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Title: **Joint effects of CLimate Extremes and Atmospheric depositioN on European FORESTs**

Acronym: **CLEANFOREST**

Summary

The ability of forests to continue mitigating climate change depends on their ability to cope and adapt to global change drivers, such as more frequent climate extreme events and changes in atmospheric pollutants (namely carbon dioxide, reactive nitrogen and sulphur compounds). Different global change drivers could play a synergistic, antagonistic or predisposing role in affecting forest ecosystem functioning and health. All these drivers, however, are generally considered in isolation, and their effects on key processes (at tree, soil and ecosystem levels) are investigated separately in natural, periurban and urban forests, thus leading to uneven, un-coordinated and scattered information among different research communities. Without taking a holistic view on forest's responses to global change, the future trajectory of Europe's forests and their climate change mitigation potential can be fundamentally mis-assessed. CLEANFOREST will establish an inclusive and multidisciplinary pan-European network, which capitalizes on existing expertise and infrastructures (monitoring networks, manipulation experiments) to i) coordinate research efforts (e.g. data collection), ii) compare approaches and define common protocols to standardize measurements and methods used in global change studies, and iii) foster collaboration among different research groups to exchange and synthesize data, thus contributing to advancing scientific knowledge, identifying research gaps and providing suggestions for the next generation manipulation experiments and monitoring networks. Finally, CLEANFORST will benefit from the participation of key stakeholders (policymakers, small companies developing low-cost and effective instruments for environmental monitoring, citizen associations), by promoting mutual synergies to fulfil the urgent need of evidence-based solutions to policy, societal and technological challenges.

Key Expertise needed for evaluation

Earth and related Environmental sciences
Terrestrial ecology, land cover change
Earth and related Environmental sciences
Biogeochemistry, biogeochemical cycles
Agriculture, Forestry, and Fisheries
Biochemistry
Biological sciences
Plant biology, Botany
Earth and related Environmental sciences
Geochemistry, isotope geochemistry

Keywords

Forest functioning

Tree mortality

Manipulation experiments

Monitoring network

Global change driver interactions

TECHNICAL ANNEX

1 S&T EXCELLENCE

1.1 SOUNDNESS OF THE CHALLENGE

1.1.1 DESCRIPTION OF THE STATE-OF-THE-ART

Forests are at the forefront of our efforts to mitigate climate change and achieve the UN's Sustainable Development Goals (SDGs), to ensure a sustainable life on Earth. However, **forest ecosystems are particularly threatened by global change components**, such as **increasing frequency and severity of climate extreme events, increasing atmospheric carbon dioxide (CO_2) and pollutants concentrations,** and increasing tropospheric ozone. All these factors strongly influence the capacity of forests to continue providing important ecosystem services we rely on, including climate regulation and mitigation, biodiversity conservation, clean water and air supply, food and energy production, and improvement of human health and well-being, particularly in urban systems.

One of the results of human-induced perturbation of the climate system is the change in the frequency, intensity, spatial extent, duration, and timing of the extreme weather and climatic variables, such as temperature and precipitation. **This COST Action refers to climate and weather extremes as climate extremes** (following [1]), **and focuses on hot extremes (including heatwaves)** [2] **and drought**. The 2003 heatwaves experienced across Europe, cannot be considered as an exceptional event anymore, as **prolonged summer droughts and temperatures anomalies are becoming more common and frequent across the whole continent** (e.g. summer 2016, 2018 and 2019 [3,4]) and globally [2], with negative impacts on forest ecosystems. Indeed, these climate extreme events impair physiological mechanisms underpinning tree growth and forest productivity, thus undermining their capacity to sequester carbon (C) and, eventually, they may trigger tree mortality [5,6,7].

Frequent droughts and hot extremes are not the only challenge forests need to face. Anthropogenic activities have significantly altered atmospheric chemistry over the last century, leading to an increase in atmospheric CO_2 concentrations (C_a), but also to changes in reactive nitrogen (oxidised and reduced forms of nitrogen, Nr) and sulphur (S) compounds. While almost half of the CO_2 emitted by fossil fuel combustion remains in the atmosphere (and hence contribute to global warming [8], **Nr and S are deposited back to terrestrial and aquatic ecosystems, directly altering the N and S cycles, but indirectly also the C and water cycles**. The total amount of N deposition across Europe was estimated to be 3.8 Tg N in 2000, double that compared to 1900, with 1.4 Tg N deposited onto terrestrial ecosystems, such as forests [9]. N deposition has been suggested as a key driver not only of increased forest growth [10,11,12] but also in explaining forest health [13], suppression of soil C decomposition, and widespread tree mortality [14]. The mechanisms, which govern the effect of N deposition on tree mortality, are not well established, but have been hypothesized to be the result of forest structural changes (e.g. increasing competition), changes in soil acidification and nutrient imbalance [15,16,17], and shifts in microbial communities [18]. **N addition has been reported to increase tree sensitivity to drought, in terms of both growth** [19] **and survival** [20]. Other studies have suggested, on the contrary, that N deposition could make forests less vulnerable to drought [21], and a first theoretical framework of positive and negative drought-nutrient interactions has been recently proposed [22]. The legacy of S deposition, albeit the latter significantly decreased since the 1980's, could still affect soil processes (e.g. soil acidification, soil inorganic C loss and cation leaching) and the trade-off between C uptake and water loss through transpiration, i.e., the water-use efficiency (WUE, [23,24,25]). This, for instance, is particularly likely to be an issue in **Central and Eastern European countries**, which **are still recovering from high S and N deposition** [26,27,28]. **Increasing tree defoliation and mortality recently observed in several regions worldwide has been often attributed to the effects of increasing frequency of drought and heat stress**, but also

to biotic stressors [3,5,29,30,31]. However, **the role of concomitant changes in atmospheric deposition and drought remains underexplored**.

Different global change drivers could play a synergistic, antagonistic or predisposing role. All these drivers, however, are generally considered in isolation. Different research groups have extensively investigated the effects of droughts and atmospheric deposition on forests over recent decades. However, **they have been acting largely independently, by looking at the global change drivers separately with limited effort to merge knowledge and expertise**. Moreover, different approaches have been used, including manipulation experiments and observation along environmental gradients, within European or global monitoring networks. These different approaches, however, have sometimes yielded contradictory results. A case in point is atmospheric N deposition. The input of N to forests from the atmosphere can lead to a cascade of positive (increase in N availability, where N is 'too little') and negative (reduction in N retention by soil microbes and trees, with increase in loss pathways, when N is 'too much') effects, which eventually shift the balance between N accumulation and loss [32], with positive feedbacks to climate change, by enhancing nitrous oxide, N_2O, emission due to increasing nitrification and denitrification. Results from manipulation experiments, mostly in the form of soil amendment, suggest that i) soils are the main sink of atmospheric N [33] and that ii) an increase in N deposition leads to increase in N losses through nitrate leaching, N_2O gaseous losses and ammonia volatilization. However, these results have not been confirmed by either canopy N manipulation experiments [34,35] or long-term monitoring studies. On the contrary, the latter point to an oligotrophication in forest ecosystems, attributed in part to higher demand for N in a CO_2 richer world [16,36,37,38].

Finally, the attention of the research communities has been generally directed on natural or periurban forests, while **the ecological, climate mitigation and human well-being potentials of urban forests (UF) have been often overlooked**. A global analysis found elevated rates of Nr deposition in urban areas as compared to periurban sites, with the reduced forms of Nr contributing the most [39]. However, less than 30% of urban areas included in the analyses were in Europe and within those sites there was no consistency in the monitoring approach considered. It is clear that **a more robust and well-defined monitoring strategy is required to achieve a more systematic quantification of atmospheric deposition in urban systems and to better connect natural and UF across Europe**. Cities in Europe have been targeted as key areas to plant trees as a strategy to mitigate climate change and make citizens' life more sustainable. However, their potential to achieve this goal could be challenged by the environmental stress trees are exposed to, e.g. pollution, exacerbation of climate change (urban heat island effect), and drought. **Not accounting for this, could lead to an overestimation of the role of UF in contributing to climate change mitigation and adaptation.**

In summary, **the information available on the joint effects of extreme climate events and atmospheric deposition on forests is vast but uneven, un-coordinated and scattered among different research communities.** Little is known about interactions among individual drivers, and the potential effects of atmospheric deposition on the sensitivity of trees to drought, and their regionalisation or context dependent effects remain inadequately known [5,23]. Understanding how global change drivers interact and affect C, water and nutrient cycling is paramount for a holistic perspective on future forest function and climate mitigation potential, in NPU forests. **Progress on such a complex topic requires a transdisciplinary approach that integrates different communities, coordinates methodological approaches and harmonizes datasets**, so as to i) gain a more comprehensive understanding on how European forests are responding to global change, and identify hotspots, both in terms of monitoring required and overlooked processes; ii) synthesize the best knowledge we have for European forests, including UF, whose responses to global change are more directly connected to citizen health, and iii) to contribute to assessing impacts of global change drivers on forest ecosystem service delivery and to supporting forest managers and policies put in place to meet the ambitious goals within the EU Green Deal and the Paris Agreement.

1.1.2 DESCRIPTION OF THE CHALLENGE (MAIN AIM)

The ability of forests to mitigate climate change depends on how well they cope and adapt to more frequent climate extreme events and concomitant changes in C_a and atmospheric N-S deposition. **CLEANFOREST- Joint effects of CLimate Extremes and Atmospheric depositioN on European FORESTs - will address 3 scientific challenges, which call for a holistic perspective** (both in

terms of mechanistic processes, and expertise to study them) **of the atmosphere-biosphere interactions along the continuum natural-periruban-urban (NPU) forests in Europe**:

Challenge 1. Assessing spatio-temporal changes in global change drivers. Monitoring atmospheric N and S deposition and climate are often treated as separate actions. The Action aims to go beyond trends, integrating existing data and information on the observed and projected frequency and magnitude of climate extreme events. Moreover, it will evaluate climate tendencies with focus on hot extremes (including heatwaves) and droughts that are threatening the climate change mitigation potential of forests. Key questions are: **(Q1.1.)** Where are the hotspots in the European forests that show the largest increase of the frequency of hot extremes and droughts in the last decades? **(Q1.2)** Which are the main hotspots for atmospheric deposition? **(Q1.3.)** To what extent do these hotspots coincide, creating multi-factor hotspots of change? **(Q1.4.)** Is it possible to identify data gaps in the NPU forest continuum where intensive monitoring is necessary to mirror and/or complement existing networks? **(Q.1.5.)** Are there cost-effective-and easy to deploy-methodological approaches that can extend monitoring of atmospheric deposition in less represented regions and/or in urban areas?

Challenge 2. Interactions between global change drivers and forest ecosystems health and functioning. Recent pan-tropical and global analyses showed that the CO_2 fertilization effects on physiological and productivity metrics (e.g. WUE, tree growth and forest C uptake) have slowed down (or even decreased) over the recent decades [40,41] due to increasing moisture or nutrient limitations and/or to increases in tree mortality. Moreover, earlier studies in the 1980's identified acid deposition as the main driver of increasing tree mortality in Central Europe [42]. Two main hypotheses have been developed explaining tree mortality due to drought (carbon starvation and hydraulic failure, [43]), driving much research in this field since [43], but in these hypotheses neither nutrients nor air pollution is even mentioned. Lastly, all the above described processes (and hypotheses) have hardly been assessed (and tested) in UF. Thus, **despite the long history of assessing air pollution and drought effects on forests, we still lack a unifying framework to assess the interactions between extreme climate events and atmospheric deposition**. Key open questions are: **(Q2.1)** How do climate extremes and atmospheric N-S deposition interact and affect the response of European forests to increasing C_a? **(Q2.2)** Where does N and S deposition most strongly influence forest functioning, and how strong is their influence compared to other drivers such as forest management? **(Q2.3)** To what extent is atmospheric deposition mediating sensitivity to drought events and why? **(Q2.4)** Can we identify species and species assemblages that are more (or less) vulnerable to global change factors, in both natural and UF? **(Q2.5)** Are trees growing near the species' climatic tolerance more sensitive to global change components? **(Q2.6)** Are there management practices that can improve forest resistance and resilience to hot extremes, drought and air pollution?

