HOLISTIC RESOURCE MANAGEMENT FOR
CLIMATE RESILIENCE OF FARMING

Training Handbook
ClimateFarming

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Lesson 1: Farming in a changing climate

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In this chapter the main problems and challenges that agriculture has to deal with regarding changing climate conditions and other pressures are displayed. The complex interactions between the individual issues presented must be considered, and an isolated treatment was only chosen for a better overview of the different topics.

Knowledge about these challenges and interrelationships is relevant as one of the foundations for successful climate change adaptation. They are the basis for a comprehensive problem awareness and a resulting solution orientation. It is especially important for advisors to be able to sensitise farmers to problems (including those problems whose impacts are still in the future). This enables the existing need for action to be pointed out and a joint agreement on a committed development of an individual climate change adaptation strategy to be reached.

A changing climate[3]

The Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC Sixth Assessment Report, AR6, 2023), states that global warming is unequivocally caused by human influences (Figure 1, b) and that the present state of the climate systems together with the scale of the changes in the period 1850 – 2020 are unprecedented in more than hundred thousand years (Figure 1, a). Global warming was observed to be slightly above 1 °C today relative to 1850 – 1900, and a warming of 1.5 °C and 2 °C relative to 1850 – 1900 is expected to be exceeded during the 21st century (ibid.). A rise in global temperatures of 1.5 °C is expected to increase the frequency and intensity of heavy precipitation and flooding in most regions of the world. On the other hand, an increased frequency of severe droughts with adverse impacts on food security and terrestrial ecosystems is to be expected. Furthermore, it contributes to desertification and land degradation worldwide creating additional stresses on land, exacerbating existing risks to livelihoods, biodiversity, human and ecosystem health, and food systems (IPCC Special Report on Climate Change and Land, SRCCL 2019).

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[3] This section is based on, and partly directly cites, a Master Thesis by Lærke Daverkosen & Alena Holzknecht (2021)

Planetary boundaries

The Stockholm Resilience Center has defined nine planetary boundaries that, when crossing the safe operating space, will severely impact life on earth negatively and thus will also have grave impacts on agriculture. The biggest overshoots in 2009, when the assessment was done for the first time, were
a) biodiversity loss,
b) the climate crisis, and
c) nitrogen and phosphorus cycles.

In addition, referring to Persson et al. (2022) there are even more critical developments for 2022. These are
d) freshwater change,
e) novel entities, and
f) land-system change (Meyfroidt et al. 2022),
as well as a couple more that are on-the-edge. In freshwater change due to inclusion of "green water" (terrestrial precipitation, evaporation and soil moisture) a boundary has been crossed. There are widespread changes in soil moisture and ongoing destabilization through human pressures at continental to planetary scales. So-called novel entities are new in a geological sense which means that also naturally occuring materials are created, introduced or recirculated by humans and that way mobilized in new ways - including environmental pollutants, plastics, pesticides, or forever chemicals. These large-scale impacts are threatening the integrity of Earth system processes. At the global level, therefore, massive challenges have been scientifically documented for many years. These are part of a complex interplay of effects and have a comprehensive impact on our environment. The agricultural sector is strongly affected and will be even more so in the future. These problems can probably not be solved completely, so that an appropriate way of dealing with them must be found while at the same time minimizing their effects.

