Sustainable movement and restoration of natural and productive soils in important infrastructure projects (GREEN MOVE)

0. Relevance to the call

Building high-speed roads and railways will inevitably affect the Norwegian landscape with productive agricultural and natural land. Possible curvatures of such roads and railways are so rigid that avoiding agricultural land will be difficult due to technical and economical solutions. The expansion of the larger cities in Norway has generated a high pressure on valuable and highly productive natural or agricultural land. The pressure for building on this type of land is increasing and is often found to be unavoidable to mitigate other societal (or often economical) aims. Such changes in land use are regulated by the law of soil protection (Act No. 23 of 12 May 1995) relating to Land[1]. It is proposed that moving soil, and reconstruction of a soil profile at a new location could limit the loss of high agricultural productivity and quality as well as biodiversity.

High quality soil for agriculture is a non-renewable resource since it takes centuries to build up few centimeters of productive soil. The conversion of agricultural land to urban land is an irreversible process[2], decreasing the land's ability to supply food and other vital ecosystem services[3]. While the best preservation of high-quality soil is sustainable management of the soil at its original site, we may sometimes be forced to move soils. Moving soil should be considered the last option when other measures to protect the productive land has failed, however, if there is no other option, we need new knowledge to do it in the best possible way. In GREEN MOVE, we will explore the possibilities for moving and reestablishing soil in an alternative location with focus on climate smart land use that minimizes both environmental impacts and losses in agricultural production. We will, based also on recent knowledge and experiences[4567] develop new methods for soil moving and reestablishing soil functions after relocation.

Priority research challenges from Call	How the GREEN MOVE will address these challenges:
1.Consequences of land use	We will focus on the consequences of land demand for important infrastructure projects on agricultural production and the environment; how to move and reconstruct agricultural land to ensure continued soil functions for both crop production and the environment. Reducing the areal, environmental and visual impacts of waste rock deposits on land as well as in the sea through utilizing them in developing of soil profile.
2.Weighing of interests, conflicts, and decision-making processes in society and in the population	We will study the political and sociological process implementing urban constructions on agricultural soils. Which actors are involved (politicians, bureaucrats, landowners, developers, citizens), and what is the fabric of the decision process in order to device improvements of the decision-making processes concerning moving and reconstructing soil.
3.Innovative solutions that address climate and natural diversity for sustainable social development, infrastructure and industry	A major aim of the project is to improve methods and practices for relocating soil. This includes appropriate equipment, new logistical approaches, reestablishment of the soil profile and landscape with least possible impact on environment and biodiversity. New applications of waste rock and mine tailings in building subbase layer of soil profile may give advantages to companies re-establishing arable land in new areas not previously suitable for agriculture.

1. Excellence

1.1 State of the art, knowledge needs and project objectives

Due to climatic, topographic, and geological conditions only 3% of Norway's total land is arable, and only one third of this land is suitable for growing cereals for human consumption. Thus, Norway is vulnerable to any losses of agricultural land, particularly given the government's objective of increasing domestic production[8]. Since WW2, about 120 000 hectares of arable land in Norway have been lost from food production.[9] 71 % of the lost areas are classified as highest quality soil suitable for cereal production[10]. Urbanization has historically been occurred close to our most productive farmland[11], and most remaining farmland is located close to urban settlements[12]. Thus, urban sprawl is consuming fertile agricultural land for

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[10] SSB (2017) *Nedbygging av jordbruksareal*. Rapporter 2017/14. Kongsberg: SSB
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[12] Skog, K. L., an Steinnes, M. (2016). How do centrality, population growth and urban sprawl impact farmland conversion in Norway? Land Use Policy

urban use in Norway as well as worldwide[13.] Already in 1979, Jul Låg presented the idea to move soil and reconstruct the soil profile at new locations to maintain productive agricultural soil and two years later, a pilot study was published[14]. Soils removed due to construction of a new road in Nedre Eiker were transferred to an originally almost soil free area. Anda investigated the reconstructed soil in 2016 and found main differences between natural soil and the reconstructed soil in the subsoil horizons. While natural soils are characterized by layering within the profile, the reconstructed soil showed an apparently random alignment. After 35 years, the reconstructed subsoil still had a lower water holding capacity as well as somewhat poorer drainage. The yield produced at the reconstructed soil was also significantly lower[15].

Knowledge need 1: Agronomic production and environmental impacts (WP1 and WP3)

While normal tillage is conducted to improve the conditions for plant growth in the topsoil, moving and reconstructing activities will affect soil structure more deeply and disrupt the continuity of the pore system in the soil profile. A reconstructed soil may therefore have less capacity to infiltrate and store water from precipitation, with higher erosion losses and/or lack of water during drought periods consequently. In addition, the construction phase with heavy machinery may reduce the number of larger pores necessary for oxygen supply to roots and other soil-sustaining organisms. A major issue is therefore how to improve pore continuity across the different layers. Moving a complete soil profile, even if carefully done layer by layer, will inevitably lead to soil disruption, which in turn will increase GHG emissions due to exposure and subsequent decomposition of previously physically protected organic matter[16]. Data on the effects of mechanical disturbance on GHG emissions are based on tillage operations[17], while corresponding effects of translocating larger volumes of agricultural soils to new locations have not been studied previously.

Knowledge need 2: Use of waste rock and mine tailings to improve subsoils, mainly B horizons, with respect to hydraulic properties and fertility (WP1, WP4)

When reconstructing soil profiles in a new location, there is a chance to improve potential fertility and/or hydraulic properties of the original B horizon by adding waste rock materials and/or organic matter. The basic qualities of minerals are well known, but weathering rates at various conditions, and thus yearly delivery of plant-available nutrients or other elements, are still scarce. While crushed rock has been tested as addition to topsoil[18],[19], [20], little is known about potential short and longer-term effects of combining existing B layers with selected new minerals. The results for the topsoil indicated an effect of siliceous rock powder, but possible interactions between microbes and minerals need further investigation and verification. Furthermore, some minerals may release noticeable amounts of potentially problematic elements, e.g., carbonatite has a high content of potentially toxic barium[21].