Challenge 3. Interactions between global change drivers and tree and soil biogeochemical processes. The high levels of N deposition in Europe have resulted in N availability in forests beyond the amounts that can be utilized for tree growth (N saturation). There is evidence that in areas where forest growth is increasing due to climate warming, while N deposition has remained low, N limitation is exacerbated. In other areas, N promotion of growth is leading to deficiency of other nutrients, particularly potassium (K) and phosphorus (P). Additionally, nutrient availability is mediated by soil microbes, which in turn may also be affected by N deposition and frequent droughts. N saturated ecosystems have been associated with low microbial activity, organic matter decomposition and soil respiration, and with intensification of N loss pathways. Key open questions - which will be addressed along the NPU forests continuum - are: **(Q3.1)** Do forests become progressively N saturated, when moving across NPU forest gradients? **(Q3.2)** How does N deposition affect soil organic matter turnover and N availability, but also N loss through nitrate leaching and N_2O emissions? **(Q3.3)** How do soil microbes respond to N deposition and what are the consequences for biogeochemical processes? **(Q3.4)** Does high N availability result in deficiency of other essential nutrients, particularly P and K? **(Q3.5)** How does the interaction between climate extremes and N-S deposition affect soil biogeochemical processes and rhizosphere dynamics?

Addressing these challenges calls for a synergy among different disciplines (climate science, plant physiology, atmospheric dynamics, atmospheric chemistry, land-atmosphere exchange, soil science, forest ecology, forest management, urban ecology) **and methodological approaches** (estimates of ecosystem CO_2, water and N_2O fluxes, dendro-isotope analyses, quantification of atmospheric N and S deposition, characterization of soil nutrients and soil microbial communities) and experimental set-up (e.g. monitoring networks; nutrients and moisture manipulation experiments). Extensive work has been done within each discipline and topic listed in the Challenges, generating a

tremendous amount of data. What is missing, however, is an **international platform for interaction that ensures a FAIR and effective sharing of data and expertise across disciplines**, and that allows a critical **discussion on the most effective ways the different datasets can be integrated** and used to answer the key questions listed above. Such a platform should **integrate researchers from different disciplines, and foster exchange between researchers and stakeholders**, with particular reference to policymakers defining current and future forest monitoring, management, conservation and restoration strategies. While recent European policies tackle the urgent need of reducing CO_2 emissions, they mainly focus on one of the global change components, thus missing the complexity of the problem that we are facing in the context of global N cycle perturbation, and its implications for forest health, productivity and greenhouse gas emissions. This is partially due to the lack of effective communication between complementary scientific disciplines, and between academics and stakeholders. CLEANFOREST is a highly timely initiative because i) it can facilitate a data-based holistic assessment of the potential of European forests to mitigate climate change and air pollution (currently missing) and ii) it builds on the increasing awareness of policymakers and general public on the central role of forests to ensure a sustainable and healthy life.

1.2 PROGRESS BEYOND THE STATE-OF-THE-ART

1.2.1 APPROACH TO THE CHALLENGE AND PROGRESS BEYOND THE STATE-OF-THE-ART

The multi-faceted nature of global change makes it particularly difficult to understand the response of ecosystems as well as the underlying mechanisms. This is particularly true in the case of forests, which (i) are more exposed to global change due to their long life cycles and (ii) are buffered in the short term by internal feedback, responding only slowly to perturbations. The analysis is further hindered by several methodological problems, fragmented information and different time scale or spatial coverage data are available for, particularly in the case of UF. **This fragmentation can only be overcome by a concerted effort, so as to stimulate scientific exchange among communities working with different approaches along the NPU forests continuum, nudging them to integrate from the start. This will promote and ensure that robust methods addressing issues of forests under global change are adopted at large scale, and that policies are underpinned by robust science.** Different research communities have addressed in isolation the effects of drought and atmospheric deposition on soil functions, tree growth and mortality. Moreover, each driver has been studied using a variety of experimental approaches (manipulative studies, observational networks, along environmental gradients) and methods (e.g. retrospective dendroecological, inventory data, or ecosystem flux analyses), with limited or no planned integration. Different metrics (e.g. annual ring widths, diameter increments, tree mortality, ecosystem C and N fluxes, soil acidity, soil solution chemistry, soil greenhouse gas emissions), variable definitions (e.g. tree and ecosystem WUE, gross vs. net growth increments and productivity, mortality by tree number, volume or canopy area, soil C, N, P and cations stocks), experimental approaches (e.g. manipulation experiments and observational studies across environmental gradients), techniques (e.g. dendrochronology, stable isotopes, eddy covariance, dendrometry) and technologies (air quality monitoring from global - through remote sensing - to point measurements, by using different instruments) have been used, with sparse efforts at coordination and standardization, creating significant barriers to the comparison of results *ex-post* but also to effective dissemination of results to broader audiences. **CLEANFOREST will bring together different scientific communities working on the effects of individual drivers** (drought and climate extremes, atmospheric deposition, elevated C_a) **on forest health and functioning, tree mortality and soil biogeochemical processes**. Moreover, it will **foster synergies among different expertise, so as to compare methodological approaches, define common protocols, standardize measurements and methods used in global change studies**, reducing the need for ex-post harmonization. Core components of this effort will be the ICOS and ICP Forests networks, the International Tree-Ring Data Bank (for their high temporal resolution) and inventory data (for the high spatial resolution), and finally, established CO_2 fumigation, moisture and N manipulation experiments. Finally, separate communities have typically focused on NP forests and UF, with N and S deposition issues most commonly addressed in the former case. CLEANFOREST has the ambition to **foster collaborations between communities working on NP and UF, comparing monitoring methods (both from remote sensing and point measurements within monitoring networks)**, **and combining available data**, while **identifying what (and where) is still missing and how we can fill the knowledge and methodological gaps.** This will only be possible thanks to a collaborative effort and experience exchanges between well-established monitoring networks of natural forests and the still fragmented communities focusing on UF, but also actors involved in technological development

(e.g. building instruments for environmental monitoring), citizen networks and policymakers (data end-users). Such a **harmonized network of scientists and stakeholders, methodological approaches and databases will answer important ecological questions on soil and forest responses to global change, thus contributing to advancing scientific knowledge and to fulfilling the need of data (and evidence)-based solutions to policy and societal challenges**. Finally, experience exchanges within the network of manipulation experiments and the monitoring community will provide crucial information to define the next generation manipulation experiments (both in terms of facilities and novel methodological approaches) and monitoring solutions to develop future collaborative projects.

1.2.2 OBJECTIVES

1.2.2.1 Research Coordination Objectives

CLEANFOREST will bring together scientists actively involved in long-term monitoring networks and manipulation experiments established across Europe (and beyond), to develop a comprehensive understanding on the interactive effects of key global change drivers on forest ecosystems functioning and health and on their climate and air pollution mitigation potential - one of the cornerstones in the European Green Deal strategic plan. The specific and measurable coordination objectives of the Action are:

1. **To review i) existing monitoring networks** across the continuum NPU forests in Europe, and **ii) manipulative studies,** including moisture manipulation (precipitation additions/exclusion, modification in air relative humidity), N additions (alone or in combination with other nutrients) and elevated C_a.

2. **To coordinate the data collection and data curation** (metadata and numerical) into a common database so as to **develop a harmonized dataset of tree and forest ecosystem responses to global change drivers**. These cannot be achieved without coordination and cooperation among participants coming from different research communities, due to practical issues, such as database availability and interpretation. The database will integrate (but will not be limited to) 1) environmental (climate and atmospheric deposition), 2) ecosystem (eddy covariance data) and tree based (growth, tree ring isotope-derived WUE) and 3) soil (e.g moisture, temperature, nutrient concentrations, soil solution, mineralization, foliar and soil N isotope compositions, soil microbial diversity) parameters to link processes at vertical (atmosphere-forest-soil) and spatial scales (NPU forests, manipulation experiments).

3. **To compare and assess performance of different methodologies**, and to develop measurement protocols (for *ex-ante* standardization), which will make measurements comparable across different sites. This will include - but it will not be limited to - reviewing different approaches used to estimate atmospheric deposition from point measurement to remote sensing and modelling approaches (e.g. ion exchange resins vs. bulk and throughfall collectors, quantification of dry N deposition, different instruments/approaches to measure atmospheric pollutants, with focus on Nr and S compounds, and gross N cycling processes in soils), comparing methods used for rural compared to urban monitoring, identifying existing low-cost instruments for environmental monitoring developed by small companies).

4. **To review and compare theories developed in different research fields**, with particular reference to the integration of atmospheric deposition in the drought induced tree mortality framework, and the forest N limitation induced by CO_2 fertilization effects and/or drought. In particular, CLEANFOREST will be testing and amending the recent hypothesis [22] on different interactions between drought and nutrients related to predisposition, impacts during drought and recovery.

5. **To foster collaboration across Europe and beyond**, **and to promote the dissemination** of results during the whole Action either to scientific communities that can benefit from them or stakeholders, through a range of activities and deliverables (ref. sections 3 and 4).

1.2.2.2 Capacity-building Objectives

The multidisciplinary challenges within CLEANFOREST can only be addressed by building a highly diverse Network, which brings together investigators with different backgrounds (spanning from plant physiology, ecosystem fluxes, climate and soil science, dendroecology, stable isotopes, atmospheric

chemistry, and forest management) as well as different stakeholders (ref. section 2.2.2). Each participant, through the Action networking tools, will bring their specific background and expertise and will contribute to the development of skills and abilities of the Network as a whole. The specific capacity-buildings objectives are:

1. **To favour synergies among communities working on different aspects of global change** along the NPU forests continuum (in particular extreme climate events, atmospheric deposition and forest and soil health and functioning) to achieve breakthroughs that require an interdisciplinary approach.

2. **To foster exchanges among research communities using different methodological approaches**, and dealing with different datasets, thus integrating technological development, expertise and know-how and support research groups where such approaches are missing (e.g. sites not included in monitoring networks or urban ecosystems).

3. **To promote the development of a joint research agenda on global change impacts**, combining from the start different experimental and methodological approaches (manipulative studies, observational networks, retrospective studies) and research communities (climate impacts vs. atmospheric deposition impacts, semi-natural vs. urban ecosystems). CLEANFOREST will provide crucial information for the next-generation monitoring and experimental manipulations to address the interactive effects of global change drivers on forests. Such an experimental framework should not be carried out independently by a single research group but by a network of researchers in different countries - a network that could find its infancy through CLEANFOREST.

4. **To provide high-quality and interdisciplinary training** to i) Early Career Investigators, ECI (12 of the 95 participants), but also to ii) researchers at their transitional stage of their career, giving emphasis to those from Inclusiveness Target Countries (ITCs), who might lack other means to take part in such an experience. Training, both hands-on and theoretical, will aim at enhancing technical skills on data collection in the field, organization and analyses of big data, at developing critical thinking and at improving communication skills and leadership.

5. **To ensure inclusiveness and gender equality**. The Network at the moment of submission includes 53% of ITCs and 35% of participants are women. Active participation of women in coordinating WGs or specific tasks within them will be encouraged to support their leadership. Anonymous questionnaires will be carried out during the Action to check whether inclusiveness and gender equality are ensured.

6. **To define the most relevant research gaps**, suitable for **more budget orientated EU research schemes** (Horizon Europe, Life programme etc.), and to lay down the basis for a scientific network of collaboration to address them. This will be a crucial objective, which relies on the interactions among research communities from different regions and expertise and at different stages of career development, which can only be achieved thanks to networking facilitated by CLEANFOREST.