Soil degradation & the three roles of agriculture in climate change

Land is simultaneously a source and a sink of carbon dioxide (CO_2) and plays a key role in the climate systems and greenhouse gas (GHG) exchange between the land surface and the atmosphere (IPCC SRCCL 2019). The conversion of natural ecosystems to managed ecosystems changes the land to a GHG source and depletes the terrestrial carbon (C) stock (Poeplau & Don 2015). Thus, ecosystems have been turned into GHG sources since the onset of agriculture approximately 10,000 years ago (Lal et al. 2018). A meta study found that the conversion of forest and grassland to cropland causes a soil organic carbon (SOC) decline of 30 – 80% in the upper soil layers (Singh et al. 2018). Emissions from agriculture and expansion of the agricultural land represent 16 – 27% of total anthropogenic emissions. When emissions associated with pre- and post-production activities in the global food system are included, the emissions are estimated to be 21 – 37% of total net anthropogenic GHG emissions. Emissions from the agricultural sector are expected to increase, due to population and income growth, together with climate change-induced land degradation. Expansion of areas under agriculture and forestry have supported consumption and food availability for a growing population, but simultaneously contributed to increasing net GHG emissions, loss of natural ecosystems and declining biodiversity. On the brighter side, the natural response of terrestrial land to human-induced change caused a net sink of around 11.2 Gt CO_2 yr-1 during 2007 – 2016, which is equivalent to 29% of total CO_2 emissions. However, the persistence of this sink is uncertain (IPCC SRCCL 2019). According to IPCC (2019), about a quarter of terrestrial land is subject to human-induced degradation. Poor management practices have led to low productivity and increased risks of food insecurity (Gupta 2019).

Indiscriminate use of adverse agricultural practices like continuous monoculture and intensive tillage have contributed to widespread land and soil degradation. Because the restoration of soil quality is a difficult process, the further degradation of existing fertile soils is highly important. E.g., many soils in Europe lose more than 2 t ha^{-1} $year^{-1}$ by tillage erosion. This leads to the risk of exceeding the soil's capacity to overcome climate disturbances, such as drought and severe and frequent weather events (Lal 2015).

So apart from contributing to climate change, agriculture itself is vulnerable to global warming and the increase in extreme weather events (IPCC 2019). Additionally, agriculture faces the challenge of increased food demand caused by population and income increase (Olson et al. 2016; IPCC 2019). According to Giller et al. (2021), the solutions to this challenge include either increasing food production within or beyond the current land under cultivation. Expansion of cultivated land would involve inclusion of less productive land currently functioning as carbon sinks and would lead to habitat loss and altering of biogeochemical and hydrological cycles. A solution that does not require vast land use changes relies on improved land management and continued/ restored soil fertility.

Soil fertility is also closely related to soil organic carbon, which has potential as a land-based contribution to climate protection. Increased carbon storage in soils may help to prevent agriculture-related carbon emissions, removing atmospheric CO_2 and delivering ecosystem services. This can be achieved through a combination of improving crop lands so land conversion for food production and thus carbon loss from soils become unnecessary, as well as active carbon storage in agricultural land (Bossio et al. 2020).

The special report on climate change and land by the IPCC (2019) underlines that the challenges of sustainable land and climate change are based on a high level of complexity and a high diversity of actors involved. Sustainable land-use management, food security and low emission trajectories are facilitated by policies that involve changes across the food system. This could include the reduction of food loss and waste, change in dietary behaviour, as well as the empowerment of women and indigenous people, supporting community action, ensuring long-term access to markets and land, as well as advisory services, and reformations of trade systems. However, all of the mentioned activities need to be seen in context with previous land use, geographies, feasibility and social and environmental circumstances (Bossio et al. 2020).

Temperature and Water Resources

Extreme weather situations are likely to increase globally and in Europe. For example, intense and heavy rainfalls on the one hand and droughts on the other hand can become more common, depending on the amount of GHGs released in the atmosphere. This will lead to changing ground water level and the loss of planning ability. Mean temperature has increased globally and in Europe over the last century and is predicted to increase even more (IPCC 2021). However, it must be considered that specific effects of climate change will vary considerably regionally and between years (see first chapter on uncertainties). This is the largest challenge in climate adaptation. No universal prognosis, and thus no universal recommendation for action can be given, albeit general long-term trends are clear.

Agriculture consumes about 70 % of the freshwater worldwide and in Europe depending on the season up to more than 32% of the total water (Cai and Rosegrant 2002; Lazarova 2017). Temperature and water resources are always circular dependent parameters: If soil moisture decreases, evapotranspiration decreases as well, which leads to even less soil moisture and an increase of temperature. An increased temperature therefore lets evaporation decrease again and an decreased evapotranspiration raises temperature (Seneviratne et al. 2010).

