1. BASIC DETAILS

1.1 Flagship details

Name and abbreviation of the Flagship: Atmosphere and Climate Competence Center (ACCC)
Director: Markku Kulmala, UH; **Vice directors:** Jaana Bäck, UH, Ari Laaksonen, FMI, Kari Lehtinen, UEF, Miikka Dal Maso, TAU; **Host organizations:** University of Helsinki (UH), Finnish Meteorological Institute (FMI), University of Eastern Finland (UEF), Tampere University (TAU)

2. CENTRAL IDEA

2.1 Description of the central idea

Anticipated future prospects

The Atmosphere and Climate Competence Center (ACCC) addresses two of the most urgent global Grand Challenges: climate change and deteriorating air quality. The ***ACCC vision*** is **safe climate and clean air**. The ***ACCC mission*** is to i) make a significant contribution toward achieving a carbon neutral (and beyond) society in Finland, EU and globally, in practice by finding out the ways to take CO_2 out from the atmosphere and reliably verifying it; ii) understand the atmospheric pollution cocktail in detail and quantify the impact of reducing pollutant emissions on climate, to mitigate air pollution and sustain healthy atmosphere. In addition to carbon neutrality, ACCC will assess the climate neutrality of mitigation measures and air quality management actions: the overall climate impact accounting not only for GHGs but also other anthropogenic components affecting the Earth's energy balance, such as aerosols and albedo changes (i.e. climate neutrality means that the radiative forcing is zero). We will contribute to the solutions that will help the business sector and society to reach the Paris climate targets, to mitigate and adapt to climate change, and thus support the EU Green Deal commitments and the UN sustainable development goals. ACCC top-level interdisciplinary research will be actively transformed to the new innovation environments with business partners, leading to new practical solutions supporting climate change mitigation and adaptation, and healthy atmosphere.

In adaptation to climate change, a significant share of the needs and solutions are regional and related to changes in local weather patterns rather than the global average temperature. In the Arctic-Boreal region, projected temperature changes are twice the global average (IPCC 2013). Large uncertainties e.g. in the impact of climate change on high- and mid-latitude seasonal and extreme weather complicate the formulation of cost-effective and societally sustainable adaptation strategies. In parallel, air quality, trace gases, aerosols, and climate are tightly linked via atmospheric processes – e.g. reduction of aerosol emissions causes additional warming due to reduction in scattering of radiation and changes in cloud properties. On the other hand absorbing and toxic carbonaceous aerosol increase warming and simultaneously cause health effects. Poor understanding of the atmospheric interactions may thus lead to unwanted climate impacts and various negative health effects. Additionally, poorly known emerging pollutants complicate the regulatory landscape.

Climate change and poor air quality form a pair of problems that must be mitigated simultaneously in the coming decades. There is a need to improve the climate projections, to develop the terrestrial carbon sequestration options taking into account also other interlinked climate forcers like aerosols and trace gases, to lift up the existing monitoring and forecasting systems of the terrestrial carbon cycle to an entirely new level, to carry out more and better measurements spanning from process level to global scale for the better understanding of both natural and anthropogenic carbon sources and sinks, as well as atmospheric processes affecting air quality and furthermore health. The global annual cost of climate change impacts will reach an estimated hundreds of billions euros by 2030 (UNEP 2016), and increase sharply with the level of global warming. These practical needs provide emerging business opportunities for various industries, and European Green Deal

Investment will mobilize at least 1 trillion euros of sustainable investments over the next decade (COM 2020). The information produced by using new verification systems is essential for society to design the economically and socially optimal sustainability strategies and climate-neutrality pathways and to be able to meet Paris Agreement targets (Kriegler et al. 2018).

Key objectives for the flagship term 2020-2024

The objectives of the Atmosphere and Climate Competence Center (ACCC) are: **1)** to provide beyond state-of-the-art scientific knowledge on two of the most urgent global Grand Challenges, climate change and deteriorating air quality by quantifying carbon sink and other interlinked radiative forcers, and by quantifying non-linear processes in atmospheric pollution cocktail; **2**) to establish a platform (ACCC Service Portal) to collect big data from comprehensive observations and multiscale models to be delivered to various stakeholders; **3)** to co-create science-based solutions for guiding the world toward climate neutrality; and **4)** to establish international and interactive atmospheric research – business innovation ecosystem to Finland.

Central idea from the perspectives of research and impact

The central idea of the ACCC is to establish ***a world-leading atmosphere and climate competence center*** whose interdisciplinary research is in active interaction with the climate / air quality policy makers and private sector. The interaction facilitates effective climate policies and optimized mitigation and adaptation plans from national to international scales. The company collaboration boosts new practical solutions, such as new atmospheric instruments, climate – air quality analysis services and improved verification services for global auditing sector. ACCC contributes significantly to the integrated global climate observation system, provides novel education and distributes new knowledge on climate change to public. In a four-year period, ACCC will carry out a research and impact agenda with collaborators consolidating a new national and international business ecosystem for atmospheric and environmental sciences by transforming excellent science into solutions.

Added value generated

The seamless chain from deep scientific understanding to practical solutions enables us to utilize the SMEAR concept (Station for Measuring Earth surface-Atmosphere Relations, Kulmala 2018) to answer questions that do not even exist yet, with open big data. **(i)** The ACCC consortium ***integrates*** the expertise on modelling, collecting and analyzing data from *in situ* observation networks and satellite-based Earth Observation, and brings the currently limited understanding of natural and anthropogenic carbon sources and sinks, as well as atmospheric processes affecting air quality beyond the state of the art. The ACCC scientific approach is fundamental for the development of the next generation of economically and socially optimized terrestrial carbon sequestration options, verification and forecasting systems of the terrestrial carbon cycle (including inland waters) and other climate forcers, understanding the impacts of technological improvements and systemic changes on radiative forcing and air quality, and to carry out more and better measurements from the process level to the global scale. **(ii)** The ACCC consortium ***brings together*** the scientific knowledge of the ACCC partners (UH, FMI, UEF, TAU) and the needs and expertise of 40 stakeholders. The collaborative companies of different sizes (int. companies, SMEs) represent the energy, transport, food, forestry and auditing sectors. The ACCC will, together with global auditing companies Deloitte and KPMG, help other partners to reduce their emissions and manage their climate impact, e.g. by creating new carbon sinks with verified climate impact. The new climate / air quality business

ecosystem will form seamless public – private partnership in Finland and will improve their competitiveness internationally.

Support provided by the Flagship for the building of internationally competitive competence centres and ecosystems in Finland

ACCC is based on tight collaboration between the partner organizations and global excellence in atmospheric and Earth system science. Via the Flagship program, ACCC will be able to boost public-private partnership to new levels by taking the lead in several initiatives with big enough resources. The interest toward climate actions in different companies in Finland, EU and globally has been enhanced significantly in the last 24 months – a significant fraction of them aim to be carbon neutral as soon as possible, and the collaboration with ACCC will enable the realization and verification of this target. During the FS period, ACCC will be able to strengthen the international visibility of the Finnish innovation ecosystem using its wide international collaboration.

3. DEMONSTRATED SCIENTIFIC EXCELLENCE AND IMPACT IN SUPPORT OF ECONOMIC GROWTH AND/OR INNOVATION ECOSYSTEM(S) AND SOCIETY

3.1 Description of demonstrated excellence and impact

Previous excellence

We have published groundbreaking studies on aerosol particle formation in different environments (Jokinen et al. 2018, Lehtipalo et al. 2018, Kerminen 2018, Nieminen et al. 2018, Chu et al. 2019), atmospheric chemistry related to air pollutants and their role in climate warming and aerosol formation (Yao et al. 2018, Bianchi et al. 2019, Kulmala et al. 2020, Wang et al. 2020), global measurements of atmospheric CO_2, photosynthesis and snow mass by Earth observation (i.e. remote sensing of the Earth; Pulliainen et al. 2020), and on building a global Earth observatory (Kulmala 2018). We have created novel data- and information services and established an easy-read research information channel for the public (www.ilmastokatsaus.fi/category/research-letters/).