2 NETWORKING EXCELLENCE

2.1 ADDED VALUE OF NETWORKING IN S&T EXCELLENCE

2.1.1 ADDED VALUE IN RELATION TO EXISTING EFFORTS AT EUROPEAN AND/OR INTERNATIONAL LEVEL

CLEANFOREST will complement and foster synergies with active COST Actions (3DForEcoTech, prmoting novel terrestrial-based technologies in forest monitoring; UB3Guard focusing on alien pest stressors on UF health; SENSECO, focusing on processing remote sensing data related to plant physiology and productivity; WATSON taking a novel approach based on stable isotopes to better understand water exchange processes in the critical zone; FIRELINKS empowering synergistic collaborations between European research groups and stakeholders involved in forest fire and land management), existing European projects (ENVRI, a community of environmental Research infrastructures in Europe working together to provide environmental data that are Open and FAIR; RESONATE aiming at supporting decision-making to enhance resilience of forests and forest value chains to climate change; Life +Respira related to sustainable mobility in cities; CLEARINGHOUSE, a

Pan-European initiative proposing UF as nature-based solutions). CLEANFOREST will take advantage of **existing long-term monitoring networks** (and hence data already available over the last decades) **in Europe and worldwide**. Key monitoring efforts in Europe are: The International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests **(ICP Forests**), a transnational forest monitoring and research network under the UN Economic Commission for Europe (UNECE) Convention on Long-range Transboundary Air Pollution (Air Convention, formerly LRTAP). Launched in 1985, ICP Forests collects quantitative policy-relevant information on air pollution and climate change effects on forests via systematic large-scale monitoring ('Level I', ca, 6000 plots) and intensive monitoring at permanent, highly instrumented plots ('Level II', 100-800 plots), using highly harmonized and quality-assured methods. The Integrated Carbon Observation System (**ICOS**), a Pan-European research infrastructure, which provides harmonized and high-precision scientific data on carbon cycle and greenhouse gas budget and perturbations. The co-operative programme for monitoring and evaluation of the long-range transmission of air pollutants in Europe (**EMEP**), a scientifically based and policy driven programme under the LRTAP Convention involved in emission data collection and modelling of atmospheric transport and deposition of Nr and other pollutants. The **CAMERMED**, a network bringing together scientists addressing air pollution impacts on Mediterranean ecosystems, and created as a chapter of the UK Committee on Air Pollution Effects Research (CAPER). **AnaEE**, **Infrastructure for Analysis and Experimentation on Ecosystems,** providing researchers with distributed and coordinated set of experimental, analytical and modelling facilities in ecosystem science, agriculture and forestry in Europe. **Copernicus,** the European system for Earth monitoring. Two initiatives will be relevant for the Action: **Copernicus Climate Change Service**, and the **Regional air quality production systems**. **CLEANFOREST for the first time will foster data and knowledge exchanges among these communities so as to gain a more comprehensive understanding on responses of European forests to global change drivers.** Existing international monitoring network that CLEANFOREST can benefit, but can also contribute to are: **FLUXNET**, a global network of flux tower sites using eddy covariance methods to measure CO_2, water vapour, and energy exchanges between terrestrial ecosystems and the atmosphere, as well as micrometeorological parameters. **LTER**, a worldwide research and monitoring network, which seeks to improve knowledge of the structure and functions of ecosystems and their long-term response to environmental, societal and economic drivers. **GlobalSMEAR (**developed in Finland, but expanded in Estonia and China), a platform providing continuous, comprehensive environmental information, such as greenhouse gas fluxes, trace gases in the land ecosystem–atmosphere continuum on different terrestrial and aquatic ecosystems. **The International Tree Mortality Network** (launched in 2019 as an initiative of the IUFRO task force on tree mortality) seeks to facilitate collaboration between scientists to combine expertise, knowledge and data, thereby allowing a global assessment of tree mortality. **NEON**, The National Ecological Observatory Network**,** a continental-scale research platform in the USA, funded by the National Science Foundation, which gathers long-term, standardized data on ecological responses of the biosphere to land use and climate changes. **CLEANFOREST** will leverage **existing international networks on precipitation removal or addition manipulation experiments (DroughtNet) as well as recently established and novel experiments manipulating air relative humidity**. Several N fertilization experiments - including soil N (SNE) and canopy N (CNE) manipulation experiments - have been established in different forest ecosystems worldwide: e.g. China (CNE + SNE), Europe (Italy and Spain, both CNE and SNE, French Guiana (SNE)), UK (SNE), Costa Rica (SNE), USA (CNE and SNE), Brazil (SNE). A**ll these experiments are uncoordinated, thus CLEANFOREST will create a global network of nutrient manipulation experiments in forest ecosystems to quantify the impact of global change drivers on forests within a coordinated research efforts,** complementing the network established for grassland ecosystems (NutNet). Last, but not least, objectives set within **CLEANFOREST match goals 11**, **13** and **15** of the **2030 Agenda for SDGs**, and they meet the European research strategies within the Green Deal and the Horizon Europe programme (Pillar II, cluster 6).

2.2 ADDED VALUE OF NETWORKING IN IMPACT

2.2.1 SECURING THE CRITICAL MASS AND EXPERTISE

Establishment of a concerted network of European scientists, operating at the cutting edge of climate change, air pollution, and forest and soil response and mitigation potential will be of unique added value to CLEANFOREST. To date, **no such formal network exists**, as different research groups have been working on these topics largely acting independently. **Without bringing together the**

different research communities and taking a holistic view on responses of forests to global change drivers, **there is a real danger of fundamentally mis-assessing the future trajectory of Europe's forests. CLEANFOREST has the ambition to create such a multidisciplinary network, which capitalizes on existing expertise and infrastructures available in Europe,** to coordinate efforts and foster exchange of information and collaborations among different research communities and relevant stakeholders (ref. section 2.2.2), all unified by the overarching goal of building a sustainable future by adopting science-based policy and actionable solution. Another strengths of CLEANFOREST is the participation of investigators actively involved in - and contributing to - key monitoring networks (ICP Forests, ICOS, LTER) or leading manipulation experiments in forest ecosystems, which will provide CLEANFOREST with detailed understanding on the facilities, data availability, technical need and scientific evaluations to be used in critical reviews and protocols development. **The network will function as a cohesive unit to direct research and practical guidance in the areas of climate extreme, air pollution, forest health, soil functions, forest monitoring, identifying funding sources and engaging in collaborative research to derive maximum benefit from this forest and environmental science key areas**. The Action will function in a "pump-priming" capacity to bring together researchers from throughout Europe (and beyond), thus fostering collaborative research and advancing knowledge and scientific boundaries. Participation of scientists from Northern and Eastern Europe has been particularly encouraged, given challenges they are facing, e.g. more frequent and extreme climate events and recovery from high N and S deposition, respectively. Such collaborations will result in enhanced research funding for Action participants, add value to regional investment in science through pan-European collaborations, and generate scientifically underpinned European guidelines, criteria and indicators for robust forest monitoring, practice and policy, in addition to scientific results and publications. **The already large original network of proposers** (95 participants from 28 Full Member Countries, affiliated to Higher Education & Associated Organisations (71.6%), Government/Intergovernmental Organisations (21.1%), Business enterprise (5.3%) and NGO (2.1%)) **will expand during the Action's life** by inviting more participants, particularly from Countries not included in the Network yet and/or stakeholders.

2.2.2 INVOLVEMENT OF STAKEHOLDERS

Stakeholders that CLEANFOREST will engage with are environmental agencies or governmental bodies (at the local, regional, national, and international levels) related to forest management and protection, forest practitioners, local and national decision-makers, national parks, municipalities and regional councils, local citizen networks, urban planners, companies involved in environment monitoring, association involved in science communication. Challenges and objectives set within CLEANFOREST are relevant for several institutions at the interface between research and policy makers such as the European Forest Institute (**EFI**), the **Working Group on Effects** under the UNECE Air Convention, **International Nitrogen Initiative-Europe**, and other European (e.g. **EEA, IEEP**) or international (**FAO**) organizations. Key stakeholders playing a crucial role in promoting urban transformations and in addressing societal, environment and technological urban challenges are: existing European city networks, with the crucial participation of policymakers (e.g. **Eurocities, Urban agenda for EU**) and citizen (**European Citizen Science Association**), as well as small enterprises related to urban planning or the development and/or implementation of low-cost effective sensors for monitoring. From monitoring to policy, **CLEANFOREST will reduce the communication gap between data producers (scientists) and the identified stakeholders (data users)** by inviting them to participate in workshops and WGs meeting from the beginning of the Action, to frame discussions and activities around real needs. Moreover, they will be actively involved in the organization of Workshops for policymakers and of Training School on air quality monitoring, where participation of small companies and citizen science association involved in environmental monitoring will be crucial. This will have a mutual benefit: on the one hand, the Action will produce a 'user friendly' dataset that can be used by stakeholders and translate key scientific findings into tangible and actionable solutions that guide policy and tackle societal and technological challenges within the European Green Deal and the UN SDGs, as well as National strategies. On the other hand, the exchange will provide scientists with indications on which direction to follow in the next generation experiments and monitoring networks to fill data gaps identified by stakeholders. Representatives of some of the above institutions/association are already in the Network, thus contributing to facilitating the involvement of – and synergies with - other stakeholders during the Action's life.

2.2.3 MUTUAL BENEFITS OF THE INVOLVEMENT OF SECONDARY PROPOSERS FROM NEAR NEIGHBOUR OR INTERNATIONAL PARTNER COUNTRIES OR INTERNATIONAL ORGANISATIONS

Challenges that the Action tackles are relevant not only at the European scale, but also internationally. CLEANFOREST will be a great opportunity to bridge European research communities with scientists based in International Partner Countries (IPCs) who have significantly contributed to advancing our knowledge on the mechanisms underpinning forest responses to global change. CLEANFOREST will benefit from the participation of the leading scientist (based in the USA) developing the conceptual framework of tree mortality in relation to drought, and of scientists in the USA, Costa Rica and China, who have made significant contributions in the field of dendroecology, ecosystem carbon and N fluxes in natural and UF, some of them also leading N and precipitation manipulation experiments. Though at this stage there are no participants from Near Neighbour Countries (NNCs), their involvement in the COST Action will be encouraged, with particular reference to collaborators from Northern Africa, so as to to gain a comprehensive understanding of forest responses to global change drivers for the whole Mediterranean basin. The participation of collaborators in IPC and NNCs will be facilitated by the hybrid management system of the Action, which will have both virtual and in presence activities. However, their participation as invited speakers in Training schools and Workshops will be crucial for scientific and technological transfer, particularly for ECI.

3 IMPACT

3.1 IMPACT TO SCIENCE, SOCIETY AND COMPETITIVENESS, AND POTENTIAL FOR INNOVATION/BREAK-THROUGHS

3.1.1 SCIENTIFIC, TECHNOLOGICAL, AND/OR SOCIOECONOMIC IMPACTS (INCLUDING POTENTIAL INNOVATIONS AND/OR BREAKTHROUGHS)

This COST action will synthesise research and methodological knowledge from experts in the field of atmospheric chemistry, meteorology, climatology, forest ecology, forestry and biogeochemistry, which is vital for determining effective future environmental and forest monitoring. Critical reviews and meta-analysis of such current scientific evidence will guide and underpin practical and political decisions on the expansion and management of future treescapes (e.g. NPU forests) in view of their resilience to climate change and atmospheric deposition perturbations. Information and datasets from CLEANFOREST will be crucial for other research communities (e.g. modellers and those working with remote sensing data or focusing on effects of biotic stressors on forest health), which be invited to join CLEANFOREST Network, to facilitate the integration of data and knowledge, and to identify data gaps. A research network integrating observations, experiments and models for a better understanding of nutrient cycling in terrestrial ecosystems has been recently established in the USA. **A similar effort is currently missing in Europe, thus CLEANFOREST is timing in contributing to filling this gap by developing a novel platform where scientists and stakeholders take a proactive approach to enhancing European capacity building and competitiveness.** The identification of knowledge gaps and research priorities will determine the current and future research needs in the area of global change impacts on European forests. Development of common harmonised European guidelines and methodological/experimental manuals and protocols will contribute to the development of suitable and cost-effective verification systems for evaluating the impacts of future climate and air pollution changes on European forest health. Several citizen science projects have been created in big cities across Europe to monitor air quality by using low-cost and easy to handle instruments**. CLEANFOREST will bring together all these bottom-up initiatives to promote a coherent and standardized monitoring approach across Europe, based on common protocols and instruments, so as to be able to extend it also in regions where monitoring is lacking.** Some citizen associations and companies developing cost-effective and easy to handle instruments used to monitor air quality and tree physiological parameters are already included in the network, and more will be invited to participate, to guide the new technology to meet future research and policy needs. Last but not least, CLEANFOREST **will lead the effort of building a global network of nutrient manipulation experiments in forest ecosystems in different biomes** - the only existing network includes only grassland ecosystems (NutNet). Consolidating existing networks (Droughtnet) and creating new ones can only be achieved thanks to the involvement in the COST

Action of collaborators from IPCs so to create a global platform where to exchange data and expertise, to advance knowledge on topics that will define future research directions and priorities.