Food security & changing markets

Looking at climate impact models, rising temperatures and changes in precipitation will lead to a decline of food productivity. However, depending on the “crop types and livestock categories, short- and long-term adaptation efforts [the effects will differ] (IPCC 2019)”.

Not only climate change but also socioeconomic dynamics put farmers under pressure: demand for healthy but cheap products rises parallel to the competition for land use with buildings/ building materials, energy sources, fiber etc. Moreover, regulations in the EU e.g. referring to pesticides or animal welfare lead to higher production and labor costs. Nevertheless, farmers are often locked in dependencies on these commodities and services that are subject to price fluctuations.

Dependance on external inputs

Soil fertility historically has been improved by the addition of fertilizers, but especially in Europe nowadays there is a nitrogen surplus through the application of fertilizers and manure. This surplus not only has adverse environmental impacts, but also causes economic disadvantages. Many farms are trapped in dependencies on external inputs like fertilizers and fuel. On the one hand the nutrient loss is easy to compensate by adding more nutrients to the soil but on the other hand the fertilizer market doesn’t always develop as wished or required and prices change unpredictably. Between 1960 and 2000 the N and P fertilizer use tripled (Tilman et al. 2002), while the cereal production doubled globally. Further, nutrient losses result in high (environmental) costs through e.g. deprived water quality and algal bloom. Thus, it’s advisable to keep the nutrients on the field. In many places in Europe climate change will decrease yields. Even the predicted increase of yields in Northern Europe cannot compensate for these losses. Simultaneously nutrient use efficiency has leveled out so that often it’s not even helpful to use more fertilizers (Lassaletta et al. 2014). However, as agricultural soils often have been degraded over decades, an adjusted fertilization strategy can only follow after the management has slowly prepared a soil to function within its capabilities again. Also, the performance level of farm animals depends on the feed quality and composition and cannot be changed at once. Such adjustments are long-term processes and need planning and evaluation accordingly.

Biodiversity, pests and diseases

Parallel to, and largely caused by, climate change, ecosystems suffer an unprecedented loss of biodiversity. Strong evidence shows that we are on the trajectory towards a Sixth Mass Extinction caused by humans, whereas the five first Mass Extinctions had been caused by natural phenomena (Cowie et al. 2022). E.g., in Germany an average of 75 % of insect biomass has been lost between 1990 and 2015 (Hallmann et al. 2017). With rising mean temperatures even more habitat losses are projected in the EU and globally (IPCC 2022). This can strongly impair the stability and resilience of landscapes against external influences, including new, and/or higher loads of pests and diseases.

There are two main factors that make pests and diseases so relevant in the light of climate change:

1. The susceptibility of infections increases with climate change, as well as the regenerative capacity of plants, animals and whole ecosystems. Higher abiotic stresses caused by climate change makes plants more vulnerable to biotic stress factors. Higher solar radiation, unpredictable hails, rainfalls, frost or dry periods can cause damage to plants and can decrease their vitality.
2. The pressure of existing pests and diseases increases because of a faster succession (e.g. more generations per season), increased population growth, as well as new pests and diseases emerging and spreading their territories.

It is not possible to clearly predict which and to which extent pests and diseases will emerge. Instead of reacting to upcoming threats, comprehensive and proactive prevention measures at ecosystem level need to be implemented (See chapter about uncertainties and climate change). Ecosystem resilience must be supported and expanded, and one way of doing this can be by consciously making use of their multi-functionality.

