Brussels, 27 May 2022

COST 041/22

DECISION

Subject: Memorandum of Understanding for the implementation of the COST Action “Techno-economic analysis of carbon mitigation technologies” (TrANsMIT) CA21127

The COST Member Countries will find attached the Memorandum of Understanding for the COST Action Techno-economic analysis of carbon mitigation technologies approved by the Committee of Senior Officials through written procedure on 27 May 2022.

MEMORANDUM OF UNDERSTANDING

For the implementation of a COST Action designated as

COST Action CA21127
TECHNO-ECONOMIC ANALYSIS OF CARBON MITIGATION TECHNOLOGIES (TrANsMIT)

The COST Members through the present Memorandum of Understanding (MoU) wish to undertake joint activities of mutual interest and declare their common intention to participate in the COST Action, referred to above and described in the Technical Annex of this MoU.

The Action will be carried out in accordance with the set of COST Implementation Rules approved by the Committee of Senior Officials (CSO), or any document amending or replacing them.

The main aim and objective of the Action is to The main aim and objective of the Action is to tackle the current research and techno-economic challenges, bottlenecks and barriers to drive the deployment of carbon dioxide capture, transport, utilization and storage (CCUS) chain by harmonising, sharing and disseminating knowledge and breakthroughs on CCUS across different stakeholders, domains and sectors.. This will be achieved through the specific objectives detailed in the Technical Annex.

The present MoU enters into force on the date of the approval of the COST Action by the CSO.

TECHNICAL ANNEX

OVERVIEW

Summary

TrANsMIT proposes a COST Action on the techno-economic analysis (TEA) of the overall, integrated CO2 Capture, Utilisation, and Storage (CCUS) value chain. It aims to bring together academia, research institutes and industry into a cutting-edge, pan-European knowledge network. The Action advances the research frontier of CCUS TEA from partially unharmonized and disciplinary research to harmonized, holistic pan-European, coordinated research on the full CCUS system, facilitating development of the most technologically, economically and commercially feasible CCUS technologies and systems. It will be achieved by harmonizing and coordinating the methods and tools used for CCUS TEA in Europe, leveraging the knowledge created by our partners in national or international research projects. The project focuses most on holistic assessment of the CCUS chain, and on those areas where most development is needed (e.g. CO2 capture from air, CO2 utilization). The created science will be an essential means to steer CCUS R&D and deployment in a direction that allows reaching climate targets on-time and in a cost-effective manner, while harnessing the competitiveness of European industry. TrANsMIT will have a strong focus on knowledge sharing and career development, tackling existing disparities in knowledge distribution and career opportunities. It will foster strong collaboration between the more and the less research intensive countries in Europe, improving the access of the latter to State-of-the-Art science and new research projects. It will put into leadership roles early-career researchers and minorities, helping to fast-track their career development. TrANsMIT will lead to top-tier techno-economic analysis of CCUS systems across European countries.

Areas of Expertise Relevant for the Action	**Keywords**
● Environmental engineering: Engineering of energy production and energy systems, energy distribution and application ● Environmental engineering: Energy and fuels ● Chemical engineering: Chemical engineering: processes and products (others) ● Chemical engineering: Sustainable engineering ● Environmental engineering: Environmental and geological engineering	● CO2 capture, utilization and storage ● negative emission technologies and direct air capture ● economic system analysis ● process modelling and analysis ● climate neutrality

Specific Objectives

To achieve the main objective described in this MoU, the following specific objectives shall be accomplished:

Research Coordination

● Establish a pan-European, interdisciplinary network for techno-economic analysis (TEA) that will put the necessary focus on CCUS. This network will bring together researchers and industrial practitioners who will engage in collaborative networking activities that will enable solving the challenges associated with TEA of current and novel CCUS technologies.

● Understand the current status of science in TEA approaches for CCUS. The existing methodologies and guidelines, along with the existing benchmarks for CCUS technologies and systems, will be thoroughly and systematically reviewed and inventoried.

● Improve the quality of CCUS TEA and thereby enable more informed investment and R&D decision-making by research, industry and other stakeholders. A tangible output will be harmonized guidelines and approaches to process modelling and TEA of CCUS technologies and systems, which will include technological, regional and time-related considerations.

● Ensure that the existing and developed research is easily accessible and encourage its wide use in research as well as industry. To this end, an open-access online database will be created.
● Establish the future direction for development of CCUS TEA and support its members in developing collaborative interdisciplinary research proposals and joint publications.

Capacity Building
● Support the career development of Early Career Investigators and female researchers, while leveraging the existing and new knowledge for less research-intensive countries.
● Develop a joint research agenda on solving the identified TEA challenges associated with negative emissions, advanced/emerging topics in classical CCS technologies and their integration.
● Bridge the gap between the research and expertise of practitioners in CO2 capture, transport, utilisation and storage. By including disciplinary and interdisciplinary experts on CCUS and TEA, the partially existing disconnection between the individual chain elements will be addressed, leading to overall better CCUS system designs and analysis.
● Establish the pan-European knowledge platform of choice and reference point for TEA of CCUS, while developing a critical mass in CCUS research.
● Support individuals in acquiring and developing know-how and key competencies in TEA CCUS. The TrANsMIT COST Action will promote multidisciplinary and multisector teaming and twinning exercises, further covering the pillars of policy, environment, and social.

TECHNICAL ANNEX

1. S&T EXCELLENCE

1.1. SOUNDNESS OF THE CHALLENGE

1.1.1. DESCRIPTION OF THE STATE OF THE ART

One of the key elements of the 2015 Paris Agreement shaping the global framework of climate policy is the pursuit of climate neutrality, i.e., a balance between anthropogenic greenhouse gas (GHG) emissions and their removal from the atmosphere. In lieu of this, the European Union (EU) aims to achieve net zero emissions by 2050, strongly aided by the objectives of the European Green Deal programme. The concentration of CO_2, the most dominant GHG, has reached 412 ppm in the air in 2020 when compared to 180-210 ppm during pre-industrial time. A solution complementary to activities leading to the elimination of CO_2 emissions is CO_2 capture, followed by its transport and use in the economy, or by permanent geological storage. Carbon Capture, Utilization and Storage (CCUS), which is the focus of this Action, is therefore a valuable and necessary complement to other low-emission solutions that allow to reconcile the use of fossil fuels and the occurrence of inevitable process emissions (e.g. in the cement industry) with the assumption of a climate-neutral economy. In view of the relatively weak pressure from the climate policy in recent years (e.g. low emission allowance prices in the EU), CCUS technologies have been experiencing less interest than other emission reduction options. However, along with the increase in the costs of CO_2 emissions and the depletion of the potential of alternative solutions, their importance for the effective transformation of the economy to climate neutrality will increase. The International Energy Agency (IEA) expects CO_2 capture and storage to contribute to approximately 14% of average global CO_2 emission reductions by 2050 and highlights the need to make investment decisions in the coming decade in order to ensure time for an adequate scale and availability of the technology. Intergovernmental Panel on Climate Change (IPCC) indicates that on a global scale, 348 to 1,218 Gt CO_2 should be captured and sequestered in 2100. Particular attention is paid to the technologies of CO_2 capture from sources using bioenergy, which from the point of view of the carbon cycle in the environment lead to the so-called negative CO_2 emissions. The European Commission (EC) also points to the significant role of CCUS in relation to industries where switching to RES is technologically impossible or unprofitable. The EC also emphasizes that an alternative to CO_2 storage may be its reuse for the production of synthetic fuels and materials. CCU technologies can be widely used in the economy and at the same time are consistent with the hydrogen policy and the assumptions of the circular economy. It is therefore necessary to understand, develop and implement measures to ensure adequate potential in the area of CCUS technology. This Action responds to this challenge.