3.2 MEASURES TO MAXIMISE IMPACT

3.2.1 KNOWLEDGE CREATION, TRANSFER OF KNOWLEDGE AND CAREER DEVELOPMENT

CLEANFOREST will respect an appropriate gender balance in all its activities and this will be a standard item on all the Management Committee agendas. Priority will be given to the active participation of women (35% of the participants) in the work program (WG) of the Action, when deciding on WG composition and task coordination. The Action will also be committed to considerably involve ECI (currently 12 of 95 participants, but more will be invited to join later), which will be achieved by promoting their participation in STSMs, in specific activities within each WG (e.g. in state-of-the-art reviews, data mining and analyses, scientific publications, organization of monthly series of one-hour virtual Symposia), and by organizing high quality and multidisciplinary Training Schools for PhD students and ECI. Specifically, CLEANFOREST will organize **5 different Training schools**, 3 of them will be **science-focused and will provide hands-on and theoretical background on processes investigated** (and **methodological approaches used**) **at monitoring and experimental manipulation sites**. Specific stakeholders involved in environmental monitoring and collaborators from IPC will also be invited as speakers so as to provide already to participants a multidisciplinary view of tacked issues and approaches they could use in their research. The other 2 TS will focus on: **Data science**, including big data mining and statistical analyses, data visualization in both scientific and outreach publications; **Open and inclusive science**, covering FAIR principles and open access for data sharing and science communication, as well as how to promote gender equality, diversity and inclusiveness in science. The latter two Training Schools will benefit researchers at any stage of their career (including senior scientists, which have the crucial role of mentoring ECI and next generation of scientists). Different stakeholders will also be invited so as they can be fully aware of the steps following data collection and interpretation, thus facilitating evidence-based decision and policy. Exchanges among participants and progress on the challenges of the COST Action will be achieved through a set of target activities: monthly virtual (through online platforms) WG and across WGs meetings and workshops, while annual WG meetings will be scheduled, when possible, in combination with other meetings/conferences to ensure wide participation and to reduce the environmental footprint. Workshops are a more effective way of bringing together participants and working on specific tasks (data mining, discussions on data analyses, exchange between scientists and stakeholders in the Network, producing first drafts of papers or reports) to achieve the set goals. Moreover, they are where deep discussions on specific topics will happen, thus contributing to generating new insights and ideas particularly for ECI, which will lead to projects for individual fellowships (Marie Skłodowska-Curie Action and ERC programs). Geographical balance will be ensured when deciding the location where Training School and Workshops will be organized. **Short-Term Scientific Missions** (STSMs) allowing participants, particularly ECI and PhD students, visit member institutions within the network, including those working at the interface between science and policy, to identify research gaps, policy needs, to cover specific tasks (data mining, creation of datasets, meta-analyses – ref. section 4.1.1.), and to foster knowledge exchange. Finally, two Conferences will be organized (on the second and the last years), where the Action and its progress or final results will be presented to a broader research and stakeholder communities.

3.2.2 PLAN FOR DISSEMINATION AND/OR EXPLOITATION AND DIALOGUE WITH THE GENERAL PUBLIC OR POLICY

CLEANFOREST strategic plan for dissemination includes several activities that all WGs will contribute to, directed to (1) Scientific communities and (2) Stakeholders. In the case of (1) CLEANFOREST will lead to i) scientific papers collecting main results from meta-analyses from each WGs (target journals: Forest Ecology and Management, STOTEN, Global Change Biology, European Journal of soil science, New Phytologist); ii) a final paper (targeting a high profile interdisciplinary journal, e.g. PNAS or within the Nature family), which will look at the holistic view of the global change drivers and forest ecosystem health; ii) a Special issue including case studies from Member Countries addressing the three Challenges (target journal could be Frontiers in Forests and Global Change). Participation of ECI as lead authors will be encouraged, to present results from the STSMs; iv) participation at multidisciplinary (e.g. European Geosciences Union) or more specialized conferences (e.g. organized

by ICP Forests, British Ecological Society, Eurodendro), but also international conferences (e.g. Ecological Society of America, Fluxnet) to disseminate results from CLEANFOREST to European scientific communities and beyond. Conference grants will be designated to ECI and PhD students, particularly from ITC, so as to encourage their participation to conference and presentation of results from their activities within CLEANFORST; v) a database visualisation in an online interactive map/tool to easily identify different sites where active monitoring has been carried out, what data is available and how to access it across the different forest types (natural, periurban, urban). The map will also include manipulation experiments active in Europe; vi) Dataset used in meta-analyses (see section 4). In the case of (2), activities planned are: i) Creation of corporate design logo (to clearly identify the COST Action) and a webpage where to share news on CLEANFOREST, activities going on (including advertisement of STSMs, Training Schools, Workshops), and main outputs during the life cycle of the COST Action, blog, researcher spotlight through short video interview (e.g. 'The researcher of the month' - ECI and women in science will be particularly encouraged to participate), audio-visuals showing the importance of forests under global change (target audience: All); ii) Creation of Twitter, Instagram and Facebook accounts, which will help to share continuous updates and to reach a broad audience and also to connect with other research communities and stakeholders, by using specific hashtags (target audience: All); iii) Educational materials, either a Special issue or a textbook, which will be realized in collaboration with an European journal on education, e.g. Science in School (target audience: secondary school/college). This output will be an important resource where teachers and students can get data-based science, thus inspiring the future generation of scientists and encouraging girls in STEM; iv) 'Open day' events at monitoring and manipulation sites, i.e., satellite events, carried out within each participating Member Country and short videos would be produced to share on the webpage (target audience: local policymakers, citizen, schools); v) a stakeholder/policy workshop event at the beginning (to learn from them what are their needs and priorities) and end of the Action (to report on these), which will lead to white papers and final executive reports (target audience: policy makers, specialized professional communities operating in urban planning, forest management, companies developing instruments for environmental monitoring); vi) Dissemination within the European Research Night events at Full Member Countries participating to CLEANFOREST (target audience: general public, journalists, local policymakers); vii) Final outreach event - a TED like event, where both scientists and key stakeholders will give talks - to be carried out in one of the COST Member Countries and during the final Conference of the Action (target audience: general public, journalists, policy makers).

4 IMPLEMENTATION

4.1 COHERENCE AND EFFECTIVENESS OF THE WORK PLAN

4.1.1 DESCRIPTION OF WORKING GROUPS, TASKS AND ACTIVITIES

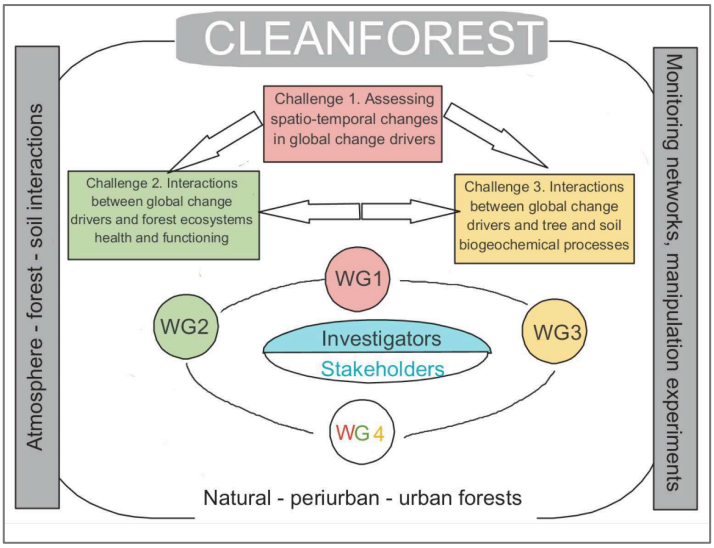


Figure 1 Overview of CLEANFOREST

CLEANFOREST is organized in **4 WGs (Figure 1) addressing the three Challenges vertically (from the atmospheric components of the global change drivers down to tree and soil in forest ecosystems) and horizontally (along the continuum NPU forests).** WG1 will provide a comprehensive overview of where and how global change drivers have changed over the last decades in Europe. The dataset produced will be crucial to achieve objectives within WG2 and WG3, exploring the effects of global change drivers on trees and soil processes. Finally, WG4 will review existing manipulation experiments and monitoring networks (in collaborations with WGs 2-3), to identify limitations and knowledge gaps that can be overcome with future transdisciplinary and

international research initiatives. The management of each WG will be coordinated by a core team composed by the WG leader and vice-leader, and 6 participants (including ECI), which will provide support with organization of different tasks and dissemination (including the monthly Symposia). **Stakeholders will be involved in all the activities planned within each WG, to ensure a participative process in achieving the Action goals and deliverables.** Specific Tasks (TSK) and Milestones (MLS) are described below, in relation to Objectives (OBJ) and the questions (Q) listed in section 1.1.2, except for WG4, which shares questions identified across all WGs.

WG1. Assessing spatio-temporal changes in global change drivers. OBJ1.1. Identify and merge datasets available for atmospheric N and S deposition and different approaches used across different monitoring networks (ICP Forests, EMEP, EAA, Ecosystem monitoring network of NEC Directive, and Copernicus) and local citizen science initiatives (e.g. in cities) (Q1.1-1.5). **OBJ1.2.** Define extreme climate events (focus on hot extremes and droughts) and harmonize datasets to assess their frequency and severity across Europe by using meteorological data from the sites identified in the OBJ1.1 and by the other WGs. **OBJ1.3.** Identify spatial hotspots for global change drivers across Europe (Q.1.1-1.2). **TSK1.1.** Literature review on atmospheric deposition and extreme events in Europe including reports of existing monitoring networks and from previous projects (e.g. NITROEUROPE). **TSK1.2.** Review of current methodologies used for atmospheric deposition monitoring, to identify gaps and where technological development should focus on, to come up with cost-effective and easy methods for large scale and standardized environmental monitoring. **TSK1.3.** Climate extremes and atmospheric deposition data collection from different sources (published papers and existing networks). **TSK1.4.** Development of a database of hotspots of global changes drivers related to climate and atmospheric deposition. **TSK1.5.** Data analysis and synthesis reports on major findings. **MLS1.1.** Monthly WG (hybrid) meetings and STSMs to define datasets, data sources, variables, spatial and temporal scale of the analyses. **MLS1.2.** Creation of the database. **MLS1.3.** Workshops on ecosystem monitoring with focus on characterization of climate extremes and atmospheric pollution and deposition. **MLS1.4.** Training School on air quality and deposition monitoring, open also to companies involved in technological development of sensors and citizen networks for air-quality monitoring in cities. **MLS1.5.** Final presentation of results from the WG.

