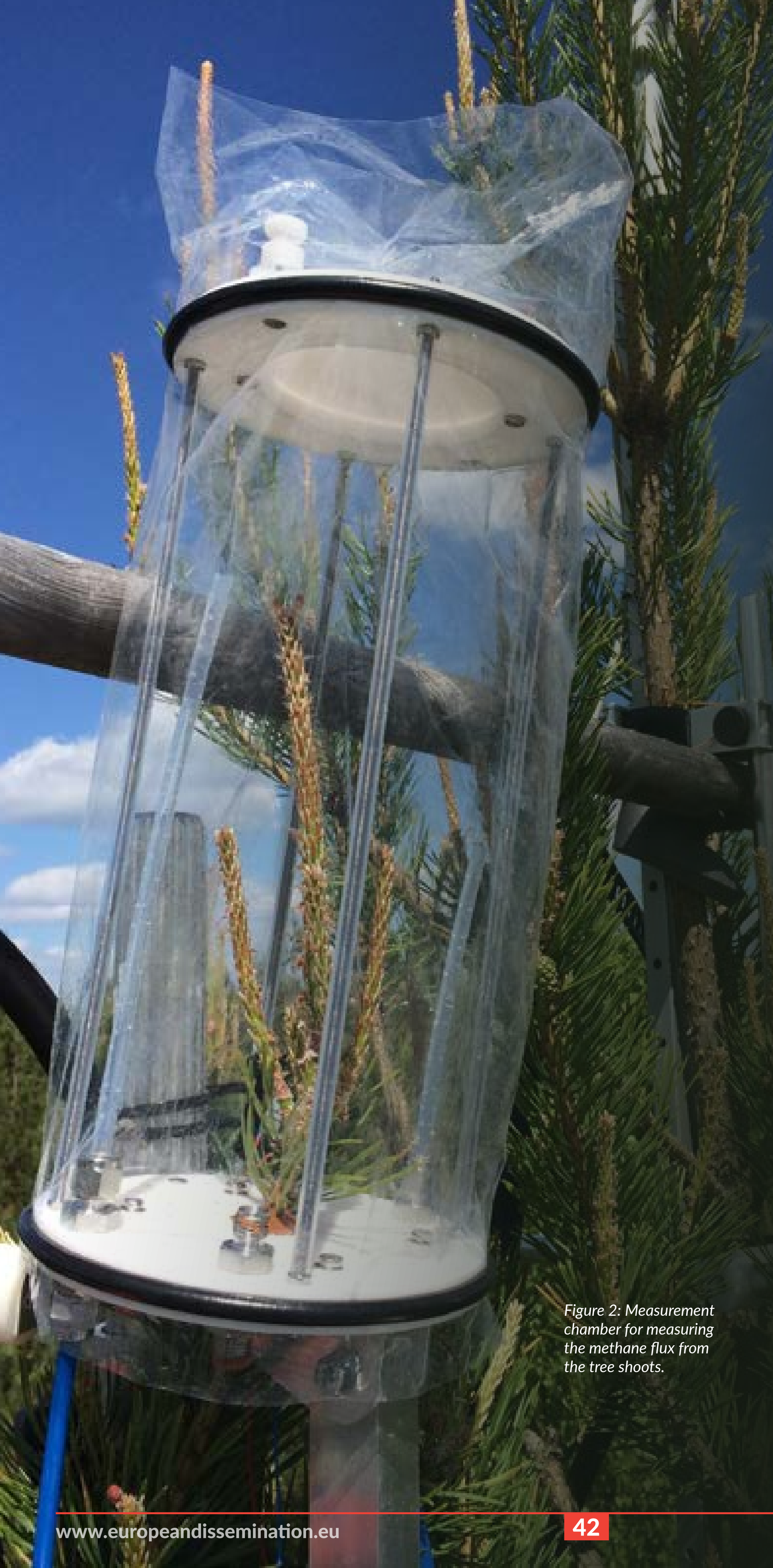

Figure 2: Measurement chamber for measuring the methane flux from the tree shoots.

and tropical forests, where trees have been found to be enormously high methane emitters during the wet season (Pangala *et al.*, 2017).

One of the lesser-known factors in forest methane cycling is tree canopies, which bear the potential for methane production and possibly consumption, independent from the soil-derived transport by abiotic and microbial processes. The methane emissions from tree canopies are mostly thought to originate from an aerobic, non-microbial production process, which has, relatively recently, been observed in the foliage of various plant species (Keppler *et al.*, 2006).

In MEMETRE, we have studied this phenomenon on the boreal conifers Scots pine. After observing that the shoots of mature Scots pine trees emit methane in magnitudes that may reduce the sink of the forest soil by up to 35 per cent (Machacova *et al.*, 2016), we followed the methane fluxes from tree saplings during spring and found that emissions are driven by solar radiation and enhanced by increasing temperature (Tenhovirta *et al.*, 2022). Based on the light-driven component of the methane emissions accompanied by ecosystem-level methane flux measurements, we will be able to increase the accuracy of earlier estimates of the aerobic emissions of boreal forest canopies.

Our measurements in a controlled environment in a greenhouse revealed that methane emissions persist regardless of the physiological status of the trees under exposure to drought, indicating that the shoot-level methane emissions are not a by-product of photosynthesis, nor are they increased under stress but, likely for the most part, are released from plant structural compounds due to thermal or light related degradation. This finding was important because, in earlier literature, the assumption of a photosynthesis-related process behind emissions from plant foliage has served as one option on which global emission estimates may be based (Kirschbaum *et al.*, 2006). Furthermore, by using drought to inhibit the production of methane in the soil and the canopy transpiration, we were able to isolate the shoots from the possible transport of methane from the soil to show that a local production process exists in the forest canopies. This finding is further supported by our model, which shows that soil-derived methane is not transported up to the canopies in mature Scots pine trees (Anttila *et al.*, 2023).

The MEMETRE project has successfully constrained estimates of the level of methane emissions from boreal upland forest ecosystems and identified the drivers and processes behind these emissions. Using the results and methodology developed in the project, future research can focus on broadening the selection of species measured and pinpointing the exact (photo)chemical reaction pathways responsible for methane production in forest canopies.

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PROJECT NAME

MEMETRE

PROJECT SUMMARY

The ERC Starting Grant project "From processes to modelling of methane emissions from trees (MEMETRE)" combines laboratory and field experiments to raise the process-based understanding of methane emissions from the soil-tree-atmosphere continuum and constructs a sound model for the methane exchange within a forest to be utilised in regional or global methane emission modelling.

PROJECT LEAD PROFILE

Associate professor Mari Pihlatie (H-index 31) has gained merit in developing methods to measure fluxes of GHGs from soils and plants. In 2017, she received an ERC starting grant to reveal processes of methane emissions from trees (MEMETRE), and in 2018, she was nominated for the Academy of Finland's prize for social impact.

PROJECT PARTNERS

The MEMETRE project is based at the Faculty of Agriculture and Forestry of the University of Helsinki, and at the Institute for Atmospheric and Earth System Research (INAR), taking advantage of their state-of-the-art field and laboratory resources. Collaboration partners include groups from Germany, the UK, the US and beyond.

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