Techno-economic analysis as essential means for CCUS policy and decision making: A key approach to evaluate the potential of, and make R&D and policy decisions on, CCUS technologies and systems is techno-economic analysis (TEA). The main elements of a TEA study are process modelling and simulation of CCUS technologies and the integration with their host plants, calculating key performance indicators (KPIs) for their technical and economic performance, and comparing the results against reference cases. Process modelling and simulation involves mathematical modelling of unit operations, combining them into a process flow diagram, optimizing the performance of the overall system and finally verifying the results against experimental data. Some important KPIs for a CCUS technology include the thermodynamic efficiency, CO_2 capture and avoidance rates, the incremental cost of a product due to CCUS (e.g., cost per tonne of product) or the amount of CO_2 utilized per ton of product (in case of utilization). Although models and tools are being developed by researchers' groups, for a comprehensive evaluation of CCUS, lessons learnt from social studies, prospective modelling or Life Cycle Assessment (LCA) need to be considered in TEA. A distinguishing element of TEA for CCUS is that many such technologies do not yet exist at commercial scale, and as with other new energy technologies, this requires advanced approaches to estimate techno-economic (TE) performance. This field is usually called ex-ante TEA, in contrast to the assessment of developed or mature commercial technologies (ex-post TEA), and is used to evaluate a scaled-up technology in order to explore its potential application by defining a range of scenarios where the technology may operate.

Large heterogeneity in the CCUS value chain: The CCUS value chain itself is characterised by large heterogeneity in terms of types of CO_2 sources, capture methods, transport modalities, storage options and utilization options (see Figure 1), which poses significant challenges as discussed next. The heterogeneity in CCUS value chain presents itself, firstly, through the many types of CO_2 point sources where CCUS can be applied, broadly categorised as CCUS from power production, CCUS in industry, and direct CO_2 capture from the atmosphere. Power production mainly includes gas, coal, and biomass-fired power plants. In the industrial sector, CCUS can be connected to steel and cement production, refineries and petrochemicals, paper and pulp, waste incineration, and reforming-based hydrogen and ammonia production, among others. Each of these CO_2 sources comes with different kinds of gas from which the CO_2 is captured, with differing parameters, CO_2 concentrations and impurities/contaminants. Second, CO_2 capture technologies are very heterogeneous. Developed technologies include liquid solvents, solid sorbents, calcium or chemical looping, cryogenic separation, membranes and combinations of those. Transport of CO_2 is less diverse and can broadly be done by pipeline, ship, or tank truck/railroads, but also here specifications on the state in which it is transported (supercritical, liquid or gas), and where it is transported to (onshore or offshore transport routes) can make a difference in the technologies used. Storage technology differs mainly in the type of storage site used (depleted oil and gas fields or saline aquifers) and the location (onshore and offshore). Options for temporary CO_2 storage and intermediate injection sites to facilitate easy offshore storage are also a current research topic. Finally, CO_2 utilisation is a very diverse field, though with huge potential which is growing fast, spanning the production of synthetic fuels, chemicals, carbonated minerals, the direct use of CO_2 in the food and beverage industry, energy storage for balancing the grid or enhanced hydrocarbon recovery; all technologies being very different in nature and spanning different scientific and engineering fields. The above-described heterogeneity results, first, from ongoing discovery, research, development and diversification, taking place in different scientific fields (e.g. in chemistry, engineering, materials science, geoscience). Second, it is a result of changing policy, societal and industrial needs or questions, where a shift of capture and storage (CCS) from the power sector to CCS for heavy industry, CO_2 utilisation, and recently (in light of the Paris 1.5°C target) to large-scale negative emission technologies (NETs) has been seen. It is expected that the current portfolio is not the final one, and that in the coming decades more technologies will emerge, as well as more combinations of technologies and systems, and new ways to mitigate GHG emissions. CCUS technology and system analysts need to follow up by developing the tools and methods to soundly and comprehensively assess these new technologies.

Efforts of the TEA community to harmonise practises towards CCUS technology assessment: The TEA community has tried to keep pace with the rapid diversification of the CCUS portfolio, by for instance focusing on best practices and harmonising methods for the assessment of new CCUS technologies, following new technology discovery and development. Examples of best practices, benchmarks and reference cases for technology assessment include work by the European Benchmarking Taskforce, US Department of Energy, and IEA Greenhouse Gas R&D Programme. As of now, many of these guideline, harmonisation or benchmarking exercises still focus on classical CCS from power plants under steady-state operational conditions. Techno-economic analyses of power with CCS under flexible operations are largely missing. For industrial CCS, most techno-economic evaluations have been published by IEAGHG, including refineries, hydrogen and ammonia production, cement and iron and steel. Recently, the CEM-CAP consortium also published an independent techno-economic framework on CO_2 capture from cement plants, based on prior FP7 and H2020 studies. Some techno-economic studies on CO_2 transport and storage in Europe are available, e.g., by Pale Blue Dot Energy and Zero Emissions Platform (ZEP) , but they are few, differ much amongst each other and sometimes rely on proprietary data, which may limit their adoption. A recent coordinated effort between 12 institutions resulted in summarizing and providing guidelines for TEA from power and industrial sectors, but do not account for utilization or negative emission technologies like bioenergy carbon capture and storage (BECCS) and direct air capture (DAC). For CCU, the University of Michigan Global CO_2 Initiative and partners are currently working on guideline documents on the economic and life cycle analysis of CO_2 utilisation technologies, of which the first has been published. Conversely, widely accepted benchmarks, best practices and KPIs for the TEA of NETs like bioenergy with CCS and DAC with CO_2 storage are yet to be developed which proves the importance of this COST Action.

Distribution of knowledge and research efforts in CCUS TEA: In Europe, there is a skewed distribution of knowledge and research on CCUS TEA. The UK, Norway and The Netherlands have shown significantly higher inherent interest in CCUS (based on their high storage capacity index and implemented CCUS policies and regulations). They ha(d/ve) strong national research programs, e.g. UKCCSRC, Climit, CATO, NCCS, NorthernLights and others, alongside substantial demonstration projects. Other European countries, like Spain or Italy, have made slightly more modest contributions to CCUS R&D and deployment with usually more specific technology focus (for instance, Spain has produced high-quality research on CO_2 capture through calcium and chemical looping). Several European countries have started to develop CCUS research (and policy) only quite recently (e.g. Poland, Serbia, Croatia), and where much research talent is currently left untapped, e.g. because of lacking national research programs. Some of these latter countries may, however, be in dire need of robust CCUS R&D because of their continued high dependence on fossil fuels. This skewed knowledge distribution also means that most of the TEA's and reference studies so far were drafted for the North Sea countries. In addition, much technology-specific and operational knowledge lies within companies, which does not always reach the public domain. This is, for instance, the case for proprietary technologies or industrial pilot plants. Another example is operational data from CO_2 producing plants on production rates and flexibility, power, heat and utility availability, turndown and process control regimes. This also limits the use of realistic data for techno-economic analyses.

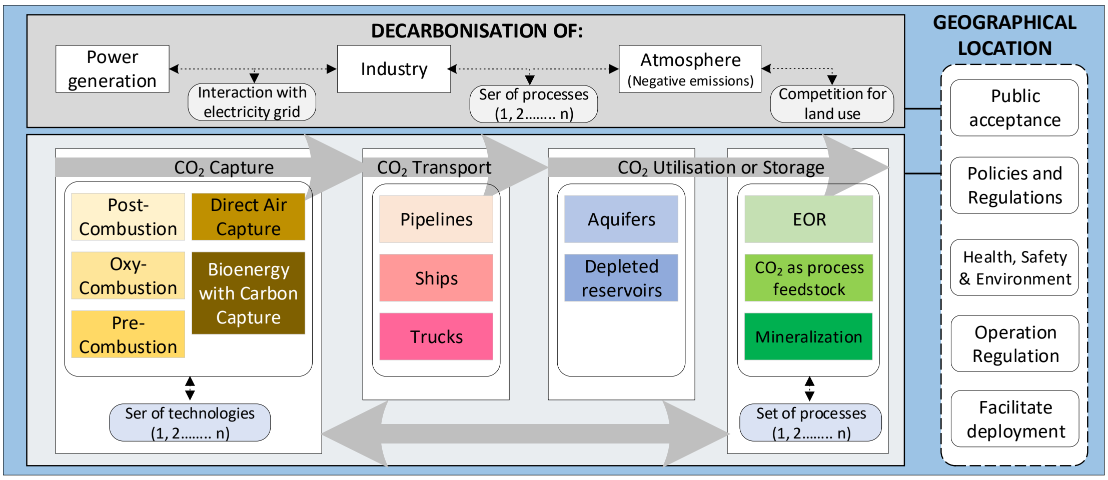


Figure 1. Overview of the CCUS system showing the heterogeneity in the value chain and interaction with location.