Our ***continuous comprehensive observations*** and deep understanding of atmospheric processes, ecosystem functioning and various important climate-relevant feedbacks have been extended to regional and global scales by establishing new stations worldwide (Kulmala, 2018) and using ***Earth observation*** (e.g. Pulliainen et al. 2020, Lipponen et al. 2018) as well as inverse and ***Earth system modelling*** (e.g. Mielonen et al. 2018, Bergamaschi et al. 2018). With these efforts, we contribute to the CMIP6 climate simulations (https://www.wcrp-climate.org/wgcm-cmip/wgcm-cmip6), our soil carbon model Yasso (https://en.ilmatieteenlaitos.fi/yasso) is used in nine European countries in the national GHG inventories, and we have developed new methodology to account for non-CO_2 radiative forcings, including methane and aerosols, in carbon budget and 1.5 C mitigation pathway calculations (Mengis et al. 2018, Hienola et al. 2018). Our sectional aerosol module SALSA is used in global climate simulations (Kokkola et al. 2018), emission and air pollution studies (Kuhn et al. 2020, Kurppa et al. 2019) and detailed cloud dynamics simulations (Ahola et al. 2020). The ACCC teams have excellency also in studying the ***optimization*** of land-based climate change mitigation (Assmuth and Tahvonen 2018, Tahvonen et al 2019).

Our recent ***air quality*** research has highlighted that the processes controlling the urban pollution cocktail are highly non-linear and heavily dependent on the emission matrix and technological choices in power production and traffic (Kulmala et al. 2020, Olin et al. 2020, Simonen et al. 2019). As a result, emission mitigation efforts do not necessarily lead to anticipated particulate pollution

reductions (and hence to expected air quality and climate impacts), e.g. due to secondary pollution formation (Yao et al. 2018). This was shown e.g. in Chinese megacities during the COVID-19 pandemic (Yan et al. 2020), and strategies to address such problems have been investigated (Karjalainen et al. 2019). We have also developed new, more accurate methodology to represent anthropogenic aerosol number emissions (Xausa et al. 2018) and a method to calculate local number size distribution of emissions from existing data (Kontkanen et al. 2020). The ACCC teams have extensive experience supporting ***climate change adaptation*** (Tuomenvirta et al. 2020), and studying global ***climate governance*** (Jordan et al. 2018). The latter includes ***climate law*** under the UN Framework Convention on Climate Change (UNFCCC), in the EU and in various other legal contexts (van Asselt et al. 2018, Yamineva and Kulovesi 2018).

Results in an international comparison

Atmospheric science in the University of Helsinki was ranked as <35th in 2018-2020 globally in its discipline in Shanghai Ranking. Further manifestations of the quality of the results in international comparison are 16 ERC grants (~10% of grants awarded to Finland), 50 Nature and Science papers through times (~10% of all from Finnish institutes), 11 Clarivate Analytics' highly cited researchers (42% of Finnish researchers on the list; over 5% globally in geosciences), and leading positions in European Research Infrastructures (one of the ACCC home campuses (Kumpula) is hosting head offices of ACTRIS and ICOS ERIC).

Demonstrated impacts originating from the previous research

8 ***spin-offs*** for atmospheric instruments, optical fibres, air cleaning solutions and air imaging and data processing have been established (Airmodus, Karsa, SMEAR Ltd. Dekati, nLight Finland, Tassu, ESP, SMAPS). We have collaboration with >40 national and >50 international **enterprises** as experts in environmental services, process understanding, and instrument development and testing such as long-lasting collaboration with **Vaisala Corporation** (products for environmental and industrial measurement) and **Neste Oyj** (refined oil products and renewable fuels, the largest renewable diesel producer and listed as the 3rd most sustainable company in the world (Corporate Knights)).

On a global scale, several ACCC researchers are actively involved in the IPCC work (AR5 and AR6 writers, CMIP6 modelling efforts, national IPCC working group members), WMO commissions and UNFCCC delegations. The ACCC team in UH leads the PEEX program (http://www.atm.helsinki.fi/peex/index.php) that has over 30 collaboration agreements with international research organizations and companies and forms our strategic contribution to Future Earth (https://futureearth.org/). Furthermore, PEEX has a sister program DBAR (http://www.dbeltroad.org/index.html) with wide partnership with the Belt and Road initiative launched by the Government of China. ***In Europe***, we have given numerous briefings for the EU parliament and led writing a report on forest policies in EU released by the European Academies' Science Advisory Council. ***In Finland***, we have given numerous briefings to our national parliament. We have members in the Finnish Climate and Nature Panels, our economic models have been used in developing the national forest management instructions, and the most used weather application in Finland is offered by FMI. ***Stakeholder engagement*** in research has been especially successful in the collaboration of UH and FMI with the city of Helsinki in planning city boulevards to optimize air quality, initiating and realizing the Helsinki Metropolitan Air Quality Testbed (http://fmispace.fmi.fi/index.php?id=haqt) to build a comprehensive measurement network for air quality, and in the collaboration with farmers and food companies to find solutions to increase soil

carbon storage in agriculture (Carbon Action, https://carbonaction.org/front-page/). To engage the public, we have e.g. organized science-art events, made science-related murals on streets and opened online 'Ask about the climate'-service (https://www.kysyilmastosta.fi/en/). We also recently established the Climate University program (https://blogs.helsinki.fi/climateuniversity/), a collaboration of 11 Finnish universities, to re-imagine and reform Finnish climate education.

Competence and merits of key researchers and impact experts

Table 3.1. ACCC key researchers (PIs) and impact experts listed with their merits. H-indices are based on ISI Web of Science Aug 2020, listed as *Hnn*.