Knowledge need 3: Holistic approach to project planning in all stages and engineering solutions to successful soil relocation (WP4)

For planning of infrastructure projects, it is important to include all aspects of the projects from the beginning. Both the budget and the logistical approach for soil relocation must be planned in detail prior to construction start, to maximize crop production in the new soil. A challenging part of soil moving is to find a suitable end location. Transport distances and efficient logistics are important factors. Local micro-climate, topography, hydrology, geology, groundwater and biodiversity are factors that also must be considered. Research has been conducted on the consequences of subsoil compaction and tools have been developed to help farmers find appropriate times and equipment for tillage operations[22]. However, there is a lack of engineering solutions for sustainable transportation of soil, use of heavy machinery and construction technology[23].

It is also important to evaluate preservation of protected landscapes and biodiversity hotspots. This would require studies and mapping of potentially destroyed land, because of soil relocation.

Knowledge need 4: *An integrated environmental and economic assessment of land relocation (WP2)*

An integrated environmental and economic assessment of land use changes and soil relocation using environmental Life Cycle Assessment (LCA) and economic Life Cycle Costing (LCC) is powerful and useful tools to explore complementary sustainability aspects of alternative land uses. The environmental assessment

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addresses impact on climate change, ecosystem services and biodiversity and non-renewable resources. To date, land-use and land-use-change (LULUC) impacts are seldom included in the impact assessment in LCA. Therefore, LCAs are not able to reflect the full spectra of the environmental impact and are consequently insufficient for many stakeholders[24]. Milà I Canals et al. (2007) list examples for impact pathways and possible indicators related to what they are calling "land quality". Biodiversity, biotic production potential and ecological soil quality are mentioned as potential impact pathways.

Knowledge need 5: ***Social and political aspect (WP3)***

The ambition to preserve farmland is stated in The Norwegian Constitution §112, The Land Act[25] and The Planning and Building Act[26]. Despite these ambitions, farmland is continuing to be relocated and pose both a serious conflict theme. Preserving food security, landscape – and biodiversity conflicts with the needs for safe and efficient infrastructure as well as attractive housing for a growing population. A policy trilemma is a specification of a wicked situation in policy making in situations of fundamentally conflicting policy goals[27]. Analysing wicked problems through a policy trilemma lens can help us untangle causes of the wickedness of a problem. Decisions on farmland preservation are handled at local municipality level, sometimes appealed by regional or state authorities, and within the context of these various types of legislation. At the outset, the restrictive legislation would deny such conversion. Institutional theory[28] will help us discuss how socioeconomic and biophysical conditions on the one hand and formal and informal rules in use on the other inform the decisions[29]. A discourse perspective will further help us clarifying the different positions that influences on decisions on land-use and the intentions influencing on these decisions.

Overall project idea and main objective

GREEN MOVE aims at creating methods to maintain cultivated land by sustainably moving and reconstructing agricultural soils to alternative locations avoiding important conflicting societal interests. The project aims at proposing an informed and strategic approach to a highly ambivalent issue that may enable both sustainable development of important infrastructure as well as preservation of valuable soil resources necessary. We aim at providing recipes for the entire process chain involved in moving soil from agricultural land, with a focus on sustainability at all stages by evaluating environmental and economic effects: developing procedures to choose appropriate new locations, addressing societal and political aspects, establishing good technological solutions for the moving process, and determining appropriate agronomic strategies to stabilize the new areas for continued productivity.

Main objectives:

O1: Develop agronomic strategies to stabilize newly constructed soils and achieve satisfactory crop yields within a few years.

O2: Evaluate the potential of utilizing crushed waste rock and other mine tailings to improve subsoil properties in new locations.

O3: Develop new methods for using tools such as LCA and LCC to evaluate environmental and socioeconomic impact of relocation of agricultural soil in construction projects.

O4: Develop new methods and tools of collaboration and engagement of different actors involved in land management processes (from farmers to decision makers).

O5: Based on best practices of moving soil projects, develop engineering solutions, construction process, and methods to keep biological structures intact when moving and to secure valuable natural land is protected or properly restored in soil move projects.

O6: Ensure a broad social acceptance from all key public and industrial stakeholders and a smooth transition from the current practice to the new approach by enabling the stakeholders with all essential tools.

1.2 Research questions and hypotheses, theoretical approach and methodology

Approaches and methodology

The GREEN MOVE project will last for 48 months and is organized into six work packages WP1-6 as shown in the following figure. Research questions are listed under each WP.

WP0: Project management and coordination. Lead: NTNU-IBM (Elena Scibilia).

Objectives: Ensure effective management, technical coordination, good communication and efficient information flow between all the WPs and partners in the project. WP0 will establish an international project advisory group (PAG) during the first six months of the project. Further are regular meetings of the consortium

[24] Milà I. Canals, Bauer C., Depestele, J.,Dubreil, A., Freiermuth Knuchel, R., Gaillard, G., Michelsen, O., Müller, R., 2007. Int J LCA 12 (1) 5-15
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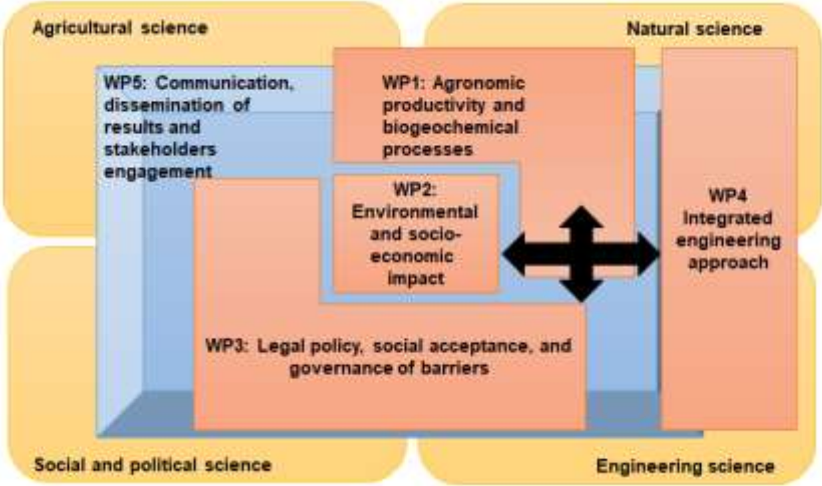
planned to ensure a timely and efficient cooperation between the partners. We will arrange regular meetings between PhD-students to secure the integration in the cross-disiplinary project.