1.1.2. DESCRIPTION OF THE CHALLENGE (MAIN AIM)

RELEVANCE. The relevance and timeliness of this COST Action is that the most feasible CCUS technologies and systems need to progress towards commercial deployment in the very short to longer term to avoid missing EU the global climate targets while securing its high economic competitiveness.

Relevance to science and technology. The relevance to science and technology development of establishing a network on TEA is, first, because of the guiding role that TEA plays in technology R&D. Being able to perform sound TEA means being able to guide R&D in the most optimal direction. For example, TEA uncertainty and/or risk analysis can pinpoint exactly those areas of technologies and systems that are weakest, incur most uncertainty, and/or have the highest influence on successful deployment (and conversely on potential failure). R&D can then be directed to address these areas, where

TEA can help to assess if the direction of improvement is indeed as required, or if further improvement is necessary. Second, TEA is a key element of the scientific field of ex-ante technology analysis, where previous work showed that there is much scientific value in systematically developing methods, tools and best practices for TEA, since they enhance the understanding and appreciation of technology and technological systems, but also because they progress science itself. Bringing CCUS techno-economic analysists, technology developers and industries together in one network, will allow learning from each other's fields, thereby improving TEA practices to an extent greater than the sum of the participants' knowledge. Previous work on CCUS TEA has also cross-fertilized other research areas on e.g. renewable technology development, energy policy and law, adding extra relevance to the development of this scientific field.

Relevance to society and economy. The relevance of CCUS to society and economy is that it is an indispensable climate mitigation technology if our society is still to produce economic goods at current levels and remain economically competitive. Addressing climate change requires a globally coordinated, long-term response across all involved sectors of the economy, leading to net-zero GHG emissions in the second half of this century. In 2018, the EC communicated that cost-effective CCUS will have to contribute significantly in most CO_2 decrease scenarios. It also stated that CCS is a vital option for decarbonization of several heavy industries and, when combined with renewable energy or direct air capture, can deliver highly needed "carbon negative" values. To reach these goals on the swift, cost-effective and large-scale role out of CCUS, sound TEA methodology across all European countries is key.

CHALLENGE. Techno-economic analysis is thus a powerful tool to evaluate the potential and assist the development and commercialization of CCUS technologies. While the number of CCUS studies and technologies is growing, several challenges hinder their impact and must be urgently faced.

Scientific & technology challenges

First, the amount and heterogeneity of technologies across the CCUS value chain and their different stages of maturity complicates integrated and systematic TEAs. With research groups still often working disciplinary, research contributions focus on issues of carbon capture, storage, or utilization alone, while important synergies and/or interface requirements remain unexplored. Bridging this gap would lead to overall better system and technology designs but is challenging and can only be done with the collaboration between specialists from different research areas through interdisciplinary approaches.

Second, insufficient networking and communication in the CCUS community between research, industry (and policy-makers) creates barriers to R&D and the deployment of optimal CCUS technologies and systems. In addition, many TEA fail to receive proper validation due to data scarcity from real plants and the limited exchange of information between researchers and industry. Considering the increasing, but still limited public information from pilot/demo and commercial plants, more effort is required to identify operational problems affecting the competitiveness of CCUS technologies, including equipment availability and reliability, operation regimes, and host plant operation. Thus, a challenge is to improve industrial-academic interaction and knowledge sharing for increasing the quality of TEA concerning the whole CCUS chain as well as its elements. Accessible public data would foster the quality of models and benchmarks, which is important to the TEA practitioners and all other relevant stakeholders.

Third, our review of the current state of CCUS TEA shows that sound analysis methods, guidelines, and benchmarks for some novel technologies are largely missing (e.g., Direct Air Capture with Carbon Storage (DACCS), BECCS or CO_2 utilization). Overall, guidelines and benchmarks are better established for CCS in power and industry than for transport, utilization and storage and less so for negative emission technologies. This limits comparative analyses of technologies and systems required to set future directions of CCUS development. Additionally, European references/benchmarks are often set at a North Sea location and may be less representative for other European regions. Coordinated efforts to fill these gaps on data quality, regarding representativeness, completeness and consistency, will contribute to an improvement in TEA and will contribute to improved TEA and thereby to better informed decision-making.

Economic & societal challenges

Fourth, although CCUS has been on the research agenda of many European countries, R&D activities and policy initiatives are far more advanced in countries such as Norway, the Netherlands or the UK than in others, including many of the International Target Countries (ITCs), where the knowledge base and access to research funding are more limited. This high disparity limits the ITC's competitiveness in applying for European funding for CCUS R&D. Additionally, many of the ITCs rely heavily on fossil fuels and, therefore, need sound solutions to decarbonise their economy while preferably improving their economic competitiveness. Thus, there is an urgent need to decrease the disparities in existing knowledge and experience within Europe between CCS frontrunners and the following countries. This should increase the possibility to develop common, pan-European R&D programs, and implement feasible policies and technologies needed to reach low carbon, competitive economies across Europe.

Fifth, issues related to efficient use of human research capital for CCUS science (as for other academic disciplines) can also be considered a societal challenge. These are mainly researcher age and gender. Early Career Investigators (ECI) often have limited experience in proposal writing and leading research projects, and still have to build up their professional network. This may lead to a chicken-and-egg kind of problem and hinder their access to research funding. Also gender inequalities still exist in science and engineering (in particular), decreasing the chances of women to advance their career and to take an active part in advancing CCUS technology.

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 approach to the challenge in TrANsMIT is to establish a holistic, pan-European, interdisciplinary, highly inclusive network of researchers and industrial practitioners covering all elements of the CCUS value chain. Holistic, thematic working groups will be established to systematically address the key CCUS TEA challenges, as described in Section 1.1.2. These working groups will set up the necessary networking activities, including workshops and joint publication of review and guideline documents (described in Section 4). Workshops and Short-Term Scientific Missions (STSM) will be tailored to foster academic/industry collaboration and to maximise knowledge sharing and new knowledge generation. The working groups will also coordinate research, facilitating collaborations between different funded research projects, e.g. national or Horizon Europe and by identifying further CCUS research needs, transforming them into joint research proposals. Dissemination activities will include the establishment of an online database containing technical and economic models developed by the partners, relevant datasets and harmonized information on CCUS benchmarks and TEA methods and tools. Knowledge dissemination will also commence through the TrANsMIT cross-sector and multi-stakeholder dialogue through interdisciplinary workshops, STSMs, Training Schools, webpage and newsletters, through presentations at national/international conferences, and through publicizing in peer-reviewed journals. Early Career Investigators and women, with an additional emphasis on those from ITCs, will be encouraged to take up leadership roles in these activities. They will receive coaching by the senior, established researchers in the network on skills like project management, network building and research definition. Hence, TrANsMIT helps to progress their careers to become valuable members of the EU CCUS research community. Finally, TrANsMIT will cater to the development needs of (especially) scientists from ITCs and industrial practitioners, by offering them relevant and state-of-the-art (SotA) Training Schools and STSMs. Through these activities, TrANsMIT will open doors for establishing a long-lasting network of interdisciplinary researchers and for promoting the holistic analysis of the total CCUS value chain. Table 1 shows the relevant TrANsMIT challenges, their approach, and the resulting progress beyond the SotA.

1.2.2. OBJECTIVES

Based on the above description of SotA, bottlenecks, challenges, and progress beyond the SotA, this section and Table 2 describe the specific objectives that TrANsMIT aims to achieve.