ACCC key researchers: ***UNIVERSITY OF HELSINKI** *Institute for Atmospheric and Earth System Research (INAR):* Academy prof. **M. Kulmala**, Atmospheric Sciences, title of "Academician" in Finland, China and Russia, ERC AdG twice, Fedor P. Litke Gold Medal of Russian Geographical Society, leads ACTRIS Finland and PEEX, *H115*; Prof. **T. Vesala**, Greenhouse gases and micrometeorology, Finnish Climate Panel, *H71*; Visiting prof. **D. Worsnop**, Atmospheric chemistry, American Chemical Society ES&T award 2017, *H112*; Prof. **J. Bäck**, Forest-Atmosphere Interactions, leads eLTER Finland, national committee to IPCC and Nature Panel, *H28*; Prof. **V.-M. Kerminen**, Aerosol-cloud-climate interactions, ISI highly cited scientist, IPCC author, *H68*; Prof. **H. Vehkamäki**, Computational aerosol physics, ERC StG and ERC AdG, *H48*; Prof. **T. Hölttä**, Physiological tree processes, *H29*; Assist. prof. **P. Paasonen**, Air quality –weather – climate interactions, *H27*; Prof. **T. Petäjä**, Experimental aerosol physics, *H67*; Assoc. prof. **A. Lohila**, Biogeochemical cycles, leads ICOS Finland, *H27*; Prof. **H. Järvinen**, Dynamic Meteorology, *H30*; **M.-L. Riekkola**, Analytical chemistry, *H35*; Prof. **A. Mäkelä**, Forest management and modelling, *H22*; Assoc. prof. **M. Ehn**, Atmospheric physical chemistry, ERC StG, *H45*; Assoc. Prof. (joint with UH and FMI) **K. Lehtipalo**, Experimental aerosol science, ACTRIS, *H32*; Assoc. prof. **M. Pihlatie**, GHG in boreal forests and agricultural ecosystems, ERC StG, *H33*; Assoc. prof. (joint with HELSUS) **L. Järvi**, Applied urban meteorology, *H24*; Assoc. prof. **M. Sipilä**, Atmospheric mass spectrometry, ERC StG, *H51*; Prof. **P. Uotila**, Polar oceans and their role in climate variability, *H25*; Assoc. prof. **F. Bianchi**, Atmospheric chemistry, ERC StG, *H27*; Assoc. prof. **A. Porcar-Castell**, Photosynthesis and remote sensing, *H18*; Prof. **P. Pellikka**, Remote sensing and land-use change, scientific leader of Taita research station, *H22*; Visiting prof. **L. Heininen**, Arctic policy, leads IIASA Arctic Future Initiative, *H4*; University lecturer **T. Kurten**, Molecular atmospheric chemistry, *H34*; University lecturer **A. Ojala**, Lacustrine studies, *H20*; *Dept Forest Sciences:* Prof. **O. Tahvonen**, Forest economics and policy, *H25*; Assoc. prof. **K. Karhu**, Soil processes and their interaction with the atmosphere, *H13*; ***FINNISH METEOROLOGICAL INSTITUTE**: Chief Scientist **A. Laaksonen**, Aerosol cloud climate interactions, *H62*; Res. prof., Head of Unit **H. Hakola**, Reactive gases, member of national committee to IPCC, *H37*; Res. prof., Director **H. Korhonen,** Earth system modelling, ERC CoG, Vice chair of Finnish Climate Panel, member of national committee to IPCC and European EC-Earth modelling consortium, *H23*; Res. Prof., Director **J. Pulliainen**, Satellite applications for cryosphere and boreal zone, ESA Earth Observation Program board delegate of Finland, *H37*; Res. Prof., Head of Unit **J. Liski**, Terrestrial carbon cycle, *H38*; Res Prof. **A. Perrels**, Socioeconomic impacts of climate change, *H14*; Res. Prof., Head of Unit **J. Tamminen**, Satellite methods and applications for atmospheric composition, air quality and GHG, Member of ESA Advisory Committee for Earth Observation, Vice director of CoE in Inverse Modeling and Imaging, *H29*; Prof. **H. Haario**, Bayesian inversion methods and uncertainty quantification in satellite imaging and climate applications, *H28*; Adj. Prof., Head of Unit **H. Gregow**, Weather and Climate Change Impact Research, member of Follow-up Group on National Adaptation Plan, *H17;* Res.Prof. **M. Sofiev**, Atmospheric composition modelling, PI of SILAM CTM and IS4FIRES, WMO Scientific Advisory Group on Applications, Board of European Aeroallergen Network, *H34.* ***UNIVERSITY OF EASTERN FINLAND**: *Dept Applied Physics*: Prof. **K. Lehtinen**, Atmospheric Physics and Chemistry, head of UEF research community "Climate forcing, ecosystems and health", member of national committee to IPCC, *H47*; Prof. **A. Virtanen**, Environmental Physics, ERC StG, *H32*; Assoc. Prof. **T. Yli-Juuti**, Process modelling of aerosol physics, *H17*, Assoc. prof. **S. Schobesberger**, Atmospheric Mass Spectrometry, *H27*; Assoc. prof. **A. Seppänen**, Computational Physics, *H18*; *Dept Bio and Environmental Sciences*: Prof. **J. Pumpanen**, Biogeochemical cycles between ecosystems and atmosphere, *H37*; Assoc. Prof. **M. Maljanen**, *H24*; Greenhouse gas fluxes and biogeochemical cycles; *School of Forest Sciences*: Prof. **E.-S. Tuittila**, Peatland vegetation and carbon dynamics, *H40*; *Dept Law*: Prof. **K. Kulovesi**, International law, ERC StG, *H4*; Prof. **H. van Asselt**, Climate Law and Policy, *H13* ***TAMPERE UNIVERSITY**: Prof. **J. Keskinen**, Instrumentation, Emissions and Air quality, *H42*; Prof. **M. Dal Maso**, Aerosol emissions and atmospheric aerosols, *H47*; Assoc. prof. **T. Rönkkö**, Instrumentation, emissions and atmospheric aerosols, *H25*; Ass. Prof. **M. Rissanen**, Aerosol analytics, *H27*.
Impact experts: **H. Lappalainen** (UH & FMI), Adjunct. prof., GlobalSMEAR, Secretary General in PEEX; **S. Sorvari,** (FMI) PhD, ACTRIS PPP leader and Environmental RIs; **A. Asmi** (UH), PhD, European open data, **K. Lauri** (UH), Univ. lecturer, Education planning and development; **J. Kujansuu** (UH), Collaboration in China, GlobalSMEAR; **A. Lintunen** (UH), Adjunct. prof., Coordination of INAR; **T. Rasilo** (UH), PhD, National and European Ecosystem RI; **L. Riuttanen** (UH), PhD, Art-science collaboration, education planning and development, climate collaboration with Finnish church; **N. Altimir** (UH), PhD, Science visualization; **S. Häme** (UH), PhD, Coordination of ACTRIS Finland; **A. Heikkilä** (FMI), PhD, Member of UNEP/EEAP; **S. Mazon** (UH), PhD, Science outreach and secretary of FES; **J. Pulliainen** (FMI), Res. Prof., Director; ESA Earth Observation Program board delegate of Finland; **I. Ialongo** (FMI), Specialist in usage of satellite data in society; **L. Höckerstedt** (FMI), PhD, Coordinator in Climate System Research and SRC MULTA, **P. Karjalainen** (TAU), PhD, Industry-University collaboration; **F. Mylläri** (TAU), TAU Energy Group coordinator; **H. van Asselt** (UEF), Implementation of international and national climate laws and policies; **S. Mikkonen** (UEF), Coordinator of research on aerosols, climate change and human health; **A. Pauli** (UH), Professor of practice at INAR; **S. Paatero** (UH), Science-society collaboration and business development; **T. Kalliokoski** (UH), Adjunct. prof., Carbon sinks and storages.

Connections to innovation networks, ecosystems, actors important for generating impact

At the global level, the important ***policy impact actors*** are the World Meteorological Organization (WMO, FMI has a representative in many commissions, and WMO Secretary General P. Taalas will join the ACCC Science and Impact Advisory Board), IPCC and UNFCCC (UH and UEF are

accredited observers). An important initiative in our policy impact is the Pan-Eurasian Experiment (PEEX, led by the UH team in ACCC). The program promotes measurements and research on the land-sea-atmosphere continuum in the changing climate of the northern high latitudes and in China. PEEX implements its research goals through 15 projects and will serve as a facilitator to convey the ACCC outputs to different policy stakeholders especially in Finland, Russia (RAS, Russian Geographical Society) and China (CAS). The UH team also hosts the European Center of International Eurasian Academy of Sciences (IEAS). In Europe, an important policy actor is the Future Earth that promotes interdisciplinary global change research, with societal impacts (ACCC/UH hosts Future Earth Finland, https://futureearth.org/2015/06/29/future-earth-finland/). FMI represents Finland in different bodies of the European Space Agency and EUMETSAT**,** related to coordination of Earth observation satellites for atmosphere and climate monitoring and research. TAU represents ACCC in the transport panel of UNECE TFEIP that provides a technical forum and expert network to identify emission factors and establish methodologies for the estimation of emissions. TAU is also in the steering committee of European Research on Mobile Emission Sources (ERMES) that supports cooperative research, competent authorities and industry associations in the field of transport emission modelling, and ETC/ATNI that supports EU environmental policy and legislative frameworks related to air pollution. Key partners in the national policy impact environment are the Finnish Climate Panel, the National committee to the IPCC, and Follow-up Group on Climate Change Adaptation Plan**,** all nominated by the Ministries.

The best possible scalability for ***business impact*** is guaranteed by the global auditing and accounting sector participation. Together with global auditing companies (typically offering audit, advisory, tax and legal services), ACCC will search partners who are willing to reduce their emissions and manage their climate impact also by creating new carbon sinks with verified impact and in this way improve their competitiveness, attractiveness, branding, marketing and business development. It is important also for global auditing companies to further develop their own services in areas such as climate roadmap development and evaluating and auditing climate related financial risks and opportunities as well as sustainability advisory. More details can be found in letters of commitment from auditing companies. We also collaborate with the XXX, whose member companies are committed to develop their operations toward carbon neutrality and sustainable use of natural resources, and with the XXX Program. ACCC will also interact with XXX a European knowledge and innovation community working to accelerate the transition to a carbon neutral economy, and XXX, which strengthens climate research in Europe. In Finland, all ACCC partner organizations are members of XXX, an open innovation cluster with the mission of creating breakthrough solutions in bioeconomy, circular economy and energy systems.

4. PLAN FOR PROMOTING SCIENTIFIC EXCELLENCE AND IMPACT IN SUPPORT OF ECONOMIC GROWTH AND/OR INNOVATION ECOSYSTEM(S) AND SOCIETY

4.1 Description of the plan for promoting excellence and impact

4.1.1 Scientific and impact objectives of the research

The objectives of ACCC are: **1)** to provide beyond state-of-the-art scientific knowledge on two of the most urgent global Grand Challenges, climate change and deteriorating air quality by quantifying carbon sink and other interlinked radiative forcers, and by quantifying non-linear processes in atmospheric pollution cocktail; **2**) to establish a platform (ACCC Service Portal) for collecting big data from comprehensive observations and multiscale models to be delivered to various stakeholders;

3) to co-create science-based solutions for guiding the world toward climate neutrality; and **4)** to establish international and interactive atmospheric research – business innovation ecosystem to Finland. With these objectives, ACCC will establish and consolidate the world-leading ***atmosphere – climate competence center*** in Finland working in interaction with private sector and public authorities. More detailed description and expected results of the two interlinked research programs and the impact program are given in *Section 4.1.4* and *Table 4.1*.