WP1: Agronomic productivity and biogeochemical processes. Lead: NMBU (Trine A. Sogn).

Objectives: Explore how to maintain crop production and minimize negative environmental impacts in (re)constructed soils. ***RQ1A:*** *How does transporting and reconstructing soils affect soil hydraulic properties, soil organic matter, microbial activity and GHG emissions? Which agronomic options are appropriate for stabilizing newly reconstructed soils and maintaining crop production?* ***RQ1B:*** *How can rock wastes and mine tailings be used in combination with soil material to improve or construct subsoil layers at destination sites? How does addition of new mineral materials affect soil pH, mobility and bioavailability of nutrients and heavy metals?*

We will use cases planned by the partners in the project, where soil is moved and reconstructed, as the basis for field experiments. In addition, we will carry out a field trial at NMBU to compare addition of different mineral materials allowing detailed observations.

T. 1.1. Agronomic management strategies to stabilize newly constructed soils and improve soil structure to achieve satisfactory crop yields within a few years. Lead: NMBU (Susanne Eich-Greatorex,) Agronomic management strategies to reestablish and improve pore continuity will be tested, i.e. cereal production with and without catch crops compared to one or two years of grass cover. We will monitor soil with respect to physical parameters, by using CT scanning of intact soil cores, and measuring soil physical characteristics such as infiltration, soil water retention, air capacity, and bulk density after reconstruction. Addition of organic material to improve soil structure through increased biological activity will be as a factor in the field experiment at NMBU.

T. 1.2. Building knowledge on how to determine the potential of utilizing crushed waste rock and other mine tailings to improve the soil B layers: Lead: NTNU-IGP (Kurt Aasly)

To determine the potential of mine waste/tailings, an initial screening and a full characterization of promising raw materials are needed. From this mapping, a mine waste/mine tailings characteristics library for use in the project and beyond will be established, including characteristics important for assessing quality and an overview of deposits/rocks/ores/tailings.

T 1.3. Plant nutrient and heavy metal bioavailability from added mineral material. Lead: NMBU (Åsgeir Almås) Determining the fate of potential nutrients and harmful substances from added mineral material in a soil system is of importance to evaluate both benefits and drawbacks. This will be studied in column experiments without plants, as well as in experiments with plants in the greenhouse and in the field experiment at NMBU. In the column experiments, new mineral materials will be added to different soil types and vertical leaching of nutrients and heavy metals, as well as dissolved organic material (DOC), will be studied by analyzing the leachate and using modelling for speciation. In the field, lysimeters will be installed to determine changes in nutrient and heavy metal mobility in the soil solution.

T 1.4. Soil carbon pool and GHG emissions of newly reconstructed agricultural soil with and without added mineral material in the subsoil B-horizon. Lead: NMBU (Peter Dörsch)

To determine how disturbance due to moving and constructing soils affects soil organic matter and the activity of the microbial population in soils, GHG emissions will be measured in the field experiments. In cooperation with Task 1.3, the leaching experiments will be maintained over time to also be used to determine immediate and long-term effects on GHG emissions.

WP2: Environmental, social, and economic impact. Lead: SINTEF (Terje Kristensen).

Objectives: The objective of WP2 is to develop an in-depth understanding of the environmental, social, and economic impacts of relocating agricultural soils. WP2 will also assess how moving, and reconstruction of agricultural soils can be better included in the environmental, social, and economic assessment of development projects, as a basis for an assessment of the overall sustainability of relocation of agricultural soils.

RQ2: *How does the act of soil moving affect the environmental and socioeconomic impact of a construction project? Which factors need to be considered that might influence the cost-benefit analysis process?*

T2.1. Incorporating the environmental impacts of moving and reconstruction of agricultural soils into a life cycle assessment (LCA) framework. Lead: SINTEF (Katrin Knoth)

This will include land degradation impacts on the development site as well as impacts on the site that receives the soil. Here, a combination of site-specific soil and landscape properties as well as climatic factors will determine the potential challenges of a particular site. Cumulative impacts related to soil and land disturbance from different stages of a development project such as construction, operation and post-operation must be considered. Input from WP1 and WP4 will help to determine appropriate indicators that are lacking in a traditional LCA framework concerning potential land degradation impacts such as nutrient decline, compaction, plant growth and hydrological properties. The possibility of a combined environmental impact assessment, LCA and socio-economic impact will be investigated when it comes to appropriately assessing the impact of development projects on soil moving and reconstruction (in collaboration with T2.2 and T2.3).

T2.2. Life cycle assessment (LCA) and life cycle cost (LCCA) of moving agricultural soils. Lead: NTNU (Rolf André Bohne) This task will provide a complete LCA and LCCA for soil relocation processes, including the adverse environmental impacts of relocation of agricultural soil. To do so, a detailed description of the soil moving process, including all machine use, physical and monetary flows (input to task T2.3), as well as how to measure past and future functionality of the soil will be analysed (input from WP1) and appropriate indicators developed (task T2.1).

T2.3. Socio-economic impacts of moving and reconstruction of agricultural soil. Lead: SINTEF (Hrefna Run Vignisdottir) Soil moving, and reconstruction of agricultural soil might entail various socioeconomic impacts related to decreased agricultural production and income for farmers, land use change, land degradation impacts and others. Input from WP3 and Task 2.1 will help to define indicators concerning the most important factors that determine short and long-term socioeconomic impacts from development projects. This task aims to provide recommendations for the development of a standardized system approach for the environmental cost-benefit for different measures regarding moving and reconstruction of agricultural soil.

T2.4 Social impact of infrastructure development and relocation of soil. Lead: SINTEF (Hrefna Run Vignisdottir). Based on the input from Task T21. T2.2 and T2.3, the social impact of both land use change (infrastructure or urban development) and soil relocation (new agricultural or recreational development), and the social impacts feedback to socio-economic development is analyzed. This task will work close to T2.3.