1.2.2.1 Research Coordination Objectives

1. Establish a pan-European, multi- and interdisciplinary network for techno-economic analysis that will put the necessary focus on CCUS. This network will bring together researchers and industrial practitioners who will engage in collaborative networking activities to exchange their experiences and knowledge that will enable solving the existing challenges associated with TEA of current and novel CCUS technologies. This is essential to drive successful commercialisation of CCUS.
2. Understand the current status of science in TEA approaches for CCUS. The existing methodologies and guidelines, along with the existing benchmarks for CCUS technologies and systems will be thoroughly and systematically reviewed and inventoried. This will establish a baseline for the state-of-the-art in TEA of CCUS upon commencement of the Action.
3. Improve the quality of CCUS TEA and thereby enable more informed investment and R&D decision-making by research, industry and other stakeholders. A tangible output through research coordination will be harmonized guidelines and approaches to process modelling and TEA of CCUS technologies and systems. This will include technological, regional and time-related considerations (currently often not included) where necessary and will account for the inputs and feedback of the industrial partners.
4. Ensure that the existing and developed research is easily accessible and encourage its wide use in research as well as industry. To this end, an open-access online database will be created. This will contain process models, along with the relevant modelling assumptions and documents with modelling guidelines that are available in the literature and that will result from the research coordination within TrANsMIT. Where possible, operational characteristics and information from pilot, demonstration and commercial campaigns will be also uploaded for the sake of further harmonisation activities. The database and its contents will be publicised through workshops, social media, and conferences.
5. Establish the future direction for development of CCUS TEA and support its members in developing i) collaborative interdisciplinary network and ii) joint publications which will make use of within-network peer-review.

Table 1. Challenges, approach and progress beyond the state of the art in TrANsMIT.

Challenge	Approach to the challenge	Progress beyond the state of the art
1. Lack of collaboration across the CCUS value chain. Specialists focus only on a certain part of the chain. Requirements from other chain elements are overlooked, synergies are missed.	Develop the network and the framework for the holistic, integral analysis of CCUS processes and systems for interdisciplinary and cross-sector collaboration.	Holistic analysis of CCUS systems building upon a set of inclusive and overarching harmonized tools and methods including expertise from each chain element. Improved communication between all parts of the CCUS chain.
2. Lack of sufficient networking and communication in the CCUS community between research, industry and policy-makers.	Establish and promote an inter-sector network where researchers and industrial representatives will interact and share relevant knowledge. Start joint push for more (publicly funded) open-access test campaigns.	Improved, more realistic system integration studies, promoting technologies that work in a real, industrial environment. Thriving industrial-academic interaction, focusing on knowledge sharing and future research and competence needs.
3. Caveats and partially outdated TEA methods, guidelines and benchmarks for existing and novel CCUS technologies.	Coordinate updating/improving existing guidelines and methods, development of guidelines and methods for new technologies (e.g. NETs).	Up-to-date, harmonised guidelines on CCUS TEA, including new technologies and systems, allowing sound technology and system analysis; creating synergistic links with other relevant methodologies, such as LCA and social study.
4. Existing knowledge and experience gap within Europe, sometimes difficult access to knowledge and/or research funding for ITCs.	Bring together countries and institutions with and without advanced knowledge on CCUS, facilitate knowledge sharing, establish new, joint, research projects.	Decreased knowledge disparities between CCUS frontrunner and following countries, improved position of ITCs.

5. Limited experience of Early Career Investigators, leading to limited funding/research opportunities. Barriers for female researchers.	Establish a network of young and diverse scientists, supported by experienced researchers and industrial representatives. Provide leadership experience/coaching.	Improved leadership experience and larger network for especially young and female investigators, leading to better access to (collaborative) funding opportunities.

1.2.2.2 Capacity-building Objectives

1. The participation in TrANsMIT management activities will support the career development of Early Career and female Investigators, while leveraging the existing and new knowledge for less research-intensive countries. Their development will include exposure to the SotA that TrANsMIT will develop, offering the chance to promote and disseminate good practice in TEA and process modelling to new generations of researchers.
2. Foster knowledge exchange in TEA of CCUS through a series of workshops, short-term scientific missions, and Training Schools that will, for example, bring ECIs and many Action participants (especially from ITCs) who have no access to research facilities, in contact with state-of-the-art infrastructures owned by several other Action participants. A large number of ECIs are already committed in this Action, as well as many infrastructure owners. The Action will provide a platform for networking and communication that will allow easy access to frontier knowledge in TEA and to support interdisciplinary education and involvement of ECIs (engineers, scientists, economists, etc.) that will better reflect interconnections of the large number of different issues faced during CCUS deployment.
3. Develop a joint research agenda on solving the identified TEA challenges associated with NETs, advanced/emerging topics in classical CCS technologies and their integration. This will guide deployment and commercialisation of CCUS technologies. The Action members will collaborate with local/regional CCUS research centres to organise activities that maximise knowledge exchange and networking opportunities. These collaborations will, for example, include joint doctoral research where international experts are directly or indirectly involved, commercial projects, etc. This objective aims to open the gates for future collaboration opportunities with strategic international partners and in strong consortia, which is of great importance especially for ECIs and young professionals.
4. Bridge the gap between the research and expertise of practitioners in CO_2 capture, transport, utilisation and storage. By including disciplinary and interdisciplinary experts on CCUS and TEA, the partially existing disconnection between the individual chain elements will be addressed, leading to overall better CCUS system designs and analysis.
5. Establish the pan-European knowledge platform of choice and reference point for TEA of CCUS, while developing a critical mass in CCUS research. The Action website will contain a database of TEA/CCUS experts that will be available to other academic, industrial and governmental organisations, raising the visibility and profile of the Action members. Through pan-European and international engagement, the Action will enable its members to become leaders in TEA/CCUS, who will promote best practices to students, researchers and practitioners.

Table 2. Summary of TrANsMIT objectives, activities contributing to their delivery and their success criteria.

Objective	Applicable (networking) tools	Success criteria and KPIs
Research coordination		
Pan-European network with special emphasis on less developed in CCUS countries	Workshops, Training Schools, conferences, STSMs, dissemination events, wepage, digital newsletters	Number and diversity of participants in Action and during Action events. Participants in workshops: min 50 from at least 20 EU countries
SotA review of CCUS TEA	Workshops, joint review paper in open sources	Published review of CCUS TEA methods, guidelines, benchmarks and tools. On white paper on TEA guidelines for CCUS including NETs.
TEA quality improvement	Workshops, STSMs, training, funded research project coordination	Published guideline document and number of dissemination outputs (conferences, publications). Open access articles: 20; Conference publications: 20
Easy accessible information	Database, publicised through, conferences, social media, TrANsMIT website	Number of complete process models, datasets, documents available in the database and number of downloads. Process models: 20; Downloads: 1000
Future direction of CCUS TEA	Workshops, joint publications	Number of publications by the Action members.
Capacity-building		

Improved career development	Coaching sessions, Training Schools, conferences, STSMs, joint PhDs	Number of ECI/female appointments in Action leadership roles, number of coaching sessions. Number of ECI/female participants in workshops (Aim: 50% gender balance)
Enhanced knowledge exchange	Workshops, STSMs, Training Schools, conference presentations	Number of Action participants, events, and event participants and their positive feedback (Satisfactory level on scale: min 4/5)
Joint research agenda	Workshops dissemination event	Drafting of comprehensive research agenda and number of aligned briefings submitted
Integrated research, no CCUS gaps	Workshops, joint publications	Ratio of experts in each element of CCUS in the network, number of interdisciplinary events
Pan-European knowledge platform	Website, conferences, dissemination event	Number of experts available on the TrANsMIT website and an increase in average engagement per expert

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

Other networking organisations on CCUS exist, however, all of them are missing the techno-economic and research focus, as well as the focus on interdisciplinary and multi-layer approach. TrANsMIT establishes the only network spanning the whole CCUS chain covering broad range of technologies, with a special for further developing TEA, in a collaboration with academia, research institutes and industry, that is open for anyone to join. Existing organisations include, for example:

- European Energy Research Alliance (EERA), European public research centres and universities association active in low-carbon energy research, including joint programmes in CCS, coordinating national and European R&I programs and actions in the field of CCS research, but without industry involvement.
- The European Technology Platform for Zero Emission Fossil Fuel Power Plants (ZEP), a coalition of mainly industrial stakeholders, (N)GOs, and non-academic research organisations aiming to progress CCS as a key technology for mitigating climate change.
- The Global CCS Institute, a not for profit international climate change organisation whose mission is to accelerate the deployment of CCS as an imperative technology in tackling climate change and providing energy security, both funded by and providing consultancy to global corporations, private companies, research bodies and non-governmental organisations.
- The Carbon Capture & Storage Association (CCSA) represents the interests of its industrial members in promoting the business side of CCS.
- The IEAGHG cost network is focused on progressing the methods used for costing of early as well as existing CCS technologies, transport and storage and demonstration plants. Participation in the network is on invitation only and has so far excluded CCU and NETs.