4.1.2 Justifications

ACCC will provide breakthrough advances from climate and air quality research to practical solutions needed for achieving climate neutrality in Finland, as a front-runner for global climate neutrality. ACCC will support Finland becoming the internationally leading expert and provider of climate change-relevant technological solutions and data services. The Paris Agreement is central to our work because it affects global, EU and national policies and the operating environment of the private sector. Our mission is in line with the EU's goal to provide global climate leadership, as well as with the Finnish Government's Programme (2019) and roadmap towards carbon neutral Finland (2020). It is also in line with more specific and long-term national strategies, including the National energy and climate strategy for 2030 (2016), the National Medium-term Climate Change Plan for 2030 – Towards Climate-Smart Day-to-Day Living (2017) and roadmap 2050 (2014), the National climate change adaptation plan 2022 (2014), and the Government's Cleantech strategy (2014). We will also consider the latest government report on international economy, competitiveness and green growth (2020) in our ACCC work. The aim of these strategies is that Finland is an active and significant actor in EU environmental policy, and a significant know-how provider in areas where Finland has substantial competence such as cleantech solutions, climate-smart forestry and agriculture, sustainable urban design and climate services. It is also clear that ambitious targets aimed at different sectors of Finnish society need impartial impact verification mechanisms based on scientific results and climate research experience. There is also a wide recognition of climate change as a security factor and threat multiplier, as many states worldwide have already defined (Heininen and Nicol 2016).

The work of ACCC is also economically justified. The European Green Deal Investment will mobilize at least 1 trillion euros of sustainable investments over the next decade, including an ambitious package of measures from investments in cutting-edge research and innovation, reducing greenhouse gas emissions and increasing carbon sinks. These goals urgently need better verification mechanisms to follow and redirect focus if needed. All major international investment funds and monetary institutions recognize the importance of climate action and are searching for new ways to contribute in projects having truly global effect, with verified climate impact. Based on sectoral statistics, we estimate that ACCC has a value creation potential of 7 Billion euros in Finland by creating new jobs in green technology and climate change mitigation and adaptation, by improving productivity and reducing costs for climate-friendly management in agriculture and forestry (~23% of export revenues come from forest industry products in Finland), by providing solid evidence for tourist industry in Finland being the world leader in clean air and environment, and by direct business opportunities in security and related areas (e.g. XXX ltd). Another important justification are the 6.8 million premature deaths that air pollution causes annually, and reduces global GDP by 2-3% (Wu et al. 2017). We estimate that the ACCC activities will re-claim about 1% of the loss of GDP to Finnish economy by promoting the export ability of Finnish companies e.g. to Chinese markets.

4.1.3 Follow-up

The Executive Team ensures that results will be reached in the planned schedule (see *chapter 5.2.2* for ACCC structure). It also sets shorter-term annual milestones to make sure that the plan reflects the latest science developments and impact achievements, as well as changing needs of the society. ***The Steering Board*** ensures that interdisciplinary ACCC activities focus on achieving the strategic objectives and, if necessary, redirects activities to reflect new scientific, policy and business developments. This work is supported by the ***Science and Impact Advisory Board***, which evaluates ACCC strategy and results annually. The ***metrics to follow-up*** the scientific and impact productivity include, in addition to the result milestones (*Tables 4.1* and *4.2*), the number of peer-reviewed scientific articles (especially in high-impact journals), highly cited researchers, ERC grants and awards granted to the ACCC, number and level of policy briefs, number of direct interactions between decision makers, presentations in policy forums, participants in ACCC cross-cutting workshops, number of patents and spin-off companies established, successful boost projects, and increased economic value of the partner companies.

4.1.4 Expected scientific results

Research Program (R) 1 - Quantifying and activating the potential of land-based climate change mitigation: R1.1 Highly improved estimates and verification of GHG sources and sinks in terrestrial ecosystems (including inland waters); **R1.2** Reliable predictions and verification of terrestrial feedbacks (involving GHGs, aerosol-cloud-climate & albedo effects) to radiative forcing; **R1.3** Quantification of the full climate impacts of land use, land use changes and forestry (LULUCF sector, also e.g. REDD+ activities in tropics), accounting for GHG balances, albedo effects, aerosol-cloud-climate and water cycle effects, and feedbacks to ecosystems; **R1.4** Identification and development of agricultural practices optimizing soil carbon sequestration, as well as stand-level forest management practices that simultaneously optimize the value of carbon storage (including long-lived wood products), biodiversity, and the economic value of forest production; **R1.5** Identifying the key limitations for increasing the terrestrial ecosystem carbon sink in the Arctic-Boreal regions, with focus on Finland; **R1.6** Quantification of the impacts of Arctic change on high-latitude societies and ecosystems (also accounting for natural feedbacks to ecosystem GHG fluxes and aerosol precursors), and improving predictions of e.g. extreme weather events, vegetation changes and insect and wildfire outbreaks; **R1.7** Quantification of key ecological, social and economic impacts (including air quality) of land-use changes. Combined with a full life cycle analysis, this permits optimizing trade-offs between e.g. forestry, food production, fossil fuel substitution and air quality.

Research Program (R) 2 - Quantifying the air quality (AQ)-climate interactions and their impacts: R2.1 Quantifying the impacts of primary aerosols, anthropogenic and biogenic secondary aerosol formation, meteorology and their non-linear interactions on air quality. Identifying the key emitted pollutants triggering the atmospheric pollution cocktail and air quality problems in different locations, conditions, and scales; **R2.2** Development and validation of exhaustive aerosol emission number size distribution modules for regional AQ- and Earth system models. Future emission scenarios in full consistency with IPCC GHG emissions until 2050, including primary particle number emissions and gaseous pollutants. Framework to estimate comprehensive climate impacts of technological advancements and systemic level changes; **R2.3** Quantitative assessment of the total (both climatic and air quality relevant) impact of vehicular traffic under various traffic scenarios; **R2.4** Top down evaluation of anthropogenic aerosol impacts on cloud droplet formation and Earth's

radiation budget with cloud data from satellites, aerosol data from in-situ observations and CAMS/satellite based proxies, and model bias analyses; **R2.5** Development of a new generation of impact modelling tools to support rapid adaptation; **R2.6** Assessment of adaptation trajectories in relation to dynamic climate risks and implemented adaptation; **R2.7** Mapping the adequacy of existing legal frameworks for meeting Paris targets, with emphasis on Finland, the EU, China and Russia, and developing recommendations for new climate policies.

4.1.5 Breakthrough potential and scientific impact

Our research produces the knowledge required for versatile analyses of short- and long-term climate and air quality impacts of anthropogenic activities, and their terrestrial feedbacks. The conducted research leads to concrete and accurate estimates of how the past and future activities will shape the climate in global and regional scales. The research themes in ACCC – impacts of agriculture and forestry on climate change and air quality-climate interactions – are major uncertainties in our current understanding of the anthropogenic climate change. ACCC has scientific breakthrough potential both from the detailed analyses of the processes within the research themes (process level breakthroughs) and from the wide and comprehensive integration of these detailed analyses (Earth system level breakthroughs), which makes it possible to determine the interactions and feedbacks between the processes and socio-economic factors (society level breakthroughs). In co-operation with the stakeholders, our results on decreasing the climate uncertainties are directly transformed to possibilities in the economic sector (economic breakthroughs). Examples of how we are able to proceed from scientific breakthroughs towards society level and economic breakthroughs include i) the verification of carbon sinks and other climate forcers to boost forestry and agriculture related climate change mitigation and ii) the understanding, observing and verifying the changes in atmospheric pollution cocktail and furthermore sustaining healthy atmosphere and optimizing climate and air quality effects.