WP3: Legal policy, social acceptance, and governance of barriers in decision making process. Lead: NTNU-ISS (Hilde Bjørkhaug).

RQ3: *What are the processes leading up to decisions on major land-use change issues and how can we employ a 'deliberative engagement' approach to public advice on policy?*

Objectives: Better understanding of the position of soil conservation in decisions on major infrastructure projects, this means understanding societal interest at stake and actors involved, understanding the processes leading up to decisions on major land-use change issues and develop methodologies and tools that foster democratic and deliberative decision-making processes for sustainable land use management strengthening environmental and climate considerations.

T.3.1. Analyse the position of soil conservation, key stakeholders (landowners, municipalities, counties, the public and developers) and civil societies interests and rights in decisions on major infrastructure projects. Whose rights are at stake? Lead: NTNU-ISS: Hilde Bjørkhaug

Analyses will be based on case studies of ongoing infrastructure projects. Data will be generated from key documents (public communication and planning), interviews and survey-data from stakeholders involved in the processes. Discussions will be informed by Institutional Theory (Ostrom) to uncover negotiations between formal and informal institutions (laws, sanctions, and norms), discourses and values (social and cultural) in planning and decision-making. Task 3.1 will also evaluate level and outcome of participation and co-creation in decision making and propose good practice methods for inclusive collaboration.

T3.2. Communicate the risks and advantages of subsoil, B-horizon, engineering. Lead: NTNU-IGP (Rune B. Larsen). Based on the results gained in WP1 and WP2, we are here aiming at communicating the basic vision to all possible stakeholders, that engineering from a variety of waste-rock sources is a sustainable approach if based on solid knowledge. Key approaches are to demonstrate the importance of geological data to verify the benign qualities of an engineered mineralogical soil make-up and to document the positive effects on the total environment in terms of reduced needs of land-fills and sea/fjord deposits of waste rock.

T3.3. Analyse policy dilemmas and adaptations in decision on agricultural soil. Lead: NTNU-ISS (Jostein Vik). Building roads on agricultural soil is a wicked problem, there is no single or right solution to the problem it arises. This task will build on T3.1 and T3.2 to analyse and discuss how conflicting policy goals are negotiated, weighted, and potentially changed to achieve outcomes and to allow progress.

WP4: Integrated engineering approach to transport and reconstruction in a sustainable way. Lead: NTNU-IBM (Inge Hoff).

Objectives: based on best practices of moving soil projects, develop engineering solutions and effective project planning to transportation and (re)construction of soil profiles at new location with main aim to achieve a satisfactory agronomic plant production and restoration of nature. To reach the goal, the results from WP1-3 must be considered; from the agronomic strategies and solutions developed in WP1, through environmental and economic assessment in WP2 and policy analyses in WP3.

RQ4: *What are the best practices and lessons-learned in Norway and worldwide from the main soil moving projects and developed construction process, methods, and equipment under different conditions?*

RQ5: *What are the requirements for a new soil locality regarding topography, geology, and the environment?*

RQ6: *How are soil biodiversity and vegetation affected by transportation and reconstruction of soils?*

T.4.1. Best practices of moving soil projects. Lead: NTNU-IBM (Rao Martand Sigh). This task will deploy a customized case study methodology for comprehensively analysing and benchmarking the best practices in moving and (re)constructing soils and strategies in Norway and worldwide. Information from the stakeholders will be instrumental to learn about the significant variations between how project planning and execution of soil moving projects are performed from within a country and between different counties, also depending on location and type of infrastructure project. This task will be dedicated to analysing the different methods used.

T.4.2. Barriers in Political, Economic, Social, Technological, Legal and Environmental (PESTLE) aspects. Lead: NTNU-IBM (Elena Scibilia). This task focuses on analysing the political, economic, social, technical, legal, and environmental (PEST) barriers for agricultural soil moving related to infrastructure projects, and to establish the connection between these barriers and the limitations/gaps in the existing plans. This task will also analyse the lessons-learned from the recent related projects reviewed in T4.1. and will consolidate knowledge built in WP1-3.

T4.3. Development of engineering solutions, construction process, and methods. Lead: NTNU-IBM (Amund Bruland). The task will focus on developing a set of indicators to identify suitable areas for establishing new agricultural fields (based on soil quality of the new area, local climate, biodiversity aspects, visual impact, transport distance etc.) and developing construction process, methods, and equipment for (1) considerate transport and reconstruction of soils, with or without adding new mineral material in the B layer, in order to retain soil hydraulic properties such as infiltration and hydraulic conductivity, (2) to keep organic matter and soil microbial activity when moving, under different conditions.

T4.4. Biodiversity restoration integrated solutions. Lead: NTNU-IBI (Bente Jessen Graae). Preserving and restoring biodiversity is needed when areas for roads are built and new areas for placing the soil are selected. We make restoration experiments for species and communities that are being destroyed by road building, so that the soil moving will not only create new agricultural land but also move and restore natural pockets of biodiversity hotspots. Furthermore, we secure that the natural land lost for the recreation of new agricultural fields will not cause destruction of valuable areas important for the biodiversity. Surveys of biodiversity on affected land will be carried out and methods for restoration of the natural flora with its soils will be developed in experiments on reconstructed soils and described for future restoration projects.

WP5: Communication, dissemination of results and stakeholder's engagement. Lead: NTNU-IBM (Inge Hoff). Additional participants: all partners. Objectives: This WP aims to effectively address the key stakeholders (people or organisations who have an interest in GREEN MOVE project or affect or are affected by its outcomes) and the wider communities to maximize the impact GREEN MOVE on the anticipated introduction of a new integrated approach when it comes to moving and reconstructing the agricultural soil. This WP also aims to maximise the communication of the project outcomes through a multi-channel approach national and regional, in synergy with platforms/networks/associations, and using project websites, newsletters, fact sheets / infographics, and strong social media presence. Stakeholder engagement will be organised in connection with the WP1-4.