Apart from the above-mentioned organisations, there was/is a limited number of national research programmes for CCUS, examples including CATO, UKCCSRC, and NCCS. In addition, several EU funded CCS R&D projects are running or have been completed, such as FP7 projects ASCENT, COALING, HIPERCAP, CAESAR, CESAR, DECARBIT or H2020 projects CEMCAP, LEILAC, NANOMEMC2, GRAMOFON and CLEANKER. These existing networks and projects are often limited to one particular technology or element of the value chain, or, when holistic, only superficially address specific problems related to CCUS TEA. Hardly any of the existing networks include incumbent as well as novel CCUS technologies such as CO_2 utilization or negative emission technologies, and some of them use TEA, but do not focus on further developing the state-of-the-art of TEA. The added value of the TrANsMIT is building a strong pan-European, interdisciplinary network with the geographical spread required to tackle existing challenges to TEA and by coordinating the research of the existing and new projects in which its members are involved. It is also the only network that has a focus on training the next generation of research and industry leaders on the foundations and advanced aspects of sound TEA. Moreover, it greatly improves accessibility for ITCswhen compared to existing efforts. Note that among the abovementioned FP7 and H2020 projects only one included a partner from an ITC. This confirms that there is a need to improve ITCs access to relevant funding and projects, which is exactly one of the objectives of TrANsMIT. It thereby also complements such networks as ZEP or the IEAGHG, which are only open to its paying members or are by invitation only. Within TrANsMIT activities strong emphasis will be put on collaboration with other network organisations in Europe in order to exploit synergise, maximise the impact and not to overlap the activities. Initials links have already been made.

2.2. ADDED VALUE OF NETWORKING IN IMPACT

2.2.1. SECURING THE CRITICAL MASS AND EXPERTISE

TrANsMIT has secured a world-leading network of experts from organisations in research and industry, distributed across Europe that have the breadth of skills to address the challenges in CCUS TEAs defined in Section 1.1.2. To successfully address these challenges, TrANsMIT has ensured the participation of senior experts as well as upcoming research talents in the relevant fields across various regions in Europe. EU countries with limited support for CO_2 storage (e.g., Germany) have invested in R&D activities focussed on CCU, whereas countries with direct access to significant storage capacity (e.g. North Sea countries) focus their activities more on storage. Other regions (e.g., Romania, Poland) are in the process of evaluating their options for CCUS. Such locational aspects have been considered when selecting the expertise required within this consortium. Moreover, links to other networks in these countries have been initially established. Our team will form an initial platform to kick-start TrANsMIT's activities and will reach out to the wider CCUS community. At the time of Action submission, the network contains 42 organisations, 50% of the proposers are female, 52% are Early Career Investigators. From the 16 countries already involved, 53% are ITCs. TrANsMIT includes researchers from the academic sector and research institutes as well as industrial partners (SME and large enterprises) and organisations. Special emphasis is put on the industry from ITCsallowing these companies to acquire expertise in and knowledge on CCUS (and in consequence increase their competitiveness in a low-carbon European economy) as well as identify problems and challenges they encounter, which is important for the future development of CCUS technology. An important aspect of the network is also that it includes participants that are active in the field of higher education, supervising MSc and PhD students. This allows the generated knowledge to be spread immediately among this new generation of engineers and researchers.

The initial TrANsMIT participants form a critical mass and have knowledge covering the range of expertise and geographical extent needed to start this COST Action, tackle the challenges and achieve its goals. The consortium composition will be monitored and, where necessary, the Management Committee (MC) will actively invite participants to encourage diversity and ensure a balance of critical expertise is present to deliver the Action's objectives. TrANsMIT will strive to widen the network in a continuous process. During the first six months of the Action, the MC will continue to invite participants from academia and industry that are strategic to leverage our activities and deliver our goals. The Action will be publicized in relevant conferences and participants will be able to join via the Action website. The role of the newly joined experts during this phase would be to strengthen expertise in key areas highlighted during the first MC meeting and to promote dissemination activities. Attention will be given to those regions or industries that are currently underrepresented. During the remaining time of the Action, the MC will seek to enlarge the network to support our dissemination activities and impact. The focus during this phase will be given to industry and policy organizations that will be invited to join the Action, to participate in working groups, panel discussion and conferences. Industrial specialists will be invited to the Training Schools and workshop to deliver training in techno-economic assessment sharing the experience of their respective organisations. Similarly, industrial practitioners will also be invited to participate in these Training Schools, getting them up to speed with the SotA knowledge present among network members and generated within the Action. The members will meet regularly to plan training events and disseminate results and the MC will align, where opportune, the Action priorities with those of industry and policy makers. The latter group will be reached through high-level, policy focused conferences and events and will be invited to a special policy-focused networking event.

2.2.2. INVOLVEMENT OF STAKEHOLDERS

The expectations for each stakeholder type and the means of dissemination are shown in Table 3. Here the involvement of each stakeholder type in TrANsMIT is identified.

- Role of the Management Committee: The MC will ensure the timely execution of the Action's plan and promote collaborative projects between researchers represented in the Action. These will provide Early Career Investigators with access to facilities and training that they would otherwise not have access to. The MC will engage with decision makers in the EU and the national states, informing them on innovative approaches to evaluate CCUS projects.
- Role of the scientific community: Researchers will be invited to workshops to contribute to knowledge transfer and strengthening competence within TEA of CCUS value chain. They will also discuss the guidelines to benchmark process modelling and TEA studies in addition to sharing experience from experimental trials (lab to pilot scale) as well as the role of CCUS TEA in social and policy frameworks. This networking arena will promote future research collaborations. Researchers will host exchange students (MSc and PhDs) that should result in joint publications (open access).
- Role of industry and technology vendors: Industrial partners will be invited to participate in the workshops and to host network members for STSMs and internships. They will also be invited to participate in the Training Schools, run by and for Early Career Investigators, which will focus on technical aspects related to the Action's scientific objectives. This involvement will provide industrial insights to the network members as well as a platform for the industrial partners to showcase their activities, good practices and benefit from the broader scientific outputs of the Action.
- Role of societal actors, policy makers and funding agencies: At the networking events and workshops, the aforementioned representatives will share knowledge about social and policy issues concerning CCUS and the challenges in deployment. Funding agencies (including banks) will be able to share information about future R&D and infrastructure investments. They also gain insight into the TEA of CCUS value chain to make policy decisions.
- Role of the general public: Feedback on TEA of CCUS from the general public will help in (i) understanding public perception on specific technologies (ii) shaping future environmental policies (iii) enhancing skills in presenting scientific results to a general audience. An example of a programme where all stakeholders can provide feedback is the Energy Pilot programme in Gotland, Sweden. The representatives from such programmes in Europe will be invited to the workshops, who will disseminate the results from the workshop and take feedback from the different stakeholders.

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

The Action includes a partner from Mexico, an international partner country. This partner was selected because of its involvement in the two planned Mexican CO_2 capture and storage pilot projects, which would bring very relevant real data into the network. The partner itself is further developing its TEA capabilities, and would therefore benefit from the large knowledge resource that TrANsMIT brings. Links have been established with other relevant partners from e.g., Canada, US, Japan, Brazil or Qatar for ad hoc involvement where there are mutual benefits to the Action and the international partners.

3. IMPACT

3.1. IMPACT TO SCIENCE, SOCIETY AND COMPETITIVENESS, AND POTENTIAL FOR INNOVATION/BREAKTHROUGHS

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

Long-term: the ultimate long-term impact of TrANsMIT is the high quality and sound techno-economic analysis of CCUS technologies and systems and the informed interpretation of its outputs across Europe and the partner countries. This will enable well-substantiated industry and policy decisions that will allow decision-makers to advance the technologies that have the most potential, to identify technology and system bottlenecks in a timely manner and to thereby focus R&D and investments on the elements that matter most, to help reach the goal of a low carbon economy on time and in a cost-efficient way, while ensuring competitiveness of European industry. Furthermore, the databases and frameworks, as well as the network developed through TrANsMIT, will enable long-term collaboration on projects on and beyond CCUS. This will be achieved through adaptation of the developed frameworks to technologies/systems and the ease to form new partnerships within the network. Moreover, the current TEA practitioners and academics will have opportunities to harmonise their knowledge and skills. Overall, TrANsMIT will lead to improvement and harmonization of TEA methods. It will also strengthen pathways that promote cross border and multi-disciplinary cooperation on CCUS topics and will raise awareness among industry, governments, NGOs and engineers which is vital for the efficient development of the sector.