4.1.6 Expected contribution to society in its various forms and routes to impact

Policy Impact: The ***Paris Agreement*** of the UNFCCC aims to limit global warming to well below two degrees. In countries that announced nationally determined contributions (NDCs) that represent their pledges to reach this objective, land-based options to mitigate climate change are expected to deliver approximately a quarter of total emissions reductions. These pledges will be evaluated against the latest climate science every five years. The ACCC will influence this process in two ways: First, we will improve the reliability of the climate science used to evaluate the adequacy of the NDCs by improving the future climate change estimates and monitoring climate change, GHGs and other climate factors. Second, we will develop methods to calculate and verify climate impacts of different actions (see *objective 1*). These methods will be used to determine the NDCs in Finland, the EU, and other countries worldwide. ACCC research contributes strongly to ***forest policy, agricultural land use*** and ***food production***. Land-based climate change mitigation is the most cost-effective of the existing and scalable methods for negative emissions (e.g. Griscom et al. 2017, 2020). In Finland, the carbon neutrality goal highlights the importance of the LULUCF sector. Optimization of land-use between forestry, agriculture and forest conservation will allow the analysis of regional and global integration of forest and climate polices, including the economic efficiency of policy instruments and LULUCF-regulation. The profound process understanding paves way for extending the efficient land sector mitigation activities outside the Arctic-Boreal ecosystems. ACCC improves the ***tools currently applied for Finnish and European air quality legislation*** (FRES and GAINS, see *section 4.1.7*) in

terms of their applicability to quantify both climate and health impacts of technological solutions and systemic changes towards non-fossil society. One key target is to improve air quality and climate impact analysis on the use of renewal fuels and/or electricity instead of fossil fuels in traffic. Our advancements in verifying natural carbon sinks and quantifying climate impacts of combustion emissions allow ***development of effective and verifiable options to emission compensation***. We will disseminate the ACCC research outcomes, quantify assessments to policy making and co-design processes at large scales. This activity connects the ACCC assessment work to international bodies and invites them to co-design the main deliverables in a format enabling large-scale influence on policy making at regional and global scales (see *objective 3*).

Business Impact: Taking into account the enhanced interest of companies and pressure from citizens around the world, there is a timely opportunity to push climate work forward with the latest scientific results. Finding the best pathways towards healthy air and safe climate can pose difficult choices for actors on many levels due to the interlinkages and tradeoffs involved. A major difficulty in this is that the complexity and multidisciplinarity of the problem leads to a situation where knowledge on best practices - researched by scientists - is difficult to obtain and verify by both decision-makers and commercial operators. ACCC will provide a platform (see *objective 2*) that enables aggregating scientific knowledge and data in a manner that can be trusted by individual citizens and business partners alike, and will lead to the development of more sustainable solutions. Consumers ***value companies based on sustainability*** of their actions to deliver value. One fundamental criterion is their responsible approach to business regarding impacts on climate change. Companies are increasingly aware of this and develop their ***corporate responsibility*** towards both society and environment. With the help of our main partners from the global audit sector, ACCC develops and delivers ***improved verification of companies' climate impacts*** by developing robust and comprehensive impact assessments, leading to new business models and more extensive assurance services for various business sectors (see *objective 4*). ACCC also provides added value for corporate responsibility directly to companies, in terms of accurate emission and sink measurements that help to reduce the climate impacts of existing businesses, up-to-date climate and accurate weather information, reliable climate scenarios and narratives for carrying out their processes in a sustainable way and with minimum climate risks and thus provide an additional competitive edge facilitating additional revenue. We also co-create future business plans by accounting for climate-smart practices and climate-related risks. Together with companies, the ACCC will co-design new solutions and services towards climate neutral society and adaptation. We will develop projects promoting sustainable energy and land use practices, in particular addressing the combined effects on carbon sequestration and air pollutant emissions.

4.1.7 Implementation of the plan, approaches and methods

The ACCC flagship is implemented by two research programs and one integrating impact program. The cornerstone of ACCC research is the combination of integrated observations of different components of the Earth surface and atmosphere, experiments, multiscale modeling and theory (*Fig. 4.1*). The collaboration partners (LoC signed), representing the policy making sectors, private sector and other stakeholders are in close interaction with the research programs and participate in the impact programs (the role identified in more detail in the LoCs).

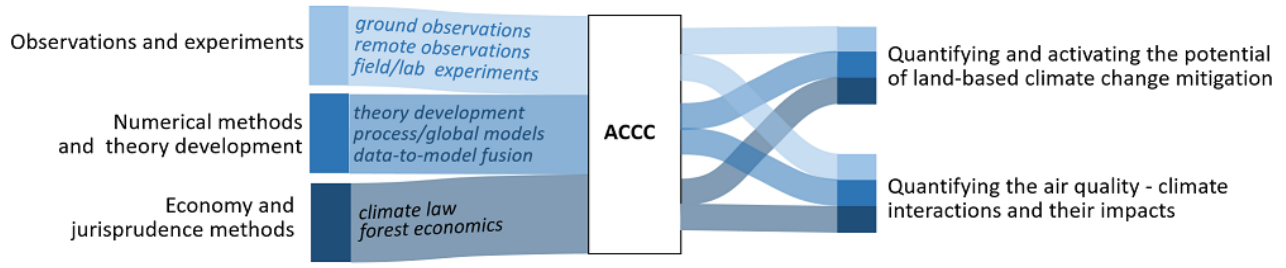

Fig. 4.1. Research methods and their contribution to Research Programs.

Research Program 1 - Quantifying and activating the potential of land-based climate change mitigation

The focus of our work on land-based mitigation will be on improving the identification of agricultural and forestry practices that are the most efficient for climate change mitigation in many regions (e.g. Griscom et al. 2017, Roe et al. 2019, Griscom et al. 2020), taking into account also the multi-functionality and economic value of agricultural and forest production. The mitigation pathways like restoration of peatlands, afforestation of agricultural fields, managing forests and agricultural lands for increased carbon stocks are recognized to include large uncertainties (Harper et al. 2018, Kalliokoski et al. 2018, Demenois et al. 2020) whose unraveling calls for transdisciplinary research approach. We will assess the potential for economically and socially optimal management of forests as carbon sinks and storages, also accounting for albedo, aerosol-cloud-climate (Kalliokoski et al. 2020) and water cycle effects, and feedbacks to ecosystem functioning and growth. In practice, photosynthesis is always accompanied with emission of volatile organic compound to the atmosphere as a side product, therefore carbon sinks are always connected to aerosol production and furthermore to aerosol-cloud-climate interactions. In agriculture, our main goal is to improve the carbon sequestration into soils for example by growing deep rooting plants, by keeping the fields crop-covered for the main part of the year, and by utilizing organic amendments (Bossio et al. 2020). Soil carbon processes in agricultural lands hold a high potential for relatively low-cost but high impact carbon sequestration. The ACCC will concentrate on the Arctic-Boreal region but will collaborate with research groups working globally.

We will use our comprehensive long-term field measurements (*GlobalSMEAR network*, Kulmala 2018) together with carefully designed manipulative field experiments and satellite observations. We will improve the quality and applicability of satellite observations at Boreal and Arctic latitudes in terms of e.g. carbon cycle, bio-geophysical feedback loops and weather forecasts, and contribute to new and planned satellite missions (e.g. Sentinel 5 measuring CH_4, CO and solar induced fluorescence, and the Copernicus high priority candidate mission by ESA). Also methods for tomography problems in a moving medium (Niemi et al 2015, Burge et al. 2017) and extended Kalman filter methods (Solonen et al. 2016) will be combined for better imaging of GHGs sinks and sources from satellite measurements. The ecosystem measurements will be tightly integrated with process and regional scale modelling. Our terrestrial ecosystem models describe carbon sequestration and production in terrestrial ecosystems as a function of environmental factors and management (e.g. *the soil carbon model YASSO15*, *the forest growth model PREBAS*, *the 1D atmosphere-biosphere model SOSAA*, *the CH_4 emission model HIMMELI* and *the Large-Eddy-Simulation model PALM*). We will combine experimental results and ecological models with flexible economic model structures to identify best management practices to increase carbon uptake to forests, while accounting for bioenergy and land use optimization between forestry, agriculture and forest conservation. Economic

optimization of carbon sequestration and timber production in forests will be based on discrete time optimal control that allows application of detailed empirical economic-ecological size-structured single and mixed species models. We will apply algorithms based on efficient interior point methods for large scale optimization problems (Parkatti and Tahvonen 2020, Sinha et al. 2017). The effect of extreme weather events on ecosystems and insect and wildfire outbreaks will be studied with numerical weather prediction model *AROME* and its Arctic version, and a regional climate model *Harmonie-Climate* will be used to provide climate scenarios for the Nordic region with an unprecedented spatial resolution (3 km). The carbon models will be further incorporated into global scale climate models (e.g. *Open-IFS*, *EC-Earth*, *NorESM* and *MPI-ESM*) to make their description of the future terrestrial carbon sink more realistic, and also to respond to different management scenarios. Revised estimates of the carbon budget will be calculated with the UVic Earth system model of intermediate complexity (EMIC). See also *section 4.1.6.*

Research program 2 - Quantifying the air quality-climate interactions and their impacts