T5.1. Stakeholders and advisory group involvement. Task leader: NTNU-IBM (Inge Hoff). This task will focus on creating long-term cooperation between the national stakeholders involved in decision making process on relocating and moving agriculture soil related to infrastructure projects, so they will remain after the GREEN MOVE project for continuing development and implementation of the new proceedings and standards. T5.1 will also establish a working platform for integration of the international Advisory Group.

T5.2. Dissemination and communication activities. Task leader: NTNU-IBM (Elena Scibilia). As a critical component to achieving the aims of the project, this task focuses on effective communication internally within the consortium, stakeholder and advisory groups, and decision makers and larger industrial and research communities. In this respect, a detailed Dissemination and Communication plan will be produced at the beginning of the project. This plan will constitute the core document describing the project's dissemination and communication activities and timeline.

Possible risks

Risks come with interdisciplinarity since it involves different science, societal and political cultures and the natural communication gaps beheld in We have mitigated these challenges by devising a core-group including experts in science, sociology and communication and further enforced by a board involving stakeholders with specific interests in the success of the project. In addition, we will have frequent meetings between PhD/post doc scholars and scientific staff. The planned secondments where students spend time with the different partners will help to join the group.

Other risks involve establishing field tests in connection with real-life soil moving projects and laboratory work. Most of our partners have ongoing activities on soil moving projects which reduces the risk. In a case of any force majeure, we will get new partners or use the advisory group. There is good interest in the topic, and it should be easy to find willing partners if needed. Expensive laboratory tests and analyses carry risk that the allocated budget is exceeded. Well thought planning of analyses and tests may mitigate. Costs may be moved between WP and Tasks to cover the costs if needed.

The third group of risk includes personnel involved in the project. PhD students may leave the position for any reason before graduation. We will make sure of good supervision and follow-up and include the students in the work environment.

Ethical issues Our basic presumption in GREEN MOVE is that the most satisfactory solution is to protect agricultural soil and avoid relocation as a result of urban constructions. However, when societal imperatives endanger productive soil, we hold that the approach for soil-relocation/ B-layer engineering outlined in this proposal may show a ground-breaking approach to the protection of agricultural land-masses.

Interdisciplinarity of research approaches

The researchers participating in the GREEN MOVE project represent four subject groups as defined at level 2 of the Norwegian Classification of Scientific Disciplines, drawn up by Universities Norway (UHR): social sciences, natural sciences, technology, and agricultural sciences. Soil transportation and (re)construction requires a holistic, problem-solving approach. For this, we need to understand not only the rock-soil-plant system, but also economical, technical, industrial, environmental, and societal aspects when it comes to re-establishing agricultural soils and making them productive in a short period of time.

1.3 Novelty and ambition

The novelty of the GREEN MOVE project lies on the integration of fundamental knowledge from different disciplines: civil engineering, soil science, social and political science, biology, geochemistry, and environmental ecology. Our approach is ambitious, as we aim at accumulating new knowledge for an integrated approach to agriculture soil transportation and reconstruction in a sustainable way. We have an intention to formulate a holistic cross-disciplinary approach to moving and (re)constructing soils. Moving soil is currently considered last option when other measures to protect farmland failed. One reason is according to Agricultural Minister Bollestad on her reply to question on the issue "Few reliable studies on moving soil and uncertainties connected to agronomic, economic, environmental and planning aspects". The minister calls for more knowledge building on moving soil before changing current policy and regulation[30].

As the interest and request from developers and authorities has been intense, practical experiences have been gained and methods of reconstructions have been developed[31] [32] [33] [34]. However, there is a great potential of improvement of the methods to maintain soil ecosystem services, health and stability, as well as agronomic plant productivity and biodiversity. An approach based on soil characteristics as the key to establishing, e.g., soils as the basis of parks and gardens is described by Haraldsen and Krogstad[35]. In the present study a systematic analysis of how excavation, transportation and reconstruction affect the key factors for soil functions will be performed to secure sustainable soil management, low GHG emissions and a minimum of harmful environmental impacts. Additionally, an exploration of the potential for utilizing mine tailings in the

[30] Government, (2019) https://regjeringen.no/no/aktuelt/svar-pa.skriftlig-sporsmal-om-omfanget-og -kvaliteten-på-jordflytting/is2645912

[31] Same as ref.4

[32] Hauge, A and T. Haraldsen (2017) *Nibio Planering og jordflytting.* NIBIO Bok;3(4) 2017 *Ås:* NIBIO

[33] Same as ref.6

[34] Same as ref.7

[35] Haraldsen, T.K. and Krogstad, T. (2018). Jordegenskaper er nøkkelen til varierte grøntanlegg. Park & Anlegg Temahefte: Jord til grøntanlegg – sammensetning, egenskaper og vekstenes vitalitet. 52 p.

reconstruction will be performed. The aim is to retain and develop agricultural soil using excess soil and tailings, utilizing waste as a resource, and thereby contributing to sustainability and a circular economy.

Today, we know little about the best way to manage newly (re)constructed agricultural land to minimize both agricultural production losses as well as environmental impact with respect to leaching of nutrients and pollutants, carbon stored in the soil or biodiversity. The potential benefits and risks of including rock residues and mine tailings from other productions to create artificial B-layers and thus improve the fertility of soils in the long-term have not been investigated in detail yet.

2. Impact

GREEN MOVE will focus on fundamental as well as applied research. The use of research results are expected to have positive impact both academically, for the society and for the commercial partners involved.

2.1 Potential impact of the proposed research

Impact on the research area: GREEN MOVE involves a new co-operation between several research groups at NTNU and NMBU. The project will educate five PhDs with a unique cross-disciplinary knowledge in both agriculture and several disciplines of construction engineering. Both NTNU and NMBU will use new knowledge developed in the project in education of new generations of Master/Bachelor – students. The field sites that we plan to establish will be used for years to come for student's field work. Accordingly, we expect the project to have a positive and important impact on the co-operation and joint development of research and education between these universities. GREEN MOVE will gather competence in a field that so far is less researched, and the results will be useful for researchers both in Norway and internationally as a reference for further studies.