Short-term: the Science and Technology and Socio-Economic impacts of TrANsMIT are described below in relation to the COST objectives below (Ref COST Open Call 2021).

Objective 1. Joining research efforts and developing common S&T programmes by coordinating nationally funded research activities led by pan-European, high quality, collaborative S&T networks. TrANsMIT will result in the use of harmonized full chain CCUS TEA methods, approaches, metrics and benchmarks that lead to sound and comparable TEA across Europe, enabling improved technology and system decision making. The involvement of industries from CCUS research-intensive countries as well as following countries will ensure that research activities have high applicability to the needs of the people that actually make the transition happen. Furthermore, the coordination in this transdisciplinary network will lead to a truly relevant, cutting-edge, research agenda for CCUS that targets those elements that matter to the value chain as a whole, as opposed to its individual elements. Knowledge from existing EU and national research projects will be brought together, leading to outputs larger than the sum of the individual research projects.

Objective 2. Building capacity by providing networking and leadership opportunities for emerging talents and thereby strengthening and building up excellent S&T communities. TrANsMIT will build a new generation of well-equipped research leaders and excellent technology modellers/analysts. This is already exemplified in Action coordination process, where the Action was written mainly by Early CareerInvestigators, receiving periodical guidance by a committee of established colleagues. TrANsMIT will also increase the share of female and talents from ITCs that emerge as main or co-proposers for national and EU funding schemes on CCUS.

Objective 3. Addressing Societal Questions by promoting transdisciplinary, new approaches and topics and identifying early warning signals of unforeseen societal problems aiming to contribute to Societal Challenges. TrANsMIT will contribute significantly to addressing the EU societal challenges *Secure, Clean and Efficient Energy* and *Climate Action, Environment, Resource Efficiency and Raw materia*ls. It will particularly address CCUS, but the knowledge created will also flow into the analysis of other technology domains through their links with CCUS and the existing transdisciplinary research of many participants (e.g., bioenergy, hydrogen economy, and energy storage technologies). It will also strongly contribute to the actual creation of negative emissions value chains and systems. Particular impacts on this COST objective include i) intense collaboration between the capture, transport, storage and utilisation disciplines, leading to enhanced understanding of each other's requirements and limitations and thereby to overall better technology and system designs; ii) a more complete and improved set of assessment metrics for the whole CCUS chain, leading to better decisions on technology and systems that support decision making on a low-carbon economy; and iii) a new wave of research projects focusing on technology and system interfaces that further help taking on the societal challenges above. TEA is an essential means for technology assessment, but also aids to early warning for societal issues such as climate justice and the affordability of climate change mitigation.

Objective 4. Strengthening COST Inclusiveness Policy by fostering better access and integration of less research-intensive countries' researchers to the knowledge hubs of the European Research Area aiming at contributing to the Widening Pillar of Horizon 2020. TrANsMIT will result in significant knowledge increase in fossil fuel dependent countries that have so far had limited R&D efforts/spending on CCS, providing them with the tools for low-carbon industry policies and R&D/investment decisions. The network will get them fully up to speed with the frontiers of CCUS TEA research and methods. A key impact here is the improved access to models, benchmarks, frameworks and other tools, reducing the time spent on repeating work that has already been done and providing the opportunity to spend more time on developing new science. A final impact on objective 4 will be the emergence of new research networks, collaborations and projects (inside and beyond TrANsMIT), leading to more equal distribution of Framework Programme research funds (and therefore resources) within the European countries.

The potential for innovation and/or breakthroughs is summarized as follows: a more complete set of harmonised and widely accepted KPIs and of reference/benchmark studies for CCUS technologies; harmonised and widely accepted techno-economic analysis frameworks for regions in Europe other than only the North Sea (e.g. Iberia, Balkans, Baltics); and the improved design of the complete CCUS system, with requirements fed back to technology development, leading to improved technology design.

3.2. MEASURES TO MAXIMISE IMPACT

3.2.1. KNOWLEDGE CREATION, TRANSFER OF KNOWLEDGE AND CAREER DEVELOPMENT

TrANsMIT brings together a top-tier network and has ensured the inclusion of experts from each part of the CCUS value chain. Within the means of a networking Action, it is foreseen to maximise knowledge creation using three measures. First, each Action workshop will revolve around a very focused subject and will be designed such that the knowledge of the participants is used to generate new knowledge/insights/guidelines of use to the total CCUS value chain. As an illustrative, simplified, example: specifications of CO_2 quality differ much per capture, utilization, transport and storage technology. A workshop can be foreseen where practitioners from every value chain element share what their respective technologies a) need and/or b) can provide in terms of CO_2 specifications. They will then use collaborative decision-making tools (e.g. group decision rooms) to advice on CO_2 specs for the total value chain and its parts, and how these specs can be reached. This will then be reported in a workshop brief or similar. At the end of the Action, all workshop briefs will be combined into a white paper or similar and published. Second, the Action ensures knowledge generation through coordinated MSc theses, where MSc students' work on an integrated CCUS TEA case study, implementing and thereby exemplifying the knowledge created in the TrANsMIT workshops. This case study shall then be disseminated publicly. Third, industrial internships for PhD students and Early Career Investigators is another measure that will help to increase cross-sector knowledge. Academic knowledge will be used to enrich industrial know-how and vice versa, and the outputs of internships will be documented in public reports.

Transfer of knowledge will commence in different ways. Because the workshops will exclusively focus on interdisciplinary topics (e.g. KPIs, CO_2 quality), transfer of knowledge will be ensured between participants with backgrounds in TEA for different types of technologies, value chain parts and industry/research. International ad-hoc partners who have a strong track record in developing tools and methods for TEA will be invited to give lectures during the workshops. Also, TrANsMIT's industrial partners and other industry stakeholders will be invited to present and participate during the workshops to enable mutual knowledge exchange. Potential invitees include industry associations like CEWEP for waste incinerators, CONCAWE for refineries or CEMBUREAU/ECRA for cement. The STSMs will provide a dedicated means for bilateral knowledge transfer on a specific topic, tool, or method. Finally, the Training

Schools will ensure the transfer of knowledge to new generations of TEA practitioners, including existing CCUS TEA knowledge as well as that newly developed during TrANsMIT.

TrANsMIT provides a platform for career development for its Early Career Investigators and minorities through its Training Schools and workshops; by enabling them to build a strong, pan-European network; by promoting them to take up Action leadership roles; and by dedicated coaching sessions. In addition, the ECIs will be part of TrANsMIT's research outputs, furthering their scientific output base, and they will supervise MSc student projects and Short-Term Scientific Missions, contributing to their supervision experience. TrANsMIT's network boasts a balance of both experienced and Early Career Investigators, with ECIs and women confirmed to take up leadership roles in managing the Action and its Working Groups. Dedicated sessions during the planned workshops will be conducted by the experienced researchers to provide soft skills training to the ECIs in project management, leadership and so forth. TrANsMIT will also encourage its Early Career and female Investigators to have a seat on PhD defence committees of PhDs graduating under supervision of other TrANsMIT partners, further contributing to their professional development. Finally, the Action will provide PhD students from ITCs the chance to visit international conferences through the ITC conference grants.

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

One of the main objectives of this COST Action is to develop a mutually beneficial network of professionals with different backgrounds. Given the wide range of topics covered by the Action and the importance of targeting various stakeholders, careful planning whom to reach and how to reach them is imperative. The dissemination activities need to be stakeholder-oriented and should use the most relevant communication channels (Table 3). To that end, a detailed plan for dissemination, communication and exploitation will be developed and implemented in the first year of this COST Action based on the outline presented here. The plan will be coordinated by WG4 (see *Implementation*) and will ensure a continuous effort to spread the Action results and knowledge during and after the Action lifetime. During the first year, the main outreach activities will be related to the objective of raising awareness for, and interest in, the COST Action among the relevant stakeholders (to allow potential members to join), development of visual identity (logo, leaflets, presentations, posters), and establishment of the online presence (i.e. website, blog, linked-in groups, Twitter). Through the whole Action, various activities (Table 3) will be deployed to spread the results and to reach a wide community, as per the project needs, where relevant policy stakeholders will be sought through acquainted national funders and COST coordinators.