Our research quantifies the impacts of aerosol and gaseous pollutant emissions and of atmospheric processes on the atmospheric chemical cocktail (Kulmala 2015), and further on climate and air quality. We investigate atmospheric composition, fluxes and processes with comprehensive long-term data (>1200 variables) from our measurement sites in Finland and China (Beijing and Nanjing) as well as our collaborators' sites around the world (e.g. Kulmala et al. 2017, 2020, Paasonen et al. 2018, Yao et al. 2018). These data, together with satellite retrievals, air mass trajectories and other reanalysis data products, allow us to determine the feedbacks and larger-scale interactions of air pollution, weather and climate. For the key compounds and reactions, we conduct laboratory experiments in our own chambers in Finland and in CERN and Leipzig (e.g. Lehtipalo et al. 2018, Dada et al. 2020). We investigate consistently the full spectrum of emissions, including GHGs, gaseous pollutants and aerosols. We apply global and national emission models (GHG Air pollution Interactions and Synergies, *GAINS*, Amann et al. 2011; Finnish Emission Scenario model *FRES,* Karvosenoja 2008) and advance their description of number size distribution of aerosol emissions to far beyond state-of-the-art (Paasonen et al. 2016). These models utilize predefined future scenarios determined e.g. for RCPs in IPCC framework, but we define also lateral scenarios with technological or systemic alternatives. Coupling GAINS and FRES with climate models and air quality models (*SILAM*, Sofiev et al. 2006) allows analyses of global climate and local air quality impacts of committed or planned changes. Together with our collaborators in the fields of toxicology and epidemiology, we can also estimate the adverse health effects caused by the air quality impacts (Yang et al. 2018, Mielonen et al. 2015). We develop observational methods for benchmarking the emission models, e.g. for number size distribution of locally emitted particles from the long-term measurement data (Kontkanen et al. 2020). We develop proxies for concentrations of particles large enough to form cloud droplets with in-situ data, global reanalysis data on air quality (*CAMS*) and satellite retrievals. We utilize these proxies with cloud observations from satellites and simulated cloud processes from Earth system models, for quantifying the impacts of anthropogenic aerosols on weather and climate.

ACCC will generate knowledge about the sustainability of climate change adaptation strategies, their connections to other sectoral policies across scales and over different adaptation trajectories. An integrated welfare evaluation of adaptation will be developed in high resolution GIS embedded model systems, encompassing urban climate models (Karsisto et al. 2015), urban spatial and regional development models (Votsis 2018, Dijst et al. 2018), and biometeorological models (Ruuhela et. al 2018). International archives of weather and climate model data reanalysis (*CMIP*, *CORDEX*,

Copernicus Climate data store) will be utilized to assess impacts, provide climate projections and further improve process understanding. This interlinked approach will enable assessment of the effects of climate change and climate variability on key human and socioeconomic indicators at local level, as well as evaluation of the effectiveness of measures. Our climate law research will identify the relevant legal frameworks and a range of regulatory options for adjusting them in light of the new scientific information generated by ACCC. We use 'global climate law' method that is more comprehensive than traditional legal research (Yamineva and Kulovesi 2018, Khan and Kulovesi 2018), building on global environmental law scholarship (Yang and Percival 2009) and the concept of polycentric climate governance (Jordan et al. 2018). This approach on the relevant legal landscape allows us to consider climate-change laws and regulations holistically at various levels and consider formal and informal interactions between the different layers.

Impact Program

The program will **1)** maximize the impact of the novel understanding of the land based climate change mitigation and ecosystem-atmosphere interactions for climate and air quality policy making in Finland and internationally; **2)** verify, in collaboration with auditing companies, the climate burden of companies and the positive climate impacts of their climate actions (due to altered GHG, aerosol emissions and carbon sinks); and **3)** promote the birth of new innovations and spin-off companies including further development of monitoring technologies and analysis services. The Impact Program is implemented via e.g. ***boost projects*** (*Table 4.1*). The climate neutrality requires emission cuts and new carbon sinks, and thus scientifically sound verification mechanisms for emissions and sinks are urgently needed in Europe and globally. This approach is exceptional in its systemic approach and scalability in the global market having concrete interface to sustainable investment development, manufacturing and raw material efficiency, circular economy values or any other aspect of climate-friendly business. By a systemic "ACCC impact track" with Research Programs and the Impact Program we create a totally new approach to business development by cooperating with the global auditing sector, guaranteeing a trusted interface between scientific results and several leading companies from various business sectors. Cooperation network will be continuously developed, especially with our collaborating partners from auditing sector. Defining measures for assessing emissions across the value chain, setting targets for managing carbon foot- and handprint and estimating the cost of reducing emissions is a necessary starting point. See also *section 4.1.6*.

The Impact Program gathers the ACCC research community, collaborating partners and stakeholders together by organizing meetings for distributing new ACCC results, facilitating further networking, organizing hackathons, competitions, brainstorming workshops, tutorials etc. We will bring the collaboration carried out in research programs (framing and iterating research questions, gathering data, conducting joint pilot projects, making narratives, applying new technologies, discussing results) into a wider context and discuss them at international policy, economic and business forums. The ACCC ***engagement team*** works together with scientists and stakeholders to translate new scientific knowledge on climate change, including land-use effects and air quality, into local, regional, national, EU-wide and international policies and regulations. The team actively engages in public outreach and builds links to agriculture, forestry, businesses and industry sectors, including SMEs. The ACCC ***services team*** creates user-relevant service prototypes, sets up adjustable innovation environments and concrete pilot projects and keeps up a dialogue with stakeholders to gain feedback. We co-design large-scale carbon offsetting scenarios with relevant partners to assess the climate impacts of forest- and soil-based offsets and ways to improve current

offset standards. Both teams support fast development and validation of sustainable solutions in private and public sectors, enable wider growth and delivery of services and innovations to support progress towards a sustainable future. ***ACCC Service Portal*** (*Objective 2*) distributes the new ACCC knowledge, data and services. This portal will be linked with existing sources of information and thus forms a market place for the ACCC capacity and network. The service portal builds on existing web-based services of the ACCC team, and will consist of different user interfaces and modules for distributing hub news, materials and services. We will also disseminate outcomes to audiences outside academia by briefings to high-level politicians and political bodies, other policy briefs and roundtable discussions, side events at international climate negotiations, public lectures and webinars, press releases and events, TV and radio documentary and YouTube interviews, website, blogs, and social media.

4.1.8 New initiatives

ACCC new initiatives are shown in *table 4.1* together with their linkage to expected research results and key collaborators. Some of the most essential new initiatives are described here. An essential new initiative is the ***Verified Climate Safety initiative*** to verify climate neutrality in scientifically sound manner in the boost projects (*I1-I8*) based on observation system. This initiative will be developed in close interaction between researchers, auditing companies and various businesses (see *section 4.1.7*). These activities are planned to be coordinated in the long term by establishing an impartial verification company, Climate Analytics Finland. For verification, we need comprehensive measurements of the Earth. The ongoing ***GlobalSMEAR initiative*** (*I11*) is a global network aiming for 1000 integrated, SMEAR II-type atmospheric-Earth system stations (Kulmala 2018). The concept relies on upgrading the existing observation networks (by national investments) into comprehensive stations that provide data from various ecosystems around the world. UH has just launched a commercial framework SMEAR Ltd, which enables station upgrading by providing a site-specific and tailored SMEAR-instrument setup together with technical guidance. This concept has already been successfully adapted to SORPES in Nanjing and HAZE Beijing. The initiative serves as a facilitator for distributing and connecting the European Environmental research infrastructures (ICOS, ACTRIS, AnaEE, eLTER) as an integrated measurement concept within and beyond Europe in close collaboration with WMO and GEO/GEOSS. ACCC will take the GlobalSMEAR Initiative to the next level by providing resources to put the concepts into action, and promote its implementation as a worldwide tool for monitoring and verifying the impacts of the actions taken to mitigate climate change and study the climate – air quality interactions. Two more initiatives to be highlighted are the ***Citizen Science Initiative*** (as part of I9) that enables the general public to contribute to problem definition, data collection and analysis in climate science and the ***Climate University*** (*I13*) coordinated by UH (https://blogs.helsinki.fi/climateuniversity/). It is a network of 11 universities in Finland developing climate change and sustainability education in higher education. Climate University will promote the sustainability transition of the society by educating active change makers who have competencies to tackle the multidimensional challenges of climate change and sustainability in the working life.