Impact on societal challenges: Use of agricultural land for different purposes is controversial and most politicians are, in principle against it. However, when it comes to the practical decisions it is often seen that principles must give way for development/workplaces or new infrastructure. The project will dive into the decision processes and make it easier to make informed decisions based on science. The project will also provide a decision support framework for selecting best technologies and best practice for transporting soil to a new location and constructing a new soil profile. One of the most difficult aspects when moving soil is to find a suitable area to relocate the soil to. Through this project we aim to develop decision support tools to improve the possibilities to evaluate candidate areas when it comes to agricultural potential, climate condition, biodiversity, water balance, life cycle cost and environmental impact. Another key challenge is the design and construction of a subbase layer, B-layer, which can offer a good water balance. The project will suggest concepts for such a B-layer based on waste rock and tailings from local rock quarries and mines. The use of this kind of rock materials for agricultural purpose will have a positive impact for the soil composition and use of otherwise surplus rock materials.

Impact for the industrial partners and public sector: GREEN MOVE will engage different actors and create increased awareness about the possibilities for moving soil and make it more likely that this will be considered as an alternative for future projects. The possibilities to move soil and reconstruct a soil profile at another site are indeed requested. If possible, to achieve high productive agricultural soil at a new site, without destroying nature. The project has non-academic partners from the public sector, quarrying and mineral production, technology consultants, building contractor and farmer associations. **Each of these partners have identified their specific interests and needs for GREEN MOVE to contribute to their value creation.** GREEN MOVE does not aim for a "carte blanche" to build on agricultural land, but to find the best possible solution for moving soil when a decision to build has been made.

GREEN MOVE **addresses several of the UN sustainable development goals (SDG)** (refs): GREEN MOVE is an *"industry innovation"* (SDG 9) aimed at contribution to *SDG 2: "Zero hunger "*. This goal involves securing sustainable food production systems and resilient agricultural practices. Ensuring that high-quality agricultural soil is conserved and new areas for food production established will contribute to protect the capacity for local food production, is also a part of *SGD 12:* "*Responsible consumption and production".* Knowledge from this project will to some extent be transferable to other countries. *SDG 11: "Sustainable cities and communities ".* Especially during the current pandemic, the disadvantages related to dependence on food imports is gaining more attention. Securing local food production could become more important. *SDG 13 "Climate action " and SDG15 "Life on land".* New infrastructure projects that occupy and seal large areas originally used for agriculture, conflict with *SDG* 13 and *15*. It is therefore important to deepen our knowledge on successful restoration of other available areas, such as former landfills and quarries to mitigate negative impacts.

2.2 Measures for communication and exploitation

Target audiences: The partners in GREEN MOVE cover the complete value chain when it comes to moving agricultural soils for infrastructure. This means that the needs of all the stakeholder groups will be represented in the project and make it easier to adapt communication for the different groups. The main target audiences of the project are entrepreneurs, infrastructure owners, farmers, farmers organizations, land protection organizations, politicians (both at municipal and national level), administration (both municipal and national), students in transport engineering, urban planning, landscape architecture, agriculture, urban farming, social and political studies and researchers within the same topics.

Plans for dissemination: We will attend farmers` fairs, regional fairs and construction industry fairs; organising workshops to reach out to farmers, municipalities, landowners and builders. The major research findings will be communicated to engineers and scientists within the scientific community through papers in scientific journals and at international conferences. More than 20 scientific papers are expected from the project. In addition, we will communicate results from the project through Norwegian popular scientific journals like Byggeindustrien, , Kommunal rapport, Bondebladet, Nationen. We also plan to participate at national conferences/meeting places for the different stakeholders.

Activities: The project will establish a webpage to share all findings and publications and establish social-media channels for information and collecting feedback from stakeholders. GREEN MOVE will organise three major workshops, open for the public audience in addition to the scientific community: one start-up meeting at the beginning of the project period, one at mid-term, and finally a closing conference to sum up results and point out the way further.

Exploitation: Project outputs will give valuable information to various actors engaged in the topic of moving and reconstruction of agricultural soil and will enable informed decision-making related to important infrastructure projects. The findings will help contractors, farmers and consultants in finding practical solutions that ensure efficient and cost-effective actions. Environmental, economic and social risks associated with soil moving can be more easily assessed and targeted compensation measures, cost estimates and incentives included in the early planning process. The individual user groups will have a basis for converting research results into dedicated guidelines and position documents.

3. Implementation

3.1 Project manager and project group

The project is coordinated at the **Department of Civil and Environmental Engineering (NTNU-IBM)** by Dr. Elena Scibilia. She holds two positions at NTNU: a researcher at Civil and Environmental Engineering and an adjunct professor at the Department of Geoscience and Petroleum. She has a PhD in a field of mineralogy and geoscience and her topic of PhD was in connection of weathering of volcanic tephra and forming soil profiles. For the last 8 years she has been working within the fields of transport infrastructure and crushed rock aggregate properties, production and use and she has been leading several national and international projects. Professor Inge Hoff will be a deputy of project manager and WP4 and WP5 leader. Professor Hoff has long experience in research on road related infrastructure. He has been working 10+ years as a professor at NTNU. Hoff and Scibilia has been working close together over several years and have been co-managing several large projects. Other participants from IBM: Professor Rolf André Bohne (leader of task 2.2) with expertise on environmental impact assessment of buildings and infrastructure. Has 20 years research experience on Sustainable Infrastructure: building and construction materials, material flows (MFA) and environmental impacts (LCA) of the AEC industry. Professor Amund Bruland (leader of task 4.3) is expert in earth moving, rock mass properties, cost, and time estimation of heavy construction projects. Professor Rao Martand Singh (leader of the task 4.1) is a geotechnical and geo-environmental engineer. He has expertise in soil strength/deformation, soil contamination, slope stability and ground movement.
The **Department of sociology and political science (NTNU-ISS)** has been doing research on understanding of the key motivations and drivers behind land-use related decisions at levels ranging from landowners to public authorities at national level, including their relative importance. Professor in sociology Hilde Bjørkhaug will be leader of WP3 and task 3.1. Her research focus over last 20 years is on sustainability of agriculture and food systems, land-use, land-use conflicts and land value negotiations, food systems, agriculture and food security policy, bioeconomy. Bjørkhaug is coordinating the ISS research group on Energy, environment, and sustainable development. Associate professor in political science Jostein Vik (leader of the task 3.3) has long research experience on public policy and economic development in rural areas, agriculture- and food security policy, agricultural production studies from Ruralis.
The **Department of Geoscience and Petroleum (NTNU-IGP)** covers the entire field of mineral production from exploration through mining and mineral production to environment and HES topics. Including basic geology, mineral characterization and waste rock and tailings handling. Professors Rune Berg-Edland Larsen (leader of the task 3.2) has specialized on the igneous and ore-forming potential of mafic, ultramafic, and felsic igneous lithologies and is particularly engaged in understanding the chemical and physical properties of minerals composing the rocks. Associate Professor Kurt Aasly (leader of the task 1.2) is an expert in process- and industrial mineralogy and the use of advanced mineral characterization techniques for assessing quality of mineral raw materials and their downstream products in the mineral processing plant.