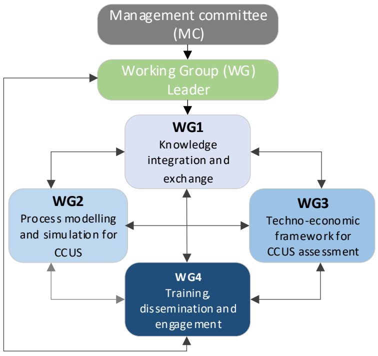
Table 3. Identified stakeholders, their objectives and expectations in relation to TrANsMIT and CCUS TEA, and means of dissemination.

Stakeholder type	Strategic objective/expectation	Means of dissemination
Scientific community (academia, research institutions)	Knowledge creation and exchange, network broadening/strengthening, identification of research opportunities.	Scientific publications, workshops, conference presentations, trainings, STSMs, MSc and PhD student internships and projects, newsletter, online presence.
Industry (SME and large corporations)	Sound R&D and investment decision-making, identification of research/market opportunities.	Workshops, Training Schools, STSMs, student internships, online presence.
Technology vendors	Technology marketing, identification of research/market opportunities.	Workshops, Training Schools, STSMs, student internships, online presence.
Policy-makers (EU, national and regional)	Understand the performance and feasibility of technology and system options. Acquire tools/information for policy decisions on climate change and energy/industry issues.	Participation in policy conferences, Final Action Dissemination Event, TrANsMIT policy/NGO meeting, press releases, newsletters, website.
Relevant non-governmental organisations and interest groups	Influence the public, policy-makers and industry by raising awareness and knowledge exchange (depending on organisation pro or contra CCUS). Expand network to reach stakeholders.	Participation in policy conferences, Final Action Dissemination Event, TrANsMIT policy/NGO meeting, press releases, newsletters, website, direct communication.
Funding agencies	Valorisation of project results; gain increased knowledge/tools for funding decision-making.	Participation in policy conferences, TrANsMIT policy/NGO meeting, Final Action Dissemination event, online presence, direct contact.
General public	Sound/feasible environmental and energy/industry policies, focusing on affordability, safety and nuisance minimisation.	Website, newsletter, social media, Final Action Dissemination Event, site visits, programmes like Energy Pilot in Gotland (Sweden), public science events (e.g., Researchers' Night).

4. IMPLEMENTATION

4.1. COHERENCE AND EFFECTIVENESS OF THE WORKPLAN

4.1.1. DESCRIPTION OF WORKING GROUPS, TASKS AND ACTIVITIES



TrANsMIT comprises of four Working Groups (WGs) which will implement the activities envisioned in this COST Action (WG1–4). Each WG will hold an annual meeting to organise its activities (M1.1–M4.4) and will deliver an annual meeting report (D1.1–D4.4); these are not further listed in the WG descriptions. Interactions between WGs will be regulated by the Management Committee (MC) through the TrANsMIT Coordination and Dissemination activities. The WG activities also aim to facilitate networking, knowledge sharing and capacity building between the different communities involved in CCUS development, including industry, academia, R&D, policy and NGO representatives. Where possible, the workshops will be organised in conjunction with European CCUS and/or NET conferences to facilitate participation.

WGs 1-4: Common secondary objectives and sub-Tasks to support achievement of the specific tasks: a) Discuss current research topics/questions/issues; b) Map CCUS related research activities and projects of participants across Europe; c) Discuss publications (published or in preparation) and technical reports; d) Establish a CCUS research literature database; e) Review techniques, methodologies and approaches employed for CCUS research; f) Share expertise in techniques, methodologies and approaches employed for CCUS; g) Identify current needs in the CCUS field and plan future activities and actions; h) Distribute updates from members on relevant R&D progress; i) Identify and discuss funding and collaboration opportunities on CCUS projects and specific WG topics.

WG1: KNOWLEDGE INTEGRATION AND EXCHANGE

Objective: Inventory current knowledge of, and best practices to, TEA of CCUS and identify existing challenges. Support WG2 and WG3 in organising their knowledge exchange, in filling existing caveats and developing new knowledge. Exemplify existing and developed best practices through a worked example using MSc projects.

Tasks: Inventory the current approaches to process modelling of CCUS technologies, as well as TEA methodologies, reference studies and guidelines (with WG2&3); Map potential synergies and differences between the TEA of CCUS and NETs; Develop one worked example through 5 MSc theses; Facilitate discussions between representatives from industry, academia and research institutes on current challenges, TEA methodologies, benchmarks and approaches to identify policy, societal, academic and industrial needs; Support the network members in preparation of joint publications; and discuss the techno-economic challenges and possible solutions with industry for full-scale deployment of CCUS technologies, including the role of emerging technologies, such as NETs.

WG2: PROCESS MODELLING AND SIMULATION FOR CCUS

Objective: Systematically review approaches to process modelling and simulation of CCUS components aiming to establish the state-of-the-art and identify further development needs. Contribute to the development of an open-access database to be shared within the Action and with the wider CCUS community, which includes process models and publicly available experimental/pilot/demonstration results for validation. This objective will be achieved by coordination with existing and past research projects, the WG1 MSc theses, and engagement with industry.

Tasks: Review the current SotA in, and structure best practices for, process modelling of components (accuracy, uncertainty, coupling, applicability, usability) in the CCUS value chain; Map the availability of experimental, pilot or commercial plant data in the open literature and from industrial partners that can be used to verify/validate process models of CCUS technologies; Coordinate development of a set of harmonised guidelines and recommendations for process modelling of CCUS technologies and reference host plants that will be used in TEAs; develop a roadmap to address remaining challenges associated with process modelling and model validation.

WG3: TECHNO-ECONOMIC APPROACHES FOR CCUS ASSESSMENT

Objective: Systematically review current TEA methodologies, benchmarks and key performance indicators aiming to establish the current state-of-the-art in TEA of CCUS. Harmonise and coordinate the further development of approaches to CCUS TEA that will be disseminated within the Action and to a wider audience. This will be achieved through coordination with existing and past research projects, MSc theses, and engagement with industry.

Tasks: Review the current state-of-the-art in, and structure best practices for, TEA of the complete CCUS value chain and its components; Coordinate further development of KPIs into harmonised, clearly defined, and widely accepted set; Coordinate development of currently lacking benchmarks for host plants, (their retrofits with) CO_2 capture systems, NETs, DACs, CO_2 utilisation, transport and storage technologies; Coordinate guideline development on the flexible operation of host plants and CCUS technologies and systems, including polygeneration facilities; and Develop a set of recommendations and guidelines for TEA of CCUS, including one worked example that will support their implementation in academia and industry. The worked example will result from abovementioned MSc theses and will span the complete CCUS chain. It will foster interdisciplinarity, acknowledge the importance of interfaces and will focus on a region now still underrepresented in CCUS TEAs.

WG4: TRAINING, DISSEMINATION AND ENGAGEMENT

Objective: Disseminate and promote the use of best practices to TEA of CCUS and discuss approaches to solving existing challenges with practitioners, academics, researchers and students from across the CCUS community. Promote best practices in TEA to the young generation of researchers and build capacity in the partner countries with a focus on ITCs. Bridge the gap between the different elements of CCUS chain and emphasise the value and benefits of using best practice ex-ante TEA to underpin sound R&D and policy decisions. Engage with the general public to raise awareness and assess change in perception of CCUS over the duration of the Action.

Tasks: Set up TrANsMIT website; organise Training Schools, that will disseminate the current research and best practices in TEA and process modelling, including tutorials in TEA of CCUS; Develop and distribute training materials through the TrANsMIT website; Coordinate dissemination of the network outcomes through Action events, external conferences, TrANsMIT website and social media; Contribute to deployment and commercialisation of CCUS technologies; conduct a survey with general public to assess the perception of CCUS, and organise the Policy/NGO event and Final Action Dissemination Event to maximise the impact of TrANsMIT outcomes.