Animal welfare

Animal husbandry is closely connected to nutrient cycling, but will also be highly affected by climate change. Livestock systems are impacted by climate change mainly through increasing temperatures and precipitation variation, as well as atmospheric CO_2 concentration and a combination of these factors. Temperature affects most of the critical factors of livestock production, such as water availability, animal production and reproduction, and animal health (mostly through heat stress). The thermo-comfort zones for sheep, cattle and pigs lie around or under 20°C (Pollmann et al. 2005; Bianca 1971). Livestock diseases are mostly affected by increases in temperature and precipitation variation (Rojas-Downing et al. 2017). Impacts of climate change on livestock productivity, particularly of mixed and extensive systems, are strongly linked to impacts on rangelands and pastures, which include the effects of increasing CO_2 on their biomass and nutritional quality. This is critical considering the very large areas concerned and the number of vulnerable people affected (Steinfeld 2010; Morton 2007).

Pasture quality and quantity are mainly affected through increases in temperature and CO_2, and precipitation variation. This can have a negative impact on the animal's health and level of performance. In extreme situations in recent years, animals had to be sold because their feed supply could not be ensured anymore. The adaptive capacity of such husbandry and feeding systems has been overstressed, leading to a shock reaction and the need to adjust the strategy for the coming years. Through comprehensive planning and monitoring with a focus on adapting to climatic changes, we can create systems that are less susceptible to environmental, but also economic or societal stressors.

Conclusion

Agriculture is affected by climate change like almost no other sector. In the context of climate change, agriculture plays different roles. It is a producer of GHGs, it can act as a GHG sink and it is directly and indirectly affected by climate change. On top of changing climatic conditions, there are a variety of interrelated topics that complicate farming nowadays. Natural resources can become scarce and less predictable, market structures are changing and often farmers are dependent on external resources, or locked in investments. Water availability is seriously impaired by changing precipitation patterns, as well as soils that are unable to infiltrate and retain water. At the same time, water bodies are polluted with nutrient run-off from agricultural land. We are also in the midst of a biodiversity crisis, and new pests and diseases are on the rise. Altogether, this creates new and unknown challenges for agriculture as a sector, but also for each individual farm. Farms are thus dealing with complex systems and are involved in a myriad of interactions, which all are subject to drastic changes in the light of climate change. To ensure long-term food security and a good livelihood for farmers, we have to plan adjustable short-, mid- and long-term strategies for each farm in their individual context to deal with these dynamic changes.

Outlook: Adapting to climate change!

In order for farmers to be able to recognise, assess and master these complex challenges, new approaches and methods are required - in farm management and day-to-day tasks on the field. These approaches and methods must take into account the specifics of the individual farm and integrate the regionally specific impacts of climate change. Furthermore, farms must be supported in using synergies between different climate protection and adaptation measures and in establishing long-term and far-sighted farm management. Furthermore, the risks resulting from the uncertainties (associated with climate change) must be included in the operational planning processes and minimized as far as possible. What we need is nothing less than a climate strategy - individually created for each business. At the same time, it must be ensured that this climate strategy also does justice to the many other challenges facing agriculture. In this context, the preservation of biodiversity and healthy soils is elementary. Not only for successful adaptation to climate change, but also to preserve our natural livelihoods.

Even with the lack of framework conditions, timely and adequate implementation embedded in regional, national and European strategies is necessary for the adaptation of agriculture to the recent and projected climate change. Adaptation options need to be feasible and effective in their local context. Biodiversity, air, soils, water and nutrient cycles and ecosystem

restoration need to be improved through structural adjustment like productive & resilient agroecosystems, nature-inspired methods or holistic-systemic approaches.
In order to motivate farmers to implement climate protection and adaptation measures, possible measures must be practical and fit the individual farm.

Climate protection & climate adaptation

In this project, we use the terms **climate mitigation** and **climate protection** synonymously. They describe actions to reduce further climate change by reducing greenhouse gas emissions (and enhancing sinks).

Climate adaptation refers to the actions that are taken to adjust to the impacts of actual and expected climate change. This can be performed on many levels, e.g. through flood protection, drought-resistant crops, or government policies that help deal with climate impacts.

“**Adaptation and mitigation are complementary strategies for reducing and managing the risks of climate change** (IPCC AR6, 2023)”.