The **Department of Biology (NTNU-IBI)** aims to increase knowledge about biodiversity and understanding life on Earth. Professor Bente J Graae (leader of the task 4.4) studies plant performance, community dynamics, productivity, and carbon fluxes and stocks in vegetation in response to land use and climate change. She is further involved in teaching the interdisciplinary Master program Natural resource management, particularly relevant for GREEN MOVE.

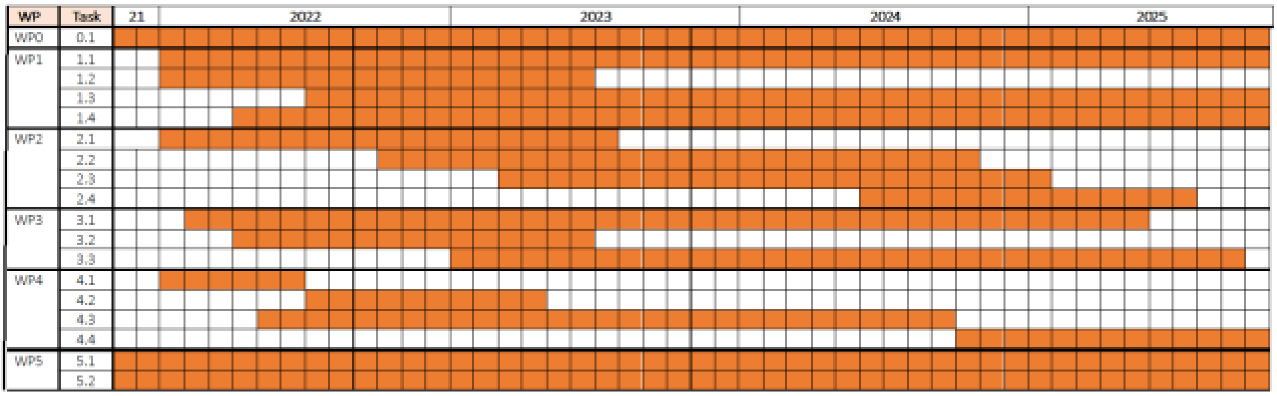
Norwegian University of Life Sciences (NMBU) is the national competence centra for education and research within sustainable land-use. The NMBU-**MINA**-faculty has the national responsibility for soil sciences. Professor Trine Sogn (WP 1 leader) is an expert in soil fertility, nutrient cycling in the soil-plant systems, soil modelling and recycling of organic residues. Professor Trond Børresen is an expert in soil physics, soil management and agronomical practices, soil compaction, infiltration, water holding capacity and soil erosion. Professor Tore Krogstad is an expert in soil chemistry and plant nutrition, analytical chemistry, geochemistry of mineral nutrition, eutrophication, and fertilizer advisory. Assoc. Professor. Susanne Eich-Greatorex (leader of the task 1.1) is an expert in plant-soil interactions, organic fertilizers, soil management and quality, as well as soil physics. Dr. Peter Dörsch (leader of the task 1.4) is an expert in soil ecology, soil microbial biology, biogeochemistry of nitrogen and carbon, agronomic practice, and climate change, as well as gas chromatography. Dr. Åsgeir R. Almås (leader of the task 1.3) is an expert in soil chemistry, biogeochemistry, and fluxes of trace metals, as well as metal and oxyanion speciation modelling.

SINTEF is one of Europe's largest independent research organizations conducting research and innovation projects. Dr. Terje Kristensen is WP3 leader. Kristensen holds a MSc in ecology and PhD in geospatial statistics focused on spatial assessments of carbon in soils. Kristensen have primarily worked at projects aiming to lowering the carbon footprint on infrastructure projects. Dr. Katrin Knoth (leader of the task 2.1) holds a PhD in Agronomy and has a background in landscape architecture. She has 17 years of relevant experience in research and consulting with a focus on soil chemistry. In addition, she has consulting experience from soil moving projects, assessing the suitability of topsoil to be moved and identifying potential suitable areas for new agricultural land. Dr. Hrefna Run Vignisdottir (leader of the task 2.3 and 2.4) holds a PhD in Life Cycle assessment with a focus on road maintenance activities. During her PhD she focused on GHG emissions but also on ecotoxicity, water toxicity and soil contamination.