WG2: Interactions between global change drivers and forest ecosystems health and functioning. OBJ2.1. Data mining (tree-ring isotopes, tree health, inventory tree growth and mortality, ecosystem fluxes) to investigate how climate extremes and atmospheric deposition interact and affect the response of European forests to increasing C_a (Q.2.1-2.6). **OBJ2.2.** Identification of more vulnerable tree species and forests to global change factors (Q2.4-2.5). **OBJ2.3.** Testing the tree mortality framework recently proposed [22], by including long-term nutrient deposition/availability and uptake in mortality assessments (Q.2.3-2.4-2.5). **TSK2.1.** Develop a meta-database detailing the contents and structure of available databases covering the categories listed in OBJ2.1. Identify an appropriate basket of metrics relating to tree species and forest responses to climatic and environmental pressures, which can be consistently derived and combined from these databases. In coordination with WG1, compile data from N deposition and climatic trends covering the spatial and temporal extent of the databases for tree and forest variables. **TSK2.2** Development of a database (including both data from published studies, reports from previous projects and unpublished data from participants to the Action) of the metrics identified in TSK2.1. Combine this database with geographically explicit climatic and environmental data. **TSK2.3** Analyses of growth, WUE and mortality trends across climatic and deposition gradients in Europe using the database from TSK1.4 and 2.1 to identify species and locations with highest vulnerability to global change (OBJ2.2). Review of research in abiotic and biotic predisposition factors undermining tree and soil health (including pests and disease). **TSK2.4.** Drawing on the database from TSK2.1 and species-specific knowledge from Task 2.2, carry out data analyses to assess OBJ2.3, including i) variations of tree and ecosystem WUE across environmental and/or atmospheric deposition gradients; ii) tree growth (including growth resistance, recovery and resilience) and mortality as affected by heat, drought and atmospheric deposition. **MLS2.1.** Monthly WG (hybrid) meetings and workshops to identify appropriate datasets and metrics. Prior to this workshop, the participants of the WG will compile relevant databases within their geographical area and research field relevant to OBJ2.1. **MLS2.2.** Development of methodology to generate metrics from the identified datasets and create associated code infrastructure through dedicated STSMs. **MLS2.3.** Dataset compiled and made available through Internet portal. **MLS2.4.** Workshop and follow-up STSMs to make analyses for TSK2.3 and TSK2.4. **MLS2.5.** Training School for PhD students and ECI to gain experience on methodological approaches to monitor forest ecophysiological parameters, which will consist of a hand-on exercise where participants will work with

the databases compiled in TSK2.1-2.2 and will be taught by participants of this COST Action and experts in the field. **MLS2.6.** Open days at monitoring sites for local communities, schools, environmental agencies and institutions to learn how forests are monitored and why it is important. **MLS2.7** Final presentation of results from the WG.

WG3: Interactions between global change drivers and tree and soil biogeochemical processes. OBJ3.1. Assess the effects of atmospheric deposition and climate extremes on soil organic matter pools and subsequent N storage and cycling in soils and trees, and consequently assess N limitation and saturation in European forests (Q3.1-3.5). **OBJ3.2.** Quantify the interactive effects of N and climate extremes on forest C balance and allocation (above and belowground), soil C inputs and flows and soil GHG fluxes (Q.3.2-.3.3). **OBJ3.3.** Evaluate the role of aboveground biodiversity (tree diversity and identity) and belowground biodiversity response to N depositions and climate extremes, as potential mitigation measures (Q3.3-3.5). **TSK3.1.** To review the effects of N deposition and climate extremes on the turnover of soil organic matter and N mineralization in forest soils, within the context in changes of soil physical (temperature, moisture, density), chemical (acidity, leaching, nutrients, GHG fluxes) biological (soil macro and microorganisms) functions and forest nutrient balance. **TSK3.2.** Review and collect data to underpin metadata review analysis of the climate extremes and N-S deposition and acidification recovery on forest (above and belowground) C allocation and stability. **TSK3.3.** To review and collect data to understand the tree species, forest type and soil types climate and N mitigation potential with relevance to the European Critical loads of N deposition **MLS3.1.** Monthly WG (hybrid) meetings and workshops to collate data from peer-reviewed literature, official reports, long term monitoring networks annual reports, grey literature and unpublished data from participants on impacts of N deposition and climate extremes on soils and forest C and nutrient cycling and availability. 2 Workshops for policymakers (synergies with WG2, ref. section 3.2.2). **MLS3.2.** Development of a protocol to harmonise soil data across monitoring sites in Europe; **MLS3.3.** Dataset compiled and made available. **MLS3.4.** STSMs to work on data analyses across deposition and tree diversity gradients. **MLS3.5.** Training School on Data science. **MLS3.6.** Final presentation of results from the WG.

WG4: Next generation manipulation experiments and monitoring network. OBJ4.1. Reviewing existing manipulation experiments and gathering existing monitoring networks (synergy with WG1) in Europe and worldwide. **OBJ4.2.** Summarizing main results on the effects of treatments applied (experiments) or observed deposition level (monitoring) on eco-physiological parameters, health, growth and diversity of forests, as well as on biogeochemical processes (synergy with WGs2-3). **OBJ4.3.** Identifying methodological limitations and/or unanswered questions. **TSK4.1.** Review the 'State of the art' of manipulation experiments in forest ecosystems (focusing on moisture, nutrients and CO_2 fumigation) and of monitoring schemes considering atmospheric deposition and environmental drivers. **TSK4.2.** Compile a synthesis of published results obtained from manipulation experiments and monitoring. **TSK4.3.** Review experimental and monitoring methodologies adopted so far to detect and quantify the effects of deposition, moisture and interaction on ecophysiological parameters, health, growth and diversity of forests, as well as on biogeochemical processes. **MLS4.1.** Monthly WG (hybrid) meetings and workshops to review manipulation experiments and evaluate the identified network from WG1. **MLS4.2.** Development of a dataset including response of main ecological and physiological parameters to the treatments applied**. MLS4.3.** Two Training Schools, i.e., one to be carried out at one of the existing manipulation experiments in Europe, to provide hands-on and theoretical understanding on processes investigated and methodological approaches considered, and the second one on Open Science. **MLS4.4.** STSMs to review data at the experimental sites for meta-analysis**. MLS4.5.** Open day for local communities, schools, environmental agencies and institutions to get to know what a manipulation experiment is. **MLS4.6.** Final presentation of the WG.

4.1.2 DESCRIPTION OF DELIVERABLES AND TIMEFRAME

Comprehensive Deliverables (DLV) across WGs. DLV1 (from the beginning of the Action, FBA): Website with free access to scientific and technical products (protocols, maps, open-access papers, technical and educational reports and videos, training materials, recommendations and best practices); **DLV2 (FBA)**: Activation of Twitter, Instagram and Facebook accounts to continuously provide updates on the Actions; **DLV3 (Year 4, Y4):** White paper prepared in collaboration with policymakers in the Network and in support to policymakers with key messages from CLEANFOREST regarding forest resilience to perturbation and implications for the ecosystem services they provide

and for forest management; **DLV4 (from year 3, FY3):** A database visualisation in an interactive online map/tool that for the first time will provide research communities and stakeholders a quick and easy tool to explore where and which data from different networks (including manipulations experiments) is available and how to access it; **DLV5 (Y4):** A Special issue in a specialized OPEN access international scientific journal; **DLV6 (FY3):** an education material for secondary schools (either in the form of a text book or special issue published by the European journal 'Science in School', which will provide support to teachers in addressing environmental and atmospheric sciences and also inspire and help developing critical thinking. The Editor of the Journal will be invited to join the Network at the beginning of the Action, to provide support during the development of the educational material. Each WG will have specific DLV, as described below.

WG1. DLV1.1. Scientific paper summarizing the results from the literature review on atmospheric deposition and extreme events in Europe; **DLV1.2.** Database of atmospheric deposition and climate extreme events; **DLV1.3.** White paper providing guidance of best practices, identifying gaps, indicators and complementarity among existing monitoring networks; **DLV1.4.** Metadata for interactive map/tool described above.

WG2. DLV2.1: Two scientific paper addressing changes in the investigated tree and ecosystem ecophysiological parameters across atmospheric deposition and climate gradients in Europe**; DLV2.2:** One scientific paper on the combined effects of climate extremes and atmospheric deposition on tree mortality and forest health**; DLV2.3:** One review paper presenting the new conceptual framework**; DLV2.4:** Technical report targeting policy makers and urban planners on identified sensitive species (and/or forests) across Europe, to be developed with stakeholders participating to the Action; **DLV2.5:** Technical report or specialized paper describing the data harmonization process across different dataset and code infrastructure developed; **DLV2.6:** Database used for all the above deliverables, which will be available to the community as a living and open-access resource to facilitate global change research on forests, including metadata for interactive map/tool.

WG3. DLV3.1. A literature review on interactive impacts of climatic extreme events and N deposition on forest soils across different temporal and spatial scales; **DLV3.2.** Publication on the evaluation of interactive impacts of drought, elevated CO2 and N deposition on soil biogeochemical responses, forest C balance and sequestration potential; **DLV3.3.** Matrix of tree species and soil types and scale for climate and N mitigation potential; **DLV3.4.** White paper providing guidelines for future forest management for maximizing climate and N mitigations; **DLV3.5.** Publication on critical evaluation of belowground indicators for setting Critical Loads of Nitrogen along the continuum natural-periurban-urban forests. It will also assess the European forest and soil potential for climate and N mitigations, and highlight the effectiveness of belowground indicators and their thresholds used for setting up Critical Load of N.

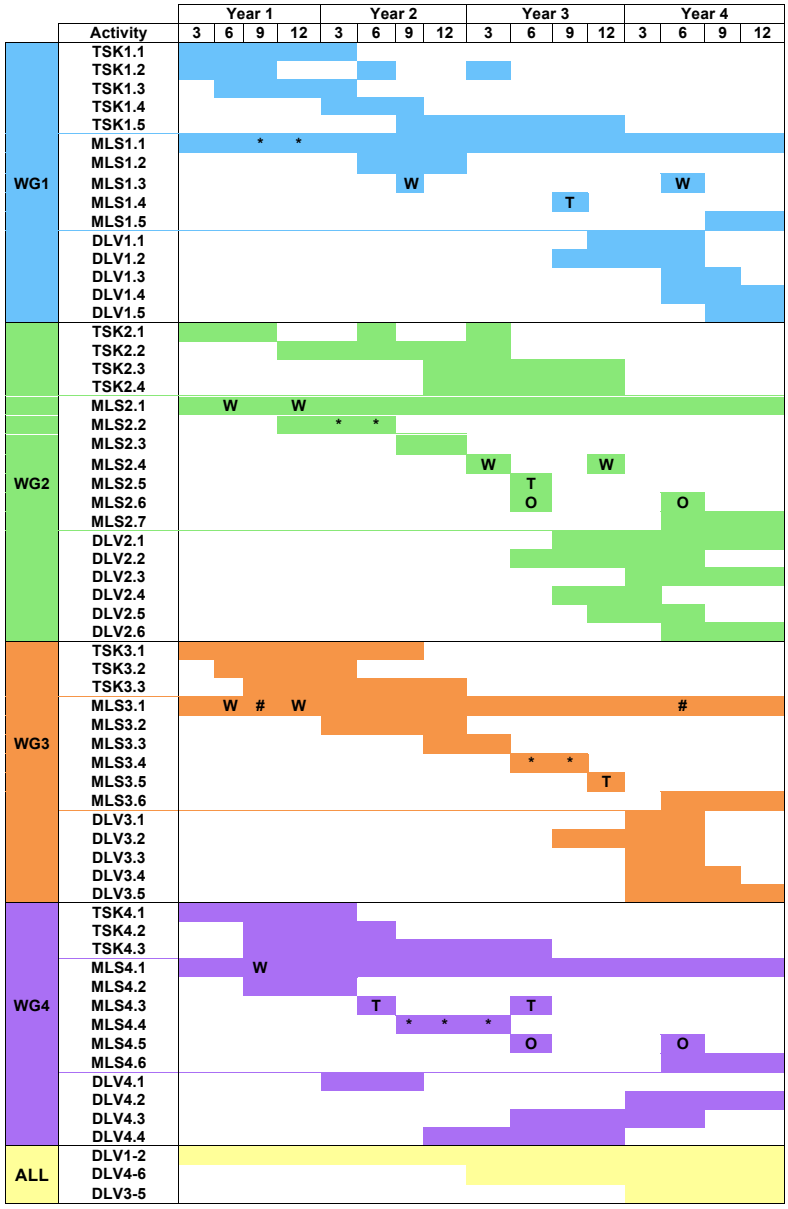
WG4. DLV4.1 Creation of a pan-European network of nutrient manipulation experiments on forest ecosystems**; DLV4.2** White paper i) reporting guidance on 'best practice' to harmonize measurements (and hence data collection) at the existing manipulation experiment sites in Europe; ii) identifying knowledge gaps and how they can be addressed; suggesting future manipulation experiments designed to address also new challenges (such as the interaction among global change drivers, the intensification of extreme events during the growing season rather than its mean)**; DLV4.3** White paper on how: i) to make current monitoring schemes more responsive to detect the impact of deposition and climate extreme; ii) to supplement existing monitoring at remote forest sites by "mirror" network located along the urban-remote gradient; iii) to develop a functional connection between manipulative experiments, large-scale monitoring, and modelling; **DLV4.4** Two scientific papers summarizing findings from manipulation experiments (e.g. canopy vs. soil N applications, responses in relation to tree age, plant functional types, level of ambient deposition and nutrient availability)**.**