Despite overwhelming evidence, the level of implementation of climate protection and adaptation measures is low (Jacobs et al., 2019). One reason for this is the uncertainty that arises above all from the complexity of the many interactions between agriculture and climate change. Not only is the development of climate change itself uncertain with regard to the intensity and speed of change (Pachauri et al., 2014), but also how these developments will affect specific regions and interact with other ecological and social factors. This fundamental uncertainty about future climatic conditions and their consequences inhibits the implementation of adaptation measures (Mitter et al., 2019). Furthermore, ignoring uncertainty and complexity can lead to the implementation of adaptation measures that turn out to be maladaptive - depending on how climate change evolves (Noble et al., 2014).

This issue is not yet sufficiently integrated into the design of (operational) adaptation measures. This is reflected in the continued focus on small-scale individual measures (Vermeulen et al., 2018), which mainly involve minor and reactive changes to operational production processes (Mitter et al., 2018). These are often based on the experience of past events. This level of adaptation measures may prove insufficient as climate change, in combination with other new developments, will create challenges outside of lived experience (Noble et al., 2014). Especially in view of a strong and not uniform course of climate change, adaptation needs to be planned and implemented proactively (i.e. preventively) (e.g. Vermeulen et al., 2013). This includes implementing profound changes in operations and production methods (Park et al., 2012) - so-called transformative adaptation.
However, it is important that the planning of climate measures is done on a farm-specific basis, as climate change and the vulnerability of the individual farm develop dynamically and

regionally (Noble et al., 2014; Shukla et al., 2019). Since the farm is the decisive point where climate protection and adaptation are implemented, the corresponding measures and strategies must fit the farm's objectives as well as its economic, ecological and social characteristics (Reidsma et al., 2010; Bloch et al., 2014; Stringer et al., 2020).

SUMMARY - Farming in a changing climate

- Agriculture has different roles in the context of climate change - as a GHG emitter, a potential GHG sink and as an affected party.
- Global warming today is observed above 1°C, and is expected to increase well over 1.5°C during the 21st century.
- Indiscriminate use of adverse agricultural practices like continuous monoculture and intensive tillage have contributed to widespread land degradation.
- Ongoing land degradation leads to the risk of exceeding the soil’s capacity to overcome climate disturbances, such as drought and severe and frequent weather events.
- Extreme weather situations like extended periods of drought or heat or strong precipitation events will increase with climate change.
- Many farms are trapped in dependencies on external inputs like fertilizers and fuel. Agricultural soils often have been degraded over decades, an adjusted fertilization strategy can only follow after the management has slowly prepared a soil to function within its capabilities again.
- Animal welfare issues will be intensified by climate change.
- Farmers are under a lot of pressure to produce enough healthy food for all, at the same time as preserving healthy ecosystems, being subjected to market demands, land-use conflicts and changing environmental conditions.

Resources

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Lesson 2: Climate Change Management

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Two basic options exist to address climate change and its impacts: climate protection and climate adaptation. Climate protection, in the context of this guide, involves the reduction and storage (negative emissions) of greenhouse gas (GHG) emissions. The second option, climate adaptation, involves modifying a system and its environment so that it is less sensitive to actual or projected climate change. These two approaches have largely been considered and researched independently of each other, with a tendency to prioritise climate protection (Füssel and Klein, 2006). This is misleading, as both approaches are strongly interlinked and - to be successful - need to be thought about, planned and implemented together (Wreford et al., 2010).

Since climate change is already taking place as a consequence of past emissions, it is no longer possible to absorb the consequences through climate protection alone. For this reason, adaptation is and will be necessary to unavoidable impacts of climate change. However, it would be just as fatal to pursue climate adaptation alone. This is the case because:

- There are limits to adaptation, determined by biophysical and socio-economic factors as well as the risk of tipping points.
- Climate protection reduces the intensity and speed of climate change, thus facilitating adaptation and reducing the costs of adaptation (Hallegatte, 2009).