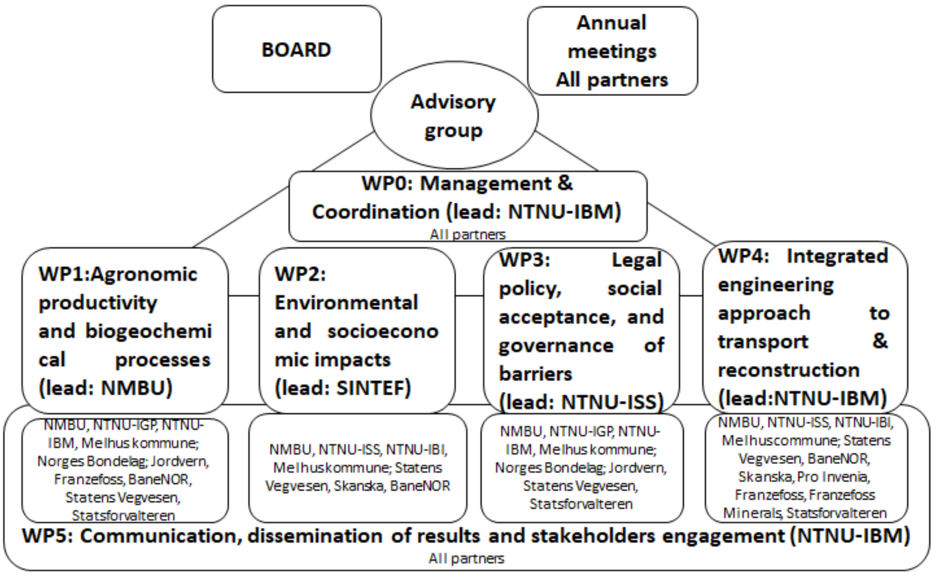
We will have **a full chain of relevant partners** including infrastructure owner, contractor, municipalities, consultant, aggregate producers, land protection and farmers association. **Statens Vegvesen** manages most of the national roads in Norway and are involved in several projects that include moving of agricultural soils e.g "Ny jord" (E18 in Follo). **BaneNOR** is responsible for the rail infrastructure and are planning several new projects where soil moving could be an option (e.g. Ringeriksbanen). **Skanska** is a large contractor working with infrastructure and other projects all over Norway. Skanska has been and expects to be involved in several projects including moving of soils connected to planned road and railway projects. **Pro Invenia** is a consultant company offering detailed planning and design of projects involving moving of agricultural soil. Pro Invenia has been involved in several relevant projects recently, especially in Trøndelag. **Melhus** is a municipality close to Trondheim in Trøndelag. They have been involved in some projects including moving of agriculture soil in the past and are expecting several projects in this field in connection with the expansion of E6 through the municipality in the coming years (E6 Gyllan -Kvål Reguleringsplan & Prestteigen Gyllan). **Statsforvalteren in Trøndelag** is an organisation that has a control function at regional level. **Francefoss Minerals** is a producer of limestone products that have several applications both in construction industry and agricultural. **Franzefoss** is a producer of hard rock and sand/gravel aggregates at several quarries e.g. in the Trondheim and Oslo areas. **Jordvern Norge (soil protection alliance)** is a political members organization working to protect agricultural soil. The organization is a national alliance with local branches several places in Norway. **Norges Bondelag** (Norwegian farmers association) is a member organization representing farmers in negations with the government and working to protect farmers' interest in political processes and increase knowledge among farmers.

3.2. Project organisation and management

Work plan: The timeline of the project is shown in a Gantt chart, Table 1. The overall management structure is shown in Fig.1, also identifying the WP-leaders. A more detailed presentation is given in Section 1 with the WP and task descriptions. The project leader will be supported by a management group consisting of the WP leaders.



Annual project meetings for all project participants will be used to present results, decide about changes in the tasks, and to inform and invite other stakeholders. The annual meeting with all partners will act as the project board, for which a board chairman will be elected at the first meeting. The advisory groups will be formed after starting the project and it will include both stakeholders from public and private sectors and scientific community.: One of the outcomes of "T.4.1. Best practices of moving soil projects" will be identifying the key stakeholders and leading research groups who have been working with soil moving projects and who can contribute to the GREEN MOVE project via advices and valuable information.



Research infrastructure: All the academic partners are university institutes and research organisations, which are heavily set-up with laboratory and field investigation equipment. Such equipment is the basis day-to-day condition for their existence. Especially we would like to highlight facilities at NTNU-IGP:

(1) The Norwegian Laboratory for Minerals and Materials Characterization (MiMaC) is a Norwegian national infrastructure funded by the RCN https://www.ntnu.edu/mimac/home. Relevant equipment for GreenMove: Automated Mineralogy System (AMS) and Electron Probe Micro Analyzer (EPMA).

(2) The Micro-CT is a Nikon XT H225 https://www.nikonmetrology.com/en-gb/product/xt-h-225. Fully financed through the PoreLab SFF.

Among the collaboration partners/stakeholders the most relevant infrastructure will be general field machinery for agriculture and civil works, production equipment for crushed rock/aggregates/limestone.

Involvement of collaboration partners: The project shall last for 4 years. In total we are planning to have 5 PhDs and 1 postdoc. From a scientific point of view this is described in detail in Section 1. One of the topics of PhD at NMBU will be on construction of B layers with new minerals in close cooperation (WP1) with co-supervision from NTNU-IGP. This is a task where the collaboration partners ProInvenia, Franzefoss and Franzefoss Minerals will be directly involved. Another PhD and postdoc at NMBU will focus on soil physics/hydraulic properties, soil organic matter and GHG emissions of newly reconstructed agricultural soil with and without added mineral material (WP1). Several users, not least from the farmer associations, will be involved directly and/or via the Stakeholder group in this research. Main topics of two PhDs at NTNU-IBM will be: (1) environmental and socioeconomic impacts of soil moving and (re)construction with co-supervisor from SINTEF (WP2) and (2) Integrated engineering approach to transport and reconstruction in a sustainable way with co-supervisor from NTNU-IBI (WP4). These are topics which will be followed closely e.g. by the representing public partners, contractor/consultant and infrastructure owners. PhD topic at NTNU-ISS will be social acceptance and policy dilemmas and adaptations in decisions on agricultural soil with co-supervision (WP3) from NTNU-IGP and NTNU-IBM. This is also very relevant for the public sector representatives and decision makers (e.g. commune). All PhDs and the postdoc are planned to start at the same time, in the beginning of the project. Each student will have secondment at a collaboration partner, and a co-advisor from the same. Thus they will be linked directly up with the needs, problems and ambitions of these partners. They will strongly collaborate both in the field and lab and share their knowledge background/environment.

Cross-discipline governance: The project collaboration provides an excellent and motivating environment to have a cross-disciplinary study ranging from microscale to large scale applications. With partners from all value chain (infrastructure owners, contractors, consultant, land protection, aggregate producers, farm association, municipalities) with large experience and interest in sustainable agriculture and responsive land relocation, the project group complements fundamental and applied research and is in the position to link the research to needs and challenges in society, industry, and agriculture. The expertise and experience of both academic and collaboration partners are described in 3.1.