4.1.3 RISK ANALYSIS AND CONTINGENCY PLANS

Risk (R1): Difficulty in achieving a critical mass of participants and stakeholders. This is minimized by the already large number of participants (95, from 28 Member Countries) and by the well-consolidated collaborative network that participants have established during their individual careers. **Contingency plan (CP1)**: Ensuring from the beginning of the Action the expansion of the original network, by promoting gender, career stage and geographical balance, and by widening participation to other scientific communities focusing on modelling, remote sensing, other pollutants (ozone, PM10, VOCs) and biotic stressors on forest health (pest and disease). (**R2):** Poor management and coordination,

and work overload. This risk is minimized by the extensive experience that several participants have in contributing to tasks in previous COST Actions, research projects, and/or in leading research groups. (**CP2**): Within each WG there will be a core team supporting the WG leader in all the activities. (**R3):** Insufficient and/or difficult transfer of scientific findings to stakeholders. **(CP3)** Different stakeholder categories are already in the network and will engage in the activities from the beginning of the Action, thus facilitating a continuous exchange and collaboration, and the inclusion of new stakeholders. **(R4):** Lack of information flow between groups **(CP4):** Regular (biweekly) informal virtual meetings (within and across WGs) will be scheduled to share updates, problems and progress on the different activities. **(R5):** Not getting sufficient data for achieving the set goals. This is a low risk, given that several participants are actively involved in forest monitoring networks. This risk, however, could be high in the case of UF. **(CP5):** Invite key contacts at existing networks of stakeholders (e.g. Eurocities) and/or explore data available from Copernicus. **(R6):** Travel restrictions due to COVID-19 pandemic. **(CP6)**: CLEANFOREST has already the plan to have a hybrid option for some activities (e.g. monthly WG meetings, Symposia) to ensure wide participation. Participants are already familiar with several virtual platforms, which will be used to ensure the continuity of Action and the exchange of information, updates and interactions among WGs. Digital tools developed by COST and by now proposed as pilot scheme until October 2021 could also be available (Virtual Networking Support and Virtual Mobility Grants.

4.1.4 GANTT DIAGRAM



Legend:

T = Training School;

* = STSMs;

W =Workshops for all participants;

= Workshops for policymakers

O = 'Open day' at monitoring and experimental manipulation sites

References

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COST Mission and Policies

CLEANFOREST supports the COST Missions and Policies through the following activities:

1) Fostering interdisciplinary research for breakthrough science

Challenges within CLEANFOREST require a holistic assessment of forest responses to global change, connecting processes at different scales (from the atmosphere to the whole ecosystem, tree and soil), and across the natural, periurban and urban (NPU) forests continuum. Progress and breakthrough on this complex topic call for a transdisciplinary approach, which integrates different expertise and research communities involved in monitoring networks and manipulation experiments, coordinates methodological approaches, and harmonizes datasets. To date, no such formal network exists in Europe, as different research groups have been independently working on these topics, and considering separately NPU forests, with no previous effort of integration. Establishment of such a multidisciplinary and concerted pan-European network of scientists operating at the cutting edge of climate change, air pollution and forest and soil response and their mitigation potential will be of unique added value of CLEANFOREST.

2) Empowering young researchers and support their career development and/or consolidation

CLEANFOREST has several activities aiming at empowering early career investigators (ECI, 12 of the > 90 participants) as well as researchers at the critical stage of their career, i.e., PhD students and experienced researchers (ER) with <15 years from their PhD. The latter is a 'category' often overlooked, but that is at the critical transitioning stage of starting a tenure track position and developing a research group. ECI and ER will be actively involved in the WGs activities and will also support the WG leader in specific tasks (e.g. leading literature review, meta-analysis) and dissemination activities. In the latter case, PhD students and ECI will organize a series of monthly virtual Symposia on topics tackled within CLEANFOREST, which will be open to participants in the COST Action, but also other scientists in Europe and beyond. Training schools, Short-Term Scientific Missions and Conference grants will specifically target ECI and PhD students, thus providing them with the great opportunity to develop or strengthen their technical and communication skills (e.g., data analyses, science communication) and scientific know-how on specific topics, and to build their own network of collaborations, which can facilitate applications for research funding at the European (Marie Skłodowska-Curie Action and ERC starting Grant) or national levels (e.g., Newton International Fellowship in the UK funded by the Royal Society).

3) Promoting geographical balance and Inclusiveness

Of the 28 participating Countries, more than the half (53.6%) are within the Inclusiveness target countries (ITCs). One of the set priorities at the beginning of the Action will be to expand the network to include other ITCs, but also Near Neighbour Countries (NNCs). Researchers from ITCs already in the Network will help expanding the network to include more researchers from their own Countries or other ITCs. Identifying participants in NNCs potentially interested in joining CLEANFOREST is more challenging, due to the difficulties of finding international publications that can help identifying groups working on research topics relevant for CLEANFORESTS. Potential collaborators in Morocco and Algeria were identified and contacted, but only one of them replied and already expressed the interest in joining the Action. More efforts will invested to include all (or most of) the Countries in the Mediterranean basin to gain a comprehensive understanding of Mediterranean forests health and responses to global change drivers. This should be facilitated by key contacts in CLEANFOREST Network that are linked to research activity in the African Continent and/or by connecting with specific research and/or policy programs established by international organizations (e.g., FAO). Moreover, the Action will not seek to enhance the critical mass just in terms of number of participants from the COST target Countries, but it will also promote their leading role in the Action activities (e.g., organization of workshops and /or training schools, dissemination activities).

4) Empowering women and ensuring gender equality

The Action will respect an appropriate gender balance in all its activities and this will be a standard item on

all the Management Committee agendas. Priority will be given to the active participation of women (36 % of the total participants) in leading WGs and key activities related to dissemination (e.g., scientific publications or organization of conferences) and training activities for ECI and PhD students. This will contribute to strengthening the active participation of women in leadership roles. Ensuring gender equality will be continuously monitored during the lifetime of the Action, by anonymous questionnaire for surveying participants on gender equality and inclusiveness issues. Feedback received will guide the Chair and Management Committee to continuous adjustment and improvements on this issue, if needed. Lastly, one of the Training schools planned is on Open and inclusive science, which will also tackle how to ensure gender balance as well as diversity and equity in the academic/research world.

5) Promoting and spreading excellence

CLEANFOREST has very detailed and structured dissemination plan aiming at making scientific findings and data available to 1) scientific community and 2) stakeholders. In case 1), outputs from this Action will include scientific publications in high impact journals (in specialized research fields and/or multidisciplinary like those in the Nature family) and presentations at international conferences, with potential benefits for scientific communities beyond the research field directly linked to CLEANFOREST, e.g. process based or Earth system modelling, chemical data assimilation and chemical atmospheric modelling, Earth observations with focus on air quality and vegetation. Lastly, CLEANFOREST will create a global network of nutrient manipulation experiments in forest ecosystems (currently missing), to quantify the impact of global change drivers on forests within a coordinated research efforts. In the case 2), the aim is to translate key scientific findings into tangible and actionable solutions that guide policy and tackle societal and technological challenges within the European Green Deal and the UN Sustainable Development Goals. Each planned activity will target specific stakeholder category, and includes (but is not limited to) continuous dissemination activities through social media and webpage dedicated to CLEANFOREST, participation to the European Research Night, open days at experimental sites, position papers in collaboration with (and directed to) policymakers, forest practitioners.

Network of Proposers - Features

COST Inclusiveness target countries
53.57 %

Number of Proposers
95

Geographic Distribution of Proposers

Country	ITC/ non ITC/ other	Number of institutions from that country	Number of researchers from that country	Percentage of the proposing network
Albania	ITC	2	2	2.11 %
Austria	non ITC	2	2	2.11 %
Belgium	non ITC	2	2	2.11 %
Bosnia and Herzegovina	ITC	4	4	4.21 %
Bulgaria	ITC	1	1	1.05 %
China	other	1	1	1.05 %
Costa Rica	other	1	1	1.05 %
Cyprus	ITC	2	2	2.11 %
Czech Republic	ITC	3	3	3.16 %
Estonia	ITC	3	3	3.16 %
Finland	non ITC	6	6	6.32 %
France	non ITC	2	2	2.11 %
Germany	non ITC	4	5	5.26 %
Greece	non ITC	5	5	5.26 %
Hungary	ITC	3	3	3.16 %
Italy	non ITC	10	10	10.53 %
Moldova	ITC	1	1	1.05 %
Netherlands	non ITC	1	1	1.05 %
Norway	non ITC	1	1	1.05 %
Poland	ITC	1	1	1.05 %
Portugal	ITC	4	4	4.21 %
Romania	ITC	1	1	1.05 %
Serbia	ITC	2	3	3.16 %
Slovakia	ITC	5	5	5.26 %
Slovenia	ITC	1	1	1.05 %
Spain	non ITC	7	7	7.37 %
Sweden	non ITC	1	1	1.05 %
Switzerland	non ITC	4	4	4.21 %
Turkey	ITC	3	3	3.16 %

United Kingdom	non ITC	6	6	6.32 %
United States	other	4	4	4.21 %

Gender Distribution of Proposers
63.2% Males
35.8% Females

Average Number of years elapsed since PhD graduation of Proposers with a doctoral degree
16.7

Number of Early Career Investigators
12

Core Expertise of Proposers: Distribution by Sub-Field of Science
36.8% Earth and related Environmental sciences
32.6% Agriculture, Forestry, and Fisheries
20.0% Biological sciences
1.1% Chemical sciences
1.1% Environmental engineering
2.2% Other
6.3% Unspecified

Institutional distribution of Network of Proposers

71.6% Higher Education & Associated Organisations
21.1% Government/Intergovernmental Organisations except Higher Education
5.3% Business enterprise
2.1% Private Non-Profit without market revenues, NGO

Higher Education & Associated Organisations:68

- Number by Field of Science of Department/Faculty of Affiliation
  Agriculture, Forestry, and Fisheries:23
  Earth and related Environmental sciences:28
  Chemical sciences:1
  Biological sciences:15
  Physical Sciences:1
- Number by Type
  Education Oriented:33
  Research Oriented:35
- Number by Ownership
  Fully or mostly public:65
  Fully or mostly private:3

Government/Intergovernmental Organisations except Higher Education:20

- Number by Level
  Central and Federal Government:14
  Local government:4
  European Union - EU:1
  International:1
- Number by Type
  R&D Funding and/or R&D Performing bodies:4
  Government department or government-run general public services:10
  Non-R&D executive agencies, including sector specific regulatory bodies:2
  Other Public Non-Profit Institution:3

European RTD organisation:1

Business enterprise:5

- Number by Market sector of unit of affiliation
  Professional, Scientific And Technical Activities:3
  Accommodation And Food Service Activities:1
  Agriculture, Forestry And Fishing:1
- Number by Type
  Private enterprises:4
  Public enterprises:1
- Number by Ownership and International Status
  Independent Enterprise:4
  Enterprise owned by a national group:1
- Number by Size
  SME (EU Definition provided underneath after selection):4
  Large company:1

Private Non-Profit without market revenues, NGO:2

- Number by Type
  Charity:1
  Other:1
- Number by Level
  International or European:1
  National:1

COST Country(28) : Albania , Austria , Belgium , Bosnia and Herzegovina , Bulgaria , Cyprus , Czech Republic , Estonia , Finland , France , Germany , Greece , Hungary , Italy , Moldova , Netherlands , Norway , Poland , Portugal , Romania , Serbia , Slovakia , Slovenia , Spain , Sweden , Switzerland , Turkey , United Kingdom
International Partner Country(3) : China, Costa Rica, United States
Near Neighbour Country(0)
European Commission or EU Agency(1)
European RTD Organisation(1)
International Organisation(0)