4.1.9 Data

ACCC will actively implement Open Science policy following the FAIR (Findable, Accessible, Interoperable and Re-usable) principles and guidelines, such as GEO Data Sharing Principles. We

employ open data services (e.g. CSC and EUDAT services) that facilitate findability and accessibility and provide persistent identifiers (DOI, URN) to the data for re-usability. The ACCC Service Portal will incorporate some of the data distribution platforms (e.g. AVAA SmartSMEAR) and provide search tools and links to other sources of ACCC's data. ACCC's own data services will be continuously improved together with CSC - IT Centre for Science. We also contribute to the development of FAIR principles and data services within ENVRI-FAIR and EOSC. Our participation in European environmental research infrastructures and international organizations (ICOS, ACTRIS, AnaEE, eLTER, GEO, WMO) supports data integration and interoperability. Data Management Plan will give guidelines for curation of data, access policy, terms of use and obligations from the relevant legal agreements.

4.1.10 Schedule

Table 4.2. Schedule for scientific results (*section 4.1.4*) and impact tasks (*Table 4.1*).
The scientific results are marked for the year when the first results are expected.

	2020	2021	2022	2023	2024
Land-based climate change mitigation					
Estimates of natural emissions and sinks	R1.6	R1.1		R1.2	
Identifying key limitations			R1.5		
Agricultural and forestry practices				R1.4	
Integrated impacts of land use change					R1.3; R1.7
Air quality & climate interactions					
Estimates of anthropogenic emissions	R2.3		R2.1		
Air quality and climate impact of emissions		R2.2		R2.4	R2.1
Legal framework			R2.7		
Impact assessment tools				R2.5	
Adaptation support					R2.6
Impact tasks					
Boost project-No1 (I1)	◆	◆	◆	◆	◆
Boost project-No2 (I2)		◆	◆	◆	◆
Boost project-No3 (I3)		◆	◆	◆	◆
Boost project-No4 (I4)		◆	◆	◆	◆
Boost project-No5 (I5)	◆	◆	◆	◆	◆
Boost project-No6 (I6)		◆	◆	◆	◆
Boost project-No7 (I7)	◆	◆	◆	◆	◆
Climate Analytics (I8)		◆	◆	◆	◆
Society Forum(s) (I9)		◆	◆	◆	◆
Operational PEEX (I10)	◆	◆	◆	◆	◆
Global Observatory (I11)	◆	◆	◆	◆	◆
Science Diplomacy (I12)		◆	◆	◆	◆
Climate University (I13)	◆	◆	◆	◆	◆
Steering Board meetings	◆	◆◆◆◆	◆◆◆◆	◆◆◆◆	◆◆◆◆
Science & Impact Adv. Board meetings		◆	◆	◆	◆

4.1.11 Risk management and mitigation

Table 4.3. shows the risk management and mitigation.

Table 4.3. The risks foreseen in science and impact. To tackle unforeseen risks arising over the course of the project, the Steering Group will design and implement a Risk Management Process.

Risks	Risk Management & Mitigation
Inadequate communication between disciplines and/or the Research and Impact Programs	Regular interdisciplinary workshops, thematic meetings with dedicated coordinators and transversal team meetings, internal interactive webpages, and annual meetings with clearly identified research impact sessions will ensure sufficient communication. The impact programs are actively engaging and closely interacting with the research programs. This will be coordinated by specific science and impact coordinators. (**Medium risk**)
Lack of coordination leading to unsuccessful implementation	Active collaboration between partners in the consortium will be further developed as part of the ***Dissemination and Interaction Plan.*** An internal reporting system is implemented, which provides continuous check-up of ACCC activities to detect potential problems early. (**Medium Risk**)
Methodological failures or lack of interoperability between RI / methodologies	Likely to occur at least for some method (**Medium Risk**). However, a wide combination of instruments and methods ensures that failure of a single method will not endanger overall progress. First-hand expertise as well as wide collaborative networks in building instrumentation and maintaining models. Careful strategic planning. Sufficient internal and international information flow.
Key personnel leaving the project	Some experts will inevitably change affiliation during the ACCC timeframe (**High risk**). However, efficient information sharing and training ensures that the ACCC is not dependent on single persons.
COVID-19 will restrict international activities	Spring and summer 2020 have shown that international collaboration can continue remotely even under restrictions (**Medium risk**). COVID-19 can also be utilized in climate change and air quality science as a emission reduction trial, and it increases the general need for mitigation of risks, such as climate change.
Global potential for cost-efficient land-based mitigation approaches found to be insufficient	ACCC is highly likely to identify at least some cost-effective approaches for land-based mitigation (**Low risk**). However, should their global potential prove to be insufficient, even more drastic and costly emission reductions, and possibly also geoengineering methods, may need to be used to reach Paris goals. ACCC will provide recommendations & analyses also for these less palatable options.
Predictions of climate change impacts not sufficiently constrained	Climate change impact assessment is a core competence of the ACCC, and significant improvements in predictive skill in this area are highly likely (**Low risk**). We will work closely with key stakeholders to maximize the impact and usefulness of our measurements as well as impact and adaptation tools.
Limited opportunities in business in Finland and abroad and in value creation to the private sector	The risk is that commercial activity and value creation based on the added value stemming from ACCC analysis on climate and air quality is not successfully capitalized by the private sector. Competition for the market share in this business will be tough (**High risk**). However, due to the huge market size, a small fraction can be significant in absolute terms. This risk is also alleviated as the potential business is distributed between several sectors and we have committed audition and business partners.
Solutions do not live up to the expectations of the stakeholders	We will apply participatory approaches from early on in the ACCC in order to share common goals and to form a better sense of responsibility among the parties. The co-creation activities of the ACCC impact programs and the active involvement of the stakeholders will minimize the risk. (**Medium Risk**)

4.2 Consideration of responsible science

ACCC will be in the forefront of maintaining and developing the FAIR principles. Our key strategy is to promote ***open science globally***: open-access publishing and open data. This enables to proactively promote ***trust*** to science utilizing also citizen science and science diplomacy. Our work is based on ***ethical research*** promoting integrity and deterring misconduct within all the components of the ACCC science and impact ecosystem. ACCC aims to ***promote equality*** and prevents direct and indirect discrimination based on gender, age, ethnic or national origin, nationality, language, religion, belief, opinion, health, disability, sexual orientation or other personal characteristics. For example, we will pay particular attention to the transparency of recruitment processes. It recognizes the importance of research integrity, following guidelines such as The European Code of Conduct for Research Integrity. ACCC produces research and data services to solve questions related to ***sustainability***, climate change, environment degradation and air quality, and thus strongly supports the sustainable development goals from the UN Agenda 2030 adopted by all the United Nations

Member States in 2015. In our own work, the aim is to monitor, report, follow and reduce the carbon footprint in all our activities. We will reduce our carbon footprint by making remote participation possible by default, by organizing face-to-face meetings in places that can be reached by public transport and by encouraging selecting vegetarian options for catering.

5. ECOSYSTEM AND ORGANISATION OF CANDIDATE FLAGSHIP

5.1 Description of the ecosystem and organization

ACCC ecosystem includes research institutes and organisations, companies, governmental organizations, NGOs and other actors that are important for activities in research, research infrastructures, knowledge transfer, business and innovations, and policy dialogue at national, Nordic/Baltic, European and global scales (see in more detail from the Letter of Commitment Appendix). The ACCC ecosystem is multinational, multidimensional and multidisciplinary.

Links to host organizations' strategic priorities

ACCC is led by UH, and it is strongly embedded into the UH strategy. ACCC builds upon the expertise of the high-quality research spearhead highlighted in the UH strategy for 2017-2020, i.e. atmosphere and climate. Atmosphere and ecosystem research was also one of the three chosen profiling areas in the UH profiling application PROFI3. In the UH's new Strategy for 2021–2030, ACCC is in the core of the strategic themes 'A meaningful life, human wellbeing and a healthy environment' and 'A sustainable and viable future for our globe'. ACCC also strongly supports UH's strategic choices to be a leader in responsibility and sustainability as well as to use openness to enhance research and collaboration. The research and collaboration in ACCC ties up excellently with the strategy of the other main partners FMI, UEF and TAU. ACCC supports the governmental strategy to deepen cooperation between the universities and the sectoral research institutes. The highest-level atmospheric science is at the core of FMI strategy. The multidisciplinary themes and approaches and the northern location make the Pallas-Sodankylä GAW an ideal site for creating important scientific innovations and testing new ideas related to climate change studies in arctic and sub-polar areas. In the future, FMI is strongly committed to develop the Pallas-Sodankylä GAW as a critical focus of FMI. A specifically important theme is calibration, validation and ground-truthing of European and global space-borne remote sensing instruments and products. UEF aims at ranking among the 50 leading universities in the world in its strong research areas including topics on aerosols, climate change and human health. "Environmental change and sufficiency of natural resources" is one of the four main global challenges that UEF seeks to find solutions for through strong expertise of the university. At TAU, the research is linked to the profiling area of "Urban Platform for the Circular Economy" that specifically links the research to ACCC.