Accordingly, climate change adaptation should have the same priority as climate protection in agriculture. Not only because of the use of possible synergy effects, but also in relation to the different conditions for the success of climate protection compared to climate adaptation. The success of climate protection, especially as an individual operation, is not directly tangible and ultimately dependent on the behaviour of other actors at the global level. In contrast, adaptation is spatially specific and can be successful locally, even if only the individual farm engages in climate adaptation. This has an important psychological component. This is because adaptation can satisfy the need for concrete and perceptible (positive) change. This is relevant because the experience of self-efficacy is an important factor that promotes the implementation of further climate measures. Since successful adaptation to climate change is more complex than climate protection, both in terms of theory and practical implementation, the following explanations will focus more on the topic of adaptation.

Core concepts of climate change adaptation

Many different approaches and concepts for climate adaptation exist. These are designed for different organisational levels (regional, national, global) and application areas (e.g. governance, business management, etc.). Many of these concepts are only suitable to a limited extent for the farm level, as adaptation planning has (so far) been a topic for higher organisational levels. Nevertheless, the most important concepts are briefly discussed here and defined for further use in the ClimateFarming material. Accordingly, it should be pointed out that no comprehensive presentation of the concepts can be given here, but only short definitions and an operationalisation in the context of the CLimateFarming materials.

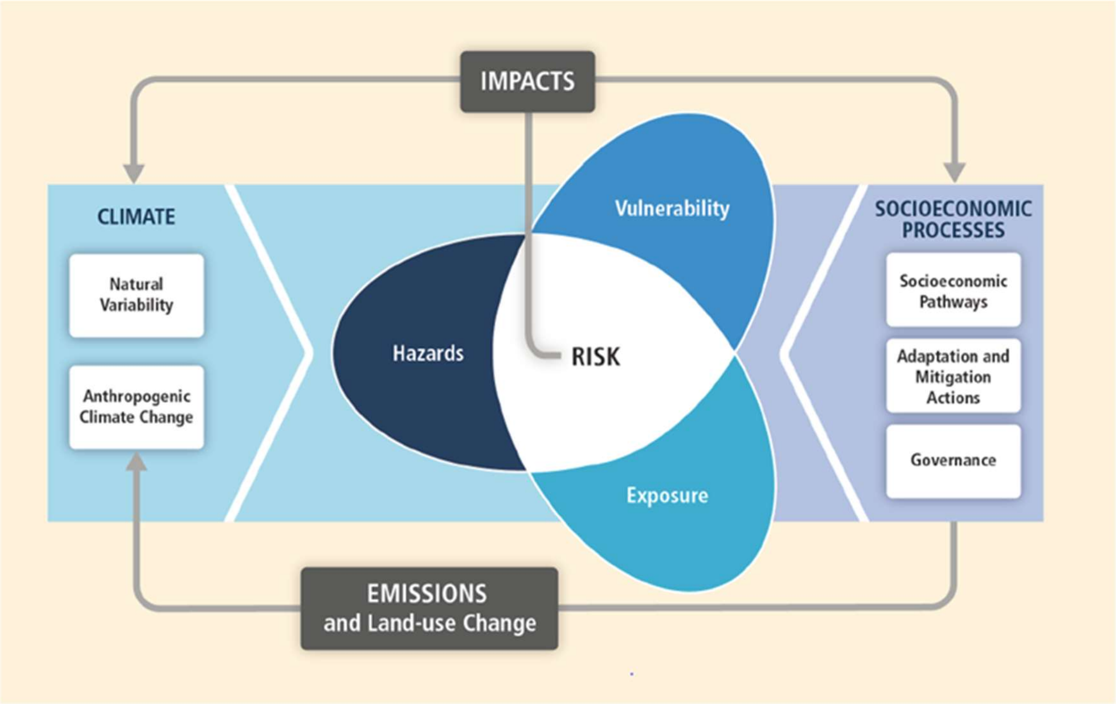

Figure 1: Key concepts of climate change adaptation - IPCC (2014)

Climate change impacts[4]

Impacts as results of extreme events (e.g. heavy rainfall) or climatic changes (e.g. increase in average temperature) on natural or human systems. In socio-economic systems, these impacts can occur directly or indirectly. Important when considering climate change impacts is the question of the severity of the impacts and the temporal and spatial dimension.