Network of Proposers - Details

Main Proposer's Details

Title:	Dr		
First Name:	Rossella (Maria Rosa)	**Gender:**	F
Last Name:	Guerrieri	**Years from PhD:**	14
Institution:	Alma Mater Studiorum, University of Bologna	**Type of Institution:**	COST Country
Sub-field of Science of Department:	Agriculture, Forestry, and Fisheries	**Core Area of Expertise:**	Agriculture, Forestry, and Fisheries (Forest ecology, plant physiology)

Secondary Proposers' Details

Albania

Prof Edmond Pasho (Agricultural University of Tirana, Faculty of Forestry Sciences [Forestry])

Participating as Secondary Proposer
Core Expertise: Agriculture, Forestry, and Fisheries: Dendroecology, Forest growth and production, GIS and Remote Sensing
Gender: M
Years from PhD: 8

Prof Arben Alla (Agricultural University of Tirana [Faculty of Forestry Sciences])

Participating as Secondary Proposer
Core Expertise: Agriculture, Forestry, and Fisheries: Dendroecology, plant physiology
Gender: M
Years from PhD: 9

Austria

Prof Douglas Godbold (Universität für Bodenkultur [Institute of Forest Ecology])

Participating as Secondary Proposer
Core Expertise: Biological sciences: Ecology
Gender: M
Years from PhD: 38

Dr Silvio Schüler (Federal Research and Training Centre for Forests, Natural Hazards and Landscape [Department of Forest Genetics])

Participating as Secondary Proposer
Core Expertise: Agriculture, Forestry, and Fisheries: Sustainable forest management
Gender: M
Years from PhD: 16

Belgium

Dr Arne Verstraeten (Research Institute for Nature and Forest (INBO) [Environment and Climate])

Participating as Secondary Proposer
Core Expertise: Earth and related Environmental sciences: Biogeochemistry, biogeochemical cycles
Gender: M
Years from PhD: 3

Dr Catherine Preece (Universiteit Antwerpen [PLECO (Plants and Ecosystems)])

Participating as Secondary Proposer
Core Expertise: Biological sciences: Ecology
Gender: F
Years from PhD: 10

Bosnia and Herzegovina

Dr Tatjana Popov (University of Banja Luka [Faculty of Natural Sciences and Mathematics - Department of Geography])

Participating as Secondary Proposer
Core Expertise: Earth and related Environmental sciences: Climatology and climate change
Gender: F
Years from PhD: No PhD

Ms Slobodan Gnjato (University of Banja Luka [Department of Geography])

Participating as Secondary Proposer
Core Expertise: Earth and related Environmental sciences: Climatology and climate change

Gender: M
Years from PhD: No PhD

Mr Dragan Kovacevic (The Republic Institute for the Protection of Cultural, Historical and Natural Heritage [Department for Nature Conservation])
Participating as Secondary Proposer
Core Expertise: Earth and related Environmental sciences: Forestry
Gender: M
Years from PhD: No PhD

Prof Goran Trbic (University of Banja Luka [Faculty of Natural Sciences and Mathematics])
Participating as Secondary Proposer
Core Expertise: Earth and related Environmental sciences: Climatology and climate change
Gender: M
Years from PhD: 15

Bulgaria

Dr Miglena Zhiyanski (Forest Research Institute - Forest Research Institute - Bulgarian academy of sciences [Forest ecology])
Participating as Secondary Proposer
Core Expertise: Earth and related Environmental sciences: Biogeochemistry, biogeochemical cycles
Gender: F
Years from PhD: 17

China

Dr Geshere Abdisa Gurmesa (Institute of Applied Ecology, Chinese Academy of Sciences [Isotope Ecology])
Participating as Secondary Proposer
Core Expertise: Earth and related Environmental sciences: Biogeochemistry, biogeochemical cycles
Gender: M
Years from PhD: 5

Costa Rica

Dr Andrea G. Vincent (Universidad de Costa Rica [Biology School])
Participating as Secondary Proposer
Core Expertise: Biological sciences: Ecology
Gender: F
Years from PhD: 14

Cyprus

Dr Dimitrios Sarris (University of Cyprus [Dept of Biological Sciences])
Participating as Secondary Proposer
Core Expertise: Agriculture, Forestry, and Fisheries: Agro-forestry
Gender: M
Years from PhD: 13

Prof Ioannis Vogiatzakis (Open University of Cyprus)
Participating as Secondary Proposer
Core Expertise: Earth and related Environmental sciences: Terrestrial ecology, land cover change
Gender: M
Years from PhD: 21

Czech Republic

Dr Monika Vejpustkova (Forestry and Game Management Research Institute)

Participating as Secondary Proposer
Core Expertise: Agriculture, Forestry, and Fisheries: Forestry: fauna and flora
Gender: F
Years from PhD: 13

Dr Katerina Machacova (Global Change Research Institute, CAS [Department of Ecosystem Trace Gas Exchange])
Participating as Secondary Proposer
Core Expertise: Biological sciences: Plant biology, Botany
Gender: F
Years from PhD: 9

Dr Karel Klem (Global Change Research Institute CAS [Laboratory of Ecological Plant Physiology])
Participating as Secondary Proposer
Core Expertise: Agriculture, Forestry, and Fisheries: Agriculture related to crop production, soil biology and cultivation, applied plant biology, crop protection
Gender: M
Years from PhD: No PhD

Estonia

Dr Kaido Soosaar (University of Tartu [Department of Geography])
Participating as Secondary Proposer
Core Expertise: Earth and related Environmental sciences: Climatology and climate change
Gender: M
Years from PhD: 10

Dr Priit Kupper (University of Tartu)
Participating as Secondary Proposer
Core Expertise: Biological sciences: Plant ecophysiology
Gender: M
Years from PhD: 15

Ms Marili Sell (University of Tartu [Faculty of Science and Technology , Institute of Ecology and Earth Sciences, Department of Botany])
Participating as Secondary Proposer
Core Expertise: Biological sciences: Plant biology, Botany
Gender: F
Years from PhD: No PhD

Finland

Dr Katja Rinne-Garmston (Natural Resources Institute Finland (Luke))
Participating as Secondary Proposer
Core Expertise: Earth and related Environmental sciences: Biogeochemistry, biogeochemical cycles
Gender: F
Years from PhD: 8

Dr Yann Salmon (University of Helsinki [INAR])
Participating as Secondary Proposer
Core Expertise: Biological sciences: Ecology
Gender: M
Years from PhD: 12

Dr Ivan Mammarella (University of Helsinki [Institute for Atmospheric and Earth System Research (INAR)])
Participating as Secondary Proposer

Core Expertise: Earth and related Environmental sciences: Meteorology, atmospheric physics and dynamics
Gender: M
Years from PhD: 17

Dr Marcus Lindner (European Forest Institute [Sustainability and Climate Change Programme])
Participating as Secondary Proposer
Core Expertise: Agriculture, Forestry, and Fisheries: Sustainable forest management
Gender: M
Years from PhD: 23

Dr Liisa Kulmala (Finnish Meteorological Institute)
Participating as Secondary Proposer
Core Expertise: Earth and related Environmental sciences: Biogeochemistry, biogeochemical cycles
Gender: F
Years from PhD: 10

Mr Esa Nikunen (Helsinki City, Environment Services - City of Helsinki [Environment Services])
Participating as Secondary Proposer
Core Expertise: Earth and related Environmental sciences: Environment chemistry
Gender: M
Years from PhD: No PhD

France

Dr Denis LOUSTAU (INRA [ISPA])
Participating as Secondary Proposer
Core Expertise: Earth and related Environmental sciences: Biogeochemistry, biogeochemical cycles
Gender: M
Years from PhD: 37

Mr Jean-Marc Limousin (CNRS [CEFE])
Participating as Secondary Proposer
Core Expertise: Earth and related Environmental sciences: Biogeochemistry, biogeochemical cycles
Gender: M
Years from PhD: 12

Germany

Dr Juergen Kreyling (University of Greifswald [Experimental Plant Ecology])
Participating as Secondary Proposer
Core Expertise: Biological sciences: Ecology
Gender: M
Years from PhD: 13

Dr Richard Nair (Max Planck Society - Max Planck Institute for Biogeochemistry [Department Biogeochemical Integration])
Participating as Secondary Proposer
Core Expertise: Earth and related Environmental sciences: Biogeochemistry, biogeochemical cycles
Gender: M
Years from PhD: 6

Dr Robert Weigel (Georg-August University Göttingen - Albrecht-von-Haller-Institute for Plant Sciences [Plant Ecology])
Participating as Secondary Proposer

Core Expertise: Biological sciences: Ecology
Gender: U
Years from PhD: No PhD

Dr Lena Muffler-Weigel (Georg-August University Göttingen - Albrecht-von-Haller-Institute for Plant Sciences [Plant Ecology])
Participating as Secondary Proposer
Core Expertise: Biological sciences: Ecology
Gender: F
Years from PhD: 1

Dr Eric Andreas Thurm (Landesforst MV AöR [Research Unit Silviculture and Forest growth, Forest research department, BT FVI])
Participating as Secondary Proposer
Core Expertise: Agriculture, Forestry, and Fisheries: Sustainable forest management
Gender: M
Years from PhD: No PhD

Greece

Dr Marangela Fotelli (National Agricultural Organisation Demeter - Forest Research Institute [Lab of Forest Ecophysiology])
Participating as Secondary Proposer
Core Expertise: Biological sciences: Plant biology, Botany
Gender: F
Years from PhD: 19

Prof Kalliopi Radoglou (Democritus University of Thrace - Department of Forestry and Managemnt of the Environment and Natural Resources [Lab of Silviculture])
Participating as Secondary Proposer
Core Expertise: Agriculture, Forestry, and Fisheries: Conservation biology, ecology, genetics
Gender: F
Years from PhD: 34

Dr Nikolaos Fyllas (University of the Aegean [Department of Environment, Biodiversity Conservation Laboratory])
Participating as Secondary Proposer
Core Expertise: Agriculture, Forestry, and Fisheries: Ecology (theoretical, community, population, microbial, evolutionary ecology)
Gender: M
Years from PhD: 14

Mr Athanasios Mylonas (SANI S.A. [Facilities Management])
Participating as Secondary Proposer
Core Expertise: Mechanical engineering: Sustainable engineering
Gender: M
Years from PhD: No PhD

Mr Michail Sismanis (Green Blue Modern Solutions)
Participating as Secondary Proposer
Core Expertise: Environmental engineering: Remote sensing
Gender: M
Years from PhD: No PhD

Hungary

Dr Adrienn Horváth (Institute of Environmental and Earth Sciences - University of Sopron)
Participating as Secondary Proposer
Core Expertise: Earth and related Environmental sciences: Sedimentology, soil science,

palaeontology, earth evolution
Gender: F
Years from PhD: 5

Dr Imre Berki (University of Sopron - Institute of Environmental Protection and Nature Conservation)
Participating as Secondary Proposer
Core Expertise:
Gender: M
Years from PhD: No PhD

Dr Borbála Gálos (University of Sopron [Faculty of Forestry/Institute of Environmental and Earth Sciences])
Participating as Secondary Proposer
Core Expertise: Earth and related Environmental sciences: Climatology and climate change
Gender: F
Years from PhD: 10

Italy

Prof Federico Magnani (Alma Mater Studiorum - Università di Bologna [DiSTAL - Department of Agricultural and Food Sciences])
Participating as Secondary Proposer
Core Expertise: Agriculture, Forestry, and Fisheries: Sustainable forest management
Gender: M
Years from PhD: 21

Prof Dario Papale (Università degli Studi della Tuscia [DIBAF])
Participating as Secondary Proposer
Core Expertise:
Gender: M
Years from PhD: No PhD

Prof Mirco Rodeghiero (University of Trento [Centro Agricoltura Alimenti Ambiente])
Participating as Secondary Proposer
Core Expertise: Agriculture, Forestry, and Fisheries: Foresy Ecology
Gender: M
Years from PhD: 18

Dr Giorgio Matteucci (National Research Council of Italy - CNR - Institute of BioEconomy - CNR-IBE)
Participating as Secondary Proposer
Core Expertise: Agriculture, Forestry, and Fisheries: Sustainable forest management
Gender: M
Years from PhD: 23