Roles of the host organizations

The aims of ACCC are in line with host organization strategies, and all hosts are committed to support ACCC financially including significant ***strategic funding***. The funding is directed to personnel, research infrastructures and premises. Rectors of all three partner universities and the Director General from FMI together with four ACCC representatives form the highest administrative body of ACCC, the Steering Board (see *Fig. 5.1*). The second important role of the host organizations is ***supporting the ACCC activities***, especially the impact activities. Examples of such supporting parties are Helsinki Think Company, an entrepreneurship society of UH helping scientists to bring their

academic skills into action, and Helsinki Innovation Services, which helps researchers to turn their research results into commercial successes. UH also supports its' research teams in building cooperation with companies and communities via a Business Collaboration Team.

All ACCC organizations are already strong in atmospheric and/or climate sciences, but the core research areas and methods of contributing teams are partly different, creating synergy and permitting efficient ***distribution of work***. The core expertise in UH is the atmospheric aerosols and atmospheric chemistry, computational aerosol physics, GHG research, ecosystem and urban micrometeorology, ecosystem process modeling, forest economics, and pioneering atmospheric measurement technologies, especially comprehensive long term observations. At FMI, the core expertise is in carbon cycle research in forests and agricultural soils, climate and air quality impacts of aerosols and trace gases, Earth system modelling, numerical forecasting, climate impact assessment, adaptation research and development of satellite techniques. At UEF, the main expertise is in atmospheric aerosol-water interactions, aerosol-cloud interactions, cloud microphysics, emission health effects, peatland ecosystem research, biogeochemical cycles and climate change laws and regulations. The specialty at TAU is anthropogenic emissions and air quality research. All this together creates an exceptional added value for research itself and also remarkable impact for innovations, business development and policy planning.

Each partner also provides their ***research infrastructure*** for a common use. The most important ones include sub-Arctic SMEAR I, SMEAR II flagship station and urban SMEAR III stations by UH that measure atmosphere-ecosystem interactions. UH also has several laboratories and greenhouses. FMI maintains the Pallas-Sodankylä GAW infrastructure focusing on Boreal and sub-Arctic climate and terrestrial environment research. FMI runs weather, ocean and climate models used for operational and research purposes, and has the responsibility of maintaining national meteorological, air-quality, and marine Baltic observational networks providing open data for citizens. UEF runs (together with FMI) the Puijo SMEAR IV station and ILMARI laboratories for aerosol and health-effects studies. TAU has cutting-edge measurement capabilities for mobile atmospheric measurement and air-quality measurements.

Flagship management and administrative structure

The ACCC management structure *(Fig. 5.1)* supports tight integration of various disciplines, adaptive decision making and impact-oriented work, thus maximizing the ACCC results for the use of society. The open and adaptive management system enables us to recognize timely scientific and impact potentials and mitigate risks. The details of the management structure will be defined in a consortium agreement.

Figure 5.1. The highest administrative body of ACCC is the ***Steering Board*** with rectors/ director general from all host organizations. It carries out joint strategic planning and follow-up of ACCC resources. Parallel to the Steering Board is an independent and international ***Science and Impact Advisory Board (SIAB)*** that evaluates the strategy and results of the ACCC in terms of science and impact. The ***Science Executive Team*** takes care of operational management together with the ACCC directorate. The leaders of thematic Research Programs are members of the team: prog. 1 J. Tamminen and prog. 2 T. Petäjä. The ***Impact Program*** plans and manages stakeholder co-design regarding knowledge transfer and climate solutions. ***Research and Impact coordinators*** coordinate the activities and help to implement the decisions of the management bodies, and work closely with engagement and service teams for the practical work. The Science Executive team and the Impact Program report to the Steering Board and SIAB through the ACCC directorate

Key collaborators and their roles together with a description of active collaborations with the business sector and possibly with other sectors of society

Altogether 40 ACCC collaborators from research and private and public sectors have singed LoCs. For details see *Table 4.1* and the attached LoCs. In addition to these key collaborators, the consortium has direct working connections with >2500 researchers (joint papers) in 800 universities and research institutes in more than 50 countries.

Description of the innovation orientation of the environment

The ACCC innovation orientation schema is shown in *Fig. 5.2*. Our flagship will create new partnerships with leading companies from various business branches. The auditing sector will support companies to develop business and fulfill their sustainable development goals with ***verified and audited climate impact***. Strong contribution from the auditing sector will significantly increase credibility and scalability of new spinoffs and other business development based on our research and innovation capability. Impact tasks are linked to Research Programs where private sector cooperation helps in finding new incentives for investments and new business models leading to verified climate impact.

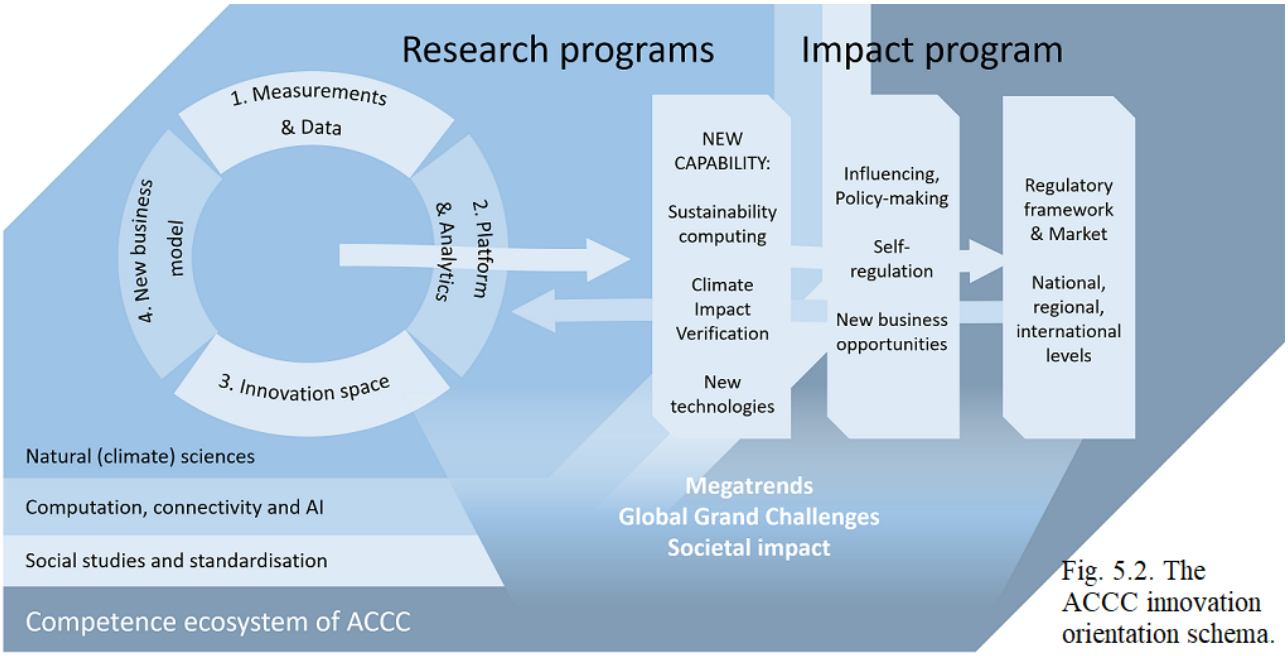

Fig. 5.2. The ACCC innovation orientation schema.

Actions to increase the appeal of the competence cluster/research environment

To use the full potential and increase the appeal of this competence cluster, ACCC will have dedicated programs for research and impact (see *chapter 4*). A revolutionary new type of business collaboration is foreseen by cooperating with global auditing sector guaranteeing trusted interface from scientific results to several leading companies from various business sectors. Majority of the business sector already recognizes the importance of climate actions and are searching for ways to aim for carbon neutrality. The ACCC competence cluster has a high potential to have truly global effects, with verified climate impact: safe climate and clean air.

6. Bibliography

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