4.1.2. DESCRIPTION OF DELIVERABLES AND TIMEFRAME

WG1 Milestones and Deliverables: Year 1: Kick-off workshop to understand synergies and differences of TEA of CCUS and NETs, focus on interfaces and holistic system assessment (M1.5) [all WGs]; Annual WG workshop report in the form of short white paper (D1.5). **Year 2:** At least one joint publication drafted (D1.6); At least one MSc thesis on TEA of the CCUS value chain, laying the foundation for the next theses (D1.7). **Year 3:** At least one joint publication drafted (D1.8); At least two MSc theses on elements of the CCUS value chain (D1.9). **Year 4:** Final workshop to discuss latest developments and trends, integrate generated knowledge and outputs, explore further research needs and plan legacy (M1.8) [all WGs]; Final WG workshop report on improvements to existing CCUS TEA frameworks (D1.10). At least two MSc theses of which one on full CCUS chain integration and evaluation (D1.11). WG reports (D1.1, 1.2, 1.3, 1.4)

WG2 Milestones & deliverables: Year 2: WG workshop on process modelling best practices, mapping of available data sets for validation of CCUS components, industrial-academic knowledge exchange and discussion of STSMs outcomes (M2.5); WG workshop report (D2.5); At least two STSMs on CCUS/NETs process modelling (D2.6); **Year 3:** WG workshop on process modelling best practices, mapping of available data sets for validation of CCUS components, industrial-academic knowledge exchange and discussion of STSMs outcomes (M2.6); WG workshop report (D2.7); At least two STSMs on CCUS/NETs process modelling (D2.8). **Year 4:** Final workshop to discuss latest developments and trends, integrate generated knowledge and outputs, explore further research needs and plan legacy (M1.8) [all WGs]; Final WG workshop report (D1.10); At least two STSMs on CCUS/NETs process modelling (D2.9); CCUS/NETs process modelling guidelines report (D2.10). WG reports (D2.1, 2.2, 2.3, 2.4)

WG3 Milestones & deliverables: Year 2: WG workshop on TEA best practices, focusing on CCUS chain synergies and differences and academic-industrial knowledge exchange (M3.5); WG workshop report (D3.5); At least two STSMs on CCUS/NETs TEA topics (D3.6). **Year 3:** WG workshop on integrated CCUS system design and evaluation and develop joint publications (M3.6); WG workshop report (D3.7); At least two STSMs on CCUS/NETs TEA topics (D3.8). **Year 4:** Final workshop to discuss latest developments and trends, integrate generated knowledge and outputs, explore further research needs and plan legacy (M1.8) [all WGs]; Final WG workshop report (D1.10); At least two STSMs on CCUS/NETs TEA topics (D3.9); TEA guidelines report (D3.10). WG reports (D3.1, 3.2, 3.3, 3.4)

WG 4 Milestones & deliverables: Year 1: WG workshop to develop public engagement plan and events, training material (M4.5); WG workshop report (D4.5); Website set up (D4.6); Open-access database set up [with WG2 and WG3] (D4.7); at least two newsletters disseminated to TrANsMIT members and key stakeholders (D4.8); an initial survey with general public performed (D4.9). **Year 2:** Open-access database updated [with WG2 and WG3] (M4.6); Policy/NGO event (M4.7); at least two newsletters disseminated to TrANsMIT members and key stakeholders (D4.10); at least one Training School on TEA for CCUS/NETs [with WG3] and at least one Training School on process modelling [with WG2] (D4.11). **Year 3:** Open-access database updated [with WG2 and WG3] (M4.8); at least two newsletters disseminated to TrANsMIT members and key stakeholders (D4.12); at least one Training School on TEA for CCUS/NETs [with WG3] and at least one training on process modelling [with WG2] (D4.13); second survey with general public performed (D4.14). **Year 4:** Open-access database updated [with WG2 and WG3] (M4.9); at least two newsletters disseminated to TrANsMIT members and key stakeholders (D4.15); at least one Training School on TEA for CCUS/NETs [with WG3] and at least one training on process modelling [with WG2] (D4.16); final survey with general public performed (D4.17); Final Action Dissemination event organised (D4.18).

4.1.3. RISK ANALYSIS AND CONTINGENCY PLANS

The risk assessment and monitoring will be undertaken semi-annually by the TrANsMIT MC and WG leaders. An initial risk register has been created for the project (Table 4) and will be maintained by the MC Vice-Chair. Throughout the Action lifetime, the severity, occurrence likelihood and probability of early detection will be scored from 1 to 5 for each identified risk. Potential risk modes will be classified according to the risk priority number (RPN) and addressed in the RPN order. The Vice-Chair will monitor the progress of the Action against the Gantt chart and will communicate with the MC immediately if potential challenges in the delivery of the provisioned TrANsMIT actions emerge. This will allow time to implement mitigation measures and ensure timely delivery of the Action.

Table 4. Risks, impacts and mitigation measures.

Risk	Impact	Mitigation
Limited scientific engagement in the envisioned activities.	WGs tasks hard to complete on time due to limited involvement of researchers and academics.	Actively engage with relevant universities and research institutes. Organise workshops in conjunction with conferences.
Limited engagement of key stakeholders outside the network.	WG outputs will not be implemented by industry and governments, or even academics beyond the TrANsMIT network.	TrANsMIT members have already established several industrial contacts at EU level who support the Action scope. Further involvement will be encouraged through academic and industrial networks

		of the TrANsMIT members. Involvement of managers and inspirational leaders will be sought.
Limited impact of dissemination activities.	WG outputs not translated into academic, industrial and governmental practice.	Actively seek stakeholder involvement and input to make outputs as relevant/applicable as possible.
Lack of communication between WGs.	WG outputs not well integrated or overlapping.	MC will focus on integrating WG results and facilitating effective communication.
Lack of coordination between WGs.	Delay in planned activities.	The WG1 and 4 leaders will ensure that all activities and events run smoothly through regular engagement with other WG leaders.

4.1.4. GANTT DIAGRAM

TrANsMIT	**2022**				**2023**				**2024**				**2025**			
	Q1	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
WG1: KNOWLEDGE INTEGRATION AND EXCHANGE																
WG meeting	M1.1				M1.2				M1.3				M1.4			
WG report		D1.1				D1.2				D1.3				D1.4		
WG workshop			M1.5				M1.6				M1.7				M1.8	
Workshop report			D1.5													D1.10
Joint publications								D1.6				D1.8				
MSc theses							D1.7				D1.9				D1.11	
WG2: PROCESS MODELLING AND SIMULATION FOR CCUS																
WG meeting	M2.1				M2.2				M2.3				M2.4			
WG report		D2.1				D2.2				D2.3				D2.4		
WG workshop			M1.5				M1.6 M2.5				M1.7 M2.6				M1.8	
Workshop report			D1.5				D2.5				D2.7					D1.10
STSMs							D2.7				D2.8				D2.9	
Guideline report															D2.10	
WG3: TECHNO-ECONOMIC FRAMEWORK FOR CCUS ASSESSMENT																
WG meeting	M3.1				M3.2				M3.3				M3.4			
WG report		D3.1				D3.2				D3.3				D3.4		
WG workshop			M1.5				M1.6 M3.5				M3.6				M1.8	
Workshop report			D1.5				D3.5				D3.7					D1.10
STSMs								D3.6				D3.8				D3.9
Guideline report															D3.10	
WG4: TRAINING, DISSEMINATION AND ENGAGEMENT																
WG meeting	M4.1				M4.2				M4.3				M4.4			
WG report		D4.1				D4.2				D4.3				D4.4		
WG workshop			M1.5 M4.5												M1.8	
Workshop report			D1.5 D.4.5													D4.7
Website		D4.6														
Open-source database				D4.7				M4.6				M4.8				M4.9
Policy/NGO event							M4.7									
Dissemination				D4.8				D4.10				D4.12				D4.15
Public perception survey				D4.9						D4.14					D4.17	
Training School						D4.11				D4.13				D4.16		
Final Dissemination Event																D4.18
Management Committee																
MC meeting																
Risk assessment																

Management Committee	All WGs / WG1&2	WG2&3&4 / WG2&4	WG1&2&3 / WG3&4	WG1	WG2	WG3	WG4