Dr Rita Baraldi (National Research Council - Institute of BioEconomy)
Participating as Secondary Proposer
Core Expertise: Agriculture, Forestry, and Fisheries: Sustainable Agriculture
Gender: F
Years from PhD: 40

Ms Alessandra Teglia (Alma Mater Studiorum - University of Bologna [Dept. Agricultural and Food Sciences])
Participating as Secondary Proposer
Core Expertise: Agriculture, Forestry, and Fisheries: Forest Ecology
Gender: F
Years from PhD: No PhD

Dr Mirco Migliavacca (Joint Research Centre - European Commission Joint Research Centre)
Participating as Secondary Proposer
Core Expertise: Earth and related Environmental sciences: Biogeochemistry, biogeochemical cycles
Gender: M
Years from PhD: 13

Dr MICAELA ONORATI (Nature 4.0 Società Benefit Srl - Nature 4.0 SB Srl)
Participating as Secondary Proposer
Core Expertise: Earth and related Environmental sciences: Terrestrial ecology, land cover change
Gender: F
Years from PhD: No PhD

Dr Enrico Pompei (Mipaaf-Difor2)
Participating as Secondary Proposer
Core Expertise: Agriculture, Forestry, and Fisheries: Sustainable forest management
Gender: M
Years from PhD: No PhD

Moldova

Dr Olesea Cojocaru (State Agrarian University of Moldova [Agroecology and Soil Scuence])
Participating as Secondary Proposer
Core Expertise: Earth and related Environmental sciences: Terrestrial ecology, land cover change
Gender: F
Years from PhD: No PhD

Netherlands

Dr Michiel van der Molen (Wageningen University [Meteorology and Air Quality])
Participating as Secondary Proposer
Core Expertise: Earth and related Environmental sciences: Biogeochemistry, biogeochemical cycles
Gender: M
Years from PhD: 19

Norway

Dr Nuria Castell (NILU-Norwegian Institute for Air Research [INBY- Urban Environment and Industry])
Participating as Secondary Proposer
Core Expertise: Earth and related Environmental sciences: Meteorology, atmospheric physics and dynamics
Gender: F
Years from PhD: 13

Poland

Ms Klaudia Ziemblińska (Poznan University of Life Sciences [Meteorology Department])
Participating as Secondary Proposer
Core Expertise:
Gender: F
Years from PhD: No PhD

Portugal

Prof Cristina Branquinho (Faculty of sciences, University of lisbon - Faculty of sciences University of lisbon [ce3c, centre for ecology, evolution and environmental changes])
Participating as Secondary Proposer
Core Expertise: Biological sciences: Ecology

Gender: F
Years from PhD: 24

Dr Maria Alexandra Oliveira (Centre for Ecology, Evolution and Environmental Changes [eChanges])
Participating as Secondary Proposer
Core Expertise: Earth and related Environmental sciences: Geomorphology
Gender: F
Years from PhD: 4

Ms Filipa Marques (Portuguese Environment Agency)
Participating as Secondary Proposer
Core Expertise: Earth and related Environmental sciences: Atmospheric chemistry and composition
Gender: F
Years from PhD: No PhD

Mr Rui Alves (Companhia das Lezírias, S.A. - Companhia das Lezirias, SA [Departamento Florestal e de Sustentabilidade])
Participating as Secondary Proposer
Core Expertise: Agriculture, Forestry, and Fisheries: Agro-forestry
Gender: M
Years from PhD: 29

Romania

Dr Lucian DINCA (National Institute for Research and Development in Forestry - INCDS Brasov [Ecology and Soil])
Participating as Secondary Proposer
Core Expertise:
Gender: M
Years from PhD: 22

Serbia

Dr Dejan Stojanović (Institute of Lowland Forestry and Environment)
Participating as Secondary Proposer
Core Expertise: Agriculture, Forestry, and Fisheries: Sustainable forest management
Gender: M
Years from PhD: 7

Prof Sasa Orlovic (University of Novi Sad, Institute of Lowland Forestry and Environment)
Participating as Secondary Proposer
Core Expertise: Agriculture, Forestry, and Fisheries: Agro-forestry
Gender: M
Years from PhD: 25

Dr Srdjan Stojnic (Institute of Lowland Forestry and Environment)
Participating as Secondary Proposer
Core Expertise: Agriculture, Forestry, and Fisheries: Conservation biology, ecology, genetics
Gender: M
Years from PhD: 8

Slovakia

Prof Jaroslav Durkovic (Technical University in Zvolen - Faculty of Forestry [Department of Phytology])
Participating as Secondary Proposer
Core Expertise: Agriculture, Forestry, and Fisheries: Tree breeding, wood structure and properties

Gender: M
Years from PhD: 25

Dr Alena Konôpková (Technical University in Zvolen [Faculty of Forestry, Department of Integrated Forest and Landscape Protection])
Participating as Secondary Proposer
Core Expertise: Agriculture, Forestry, and Fisheries: Ecophysiology of woody species
Gender: F
Years from PhD: No PhD

Prof Alexander Lux (Comenius University in Bratislava - Faculty of Natural SciencesComenius University)
Participating as Secondary Proposer
Core Expertise:
Gender: M
Years from PhD: 40

Dr Jozef Turok (Ministry of Agriculture and Rural Development [Forestry and Timber Section])
Participating as Secondary Proposer
Core Expertise: Agriculture, Forestry, and Fisheries: Conservation biology, ecology, genetics
Gender: M
Years from PhD: 26

Mr Peter Fleischer (Technical Univerzity Zvolen - Forestry Faculty, Technical University)
Participating as Secondary Proposer
Core Expertise: Agriculture, Forestry, and Fisheries: Sustainable forest management
Gender: M
Years from PhD: No PhD

Slovenia

Prof Tomislav Levanič (Slovenian Forestry Institute [Yield and Silviculture])
Participating as Secondary Proposer
Core Expertise: Agriculture, Forestry, and Fisheries: Sustainable forest management
Gender: M
Years from PhD: 25

Spain

Prof Maurizio Mencuccini (CREAF - Centre de Recerca Ecològica i Aplicacions Forestals)
Participating as Secondary Proposer
Core Expertise: Earth and related Environmental sciences: Terrestrial ecology, land cover change
Gender: M
Years from PhD: 26

Dr Teresa Gimeno (Basque Centre for Climate Change (BC3))
Participating as Secondary Proposer
Core Expertise: Biological sciences: Plant biology, Botany
Gender: F
Years from PhD: 10

Dr Rocío Alonso del Amo (Research Center for Energy, Environment and Technology – CIEMAT)
Participating as Secondary Proposer
Core Expertise: Biological sciences: Environmental and marine biology
Gender: F
Years from PhD: 23

Dr David Elustondo (University of Navarra [Chemistry])
Participating as Secondary Proposer
Core Expertise: Earth and related Environmental sciences: Atmospheric chemistry and composition
Gender: M
Years from PhD: 18

Mr Jaume Targa (4sfera Innova SLU)
Participating as Secondary Proposer
Core Expertise: Earth and related Environmental sciences: Atmospheric chemistry and composition
Gender: M
Years from PhD: No PhD

Ms Raquel Ruiz Checa (Research Center for Energy, Environment and Technology (CIEMAT) [Environmental])
Participating as Secondary Proposer
Core Expertise: Biological sciences: Ecology
Gender: F
Years from PhD: No PhD

Dr Guillermo Amo de Paz (Biodiversia S. Coop. Mad. [Projects])
Participating as Secondary Proposer
Core Expertise: Biological sciences: Systems evolution, biological adaptation, phylogenetics, systematics
Gender: M
Years from PhD: 9

Sweden

Dr Thomas Pugh (Lund University [Department of Physical Geography and Ecosystem Science])
Participating as Secondary Proposer
Core Expertise: Physical Sciences: Inorganic Synthesis
Gender: M
Years from PhD: 11

Switzerland

Dr Marco Ferretti (Swiss Federal Research Institute WSL [Forest Resources and Management])
Participating as Secondary Proposer
Core Expertise: Agriculture, Forestry, and Fisheries: Forestry: fauna and flora
Gender: M
Years from PhD: 15

Dr Mathieu Lévesque (ETH Zurich [Department of Environmental Systems Science])
Participating as Secondary Proposer
Core Expertise: Agriculture, Forestry, and Fisheries: Sustainable forest management
Gender: M
Years from PhD: 8

Dr Arthur Gessler (Swiss Federal Institute WSL)
Participating as Secondary Proposer
Core Expertise: Biological sciences: Ecology
Gender: M
Years from PhD: 22

Dr Barbara Moser (Eidg. Forschungsanstalt WSL)
Participating as Secondary Proposer

Core Expertise: Biological sciences: Ecology
Gender: F
Years from PhD: 16

Turkey

Dr Akkin Semerci (Tokat Gaziosmanpaşa University - Niksar Vocational School [Forestry and Forest Products])
Participating as Secondary Proposer
Core Expertise: Agriculture, Forestry, and Fisheries: Sylviculture, tropical forestry
Gender: M
Years from PhD: 19

Dr YUSUF SERENGİL (Istanbul University Cerrahpasa)
Participating as Secondary Proposer
Core Expertise:
Gender: M
Years from PhD: 19

Ms Erda Celer (General Directorate of Forestry [Department of Foreign Relations, Training and Research])
Participating as Secondary Proposer
Core Expertise: Agriculture, Forestry, and Fisheries: Climate Change, Adaptation, Mitigation, Ecosystem Services, Genetics
Gender: F
Years from PhD: No PhD

United Kingdom

Dr mike Perks (Forest Research (UK) [Climate Change Research Group])
Participating as Secondary Proposer
Core Expertise: Agriculture, Forestry, and Fisheries: Sustainable forest management
Gender: M
Years from PhD: 23

Dr Elena Vanguelova (Forest Research [Centre for Biodiversity, Society and Biosecurity])
Participating as Secondary Proposer
Core Expertise: Earth and related Environmental sciences: Biogeochemistry, biogeochemical cycles
Gender: F
Years from PhD: 19

Prof Sami ULLAH (University of Birmingham [Birmingham Institute of Forest Research and School of Geography, Earth and Environmental Sciences])
Participating as Secondary Proposer
Core Expertise: Earth and related Environmental sciences: Biogeochemistry, biogeochemical cycles
Gender: M
Years from PhD: 16

Dr Kevin Hicks (University of York - Stockholm Environment Institute (SEI))
Participating as Secondary Proposer
Core Expertise: Biological sciences: Environmental and marine biology
Gender: M
Years from PhD: 25

Prof Iain Hartley (University of Exeter [Geography, College of Life and Environmental Sciences])
Participating as Secondary Proposer

Core Expertise: Earth and related Environmental sciences: Biogeochemistry, biogeochemical cycles
Gender: M
Years from PhD: 15

Ms Amy Stephens (UK CENTRE FOR ECOLOGY & HYDROLOGY - UK Centre for Ecology and Hydrology [ACC])
Participating as Secondary Proposer
Core Expertise: Chemical sciences: Environmental Chemistry
Gender: F
Years from PhD: No PhD

United States

Dr Soumaya Belmecheri (University of Arizona - Soumaya Belmecheri [Laboratory of Tree Ring Research])
Participating as Secondary Proposer
Core Expertise: Earth and related Environmental sciences: Climatology and climate change
Gender: F
Years from PhD: 13

Dr Flurin Babst (University of Arizona [School of Natural Resources and the Environment])
Participating as Secondary Proposer
Core Expertise: Earth and related Environmental sciences: Terrestrial ecology, land cover change
Gender: M
Years from PhD: 8

Dr Pamela Templer (Boston University [Biology])
Participating as Secondary Proposer
Core Expertise: Earth and related Environmental sciences: Biogeochemistry, biogeochemical cycles
Gender: F
Years from PhD: 20

Dr PNNL McDowell (Pacific Northwest National Lab - PNNL)
Participating as Secondary Proposer
Core Expertise: Earth and related Environmental sciences: Biogeochemistry, biogeochemical cycles
Gender: M
Years from PhD: No PhD