An example of indirect climate change impacts would be higher import feed prices due to poor harvests in exporting countries.

An example of direct climate change impacts is a shift in annual temperatures and associated changes in plant growth patterns.

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[4] In the ClimateFarming material, usually only the term climate impacts is used, without further differentiation between risk, hazard and impact.

Risk

"Risk is defined as the potential for adverse consequences for human or ecological systems, taking into account the diversity of values and objectives associated with those systems" (IPCC, 2022 - P.3).

The concept of risk is the starting point in the various IPCC working groups for all questions around the complex consequences of climate change and how these can be addressed. Risks arise from the "dynamic interactions between climate-related hazards, exposure and vulnerability of affected human and ecological systems" (IPCC, 2022 - P.3).

Risks in the context of climate change often cannot be predicted accurately, nor can a reliable probability be calculated. This results in uncertainty, which complicates the planning of adaptation measures in particular.

(Climate) Hazard

"Hazard is defined as the potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, services, ecosystems and environmental resources. " (IPCC, 2022 - P.3).

In simple terms, hazards include all climate-related consequences that can have a negative impact on natural or human systems.

Example of connection between climate hazard and risk/potential impacts of climate change: Sea level rise (climate hazard) and associated damage to coastal cities (risk/potential impact of climate change) or an increasing number of heat-related deaths (risk/potential impact of climate change) as a result of frequent and extreme heat waves (climate hazard).

Exposure

"Exposure is defined as the presence of people, livelihoods, species or ecosystems, environmental functions, services and resources, infrastructure or economic, social or cultural values in places and environments that could be adversely affected." (IPCC, 2022 - P.3).

Exposure is a spatial factor. Formulated as a question, exposure can be summarised as: "Is a system (e.g. a farm) located in a place where certain hazards may occur?"

Example exposure: Coastal areas where inhabitants are directly exposed to sea level rise or the Sahel zone where farmers are exposed to increasingly severe droughts, even in the growing season.

Vulnerability[5]

"Vulnerability is [...] defined as the propensity or predisposition to be adversely affected and encompasses a variety of concepts and elements, including [..] vulnerability (sensitivity) to harm and lack of capacity to cope and adapt (adaptive capacity)" (IPCC, 2022 - P.3). It is important to bear in mind that vulnerability evolves dynamically and varies greatly between different societies, regions, countries and world regions. If a farm is vulnerable towards dry periods and it is located in an area where it is exposed to increasing dry periods, this farm has a high risk to suffer from yield losses due to climate change.

Sensitivity

Sensitivity is *"The degree to which a system or species is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea level rise)."* (IPCC, 2014b, P. 1772)

Example sensitivity: A dairy farm with air-conditioned barns is less sensitive to heat waves.

Adaptive Capacity

Adaptive capacity is *"The ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences."* (IPCC, 2014b, P. 1758)

Example adaptive capacity: If a dairy farm has not yet installed air conditioning measures in the barns, but has the problem awareness and the technical and financial means, the farm's adaptive capacity can be assessed positively.

Adaptation

"*Adaptation plays a key role in reducing exposure and vulnerability to climate change. Adaptation in ecological systems involves autonomous adjustments through ecological and evolutionary processes. In human systems, adaptation can be anticipatory or reactive, as well as incremental and/or transformative. The latter changes the fundamental characteristics of a socio-ecological system in anticipation of climate change and its consequences. [...]*" (IPCC, 2022 - P.3)."

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[5] In the ClimateFarming material, only the term vulnerability is generally used and no further differentiation is made between sensitivity and adaptive capacity. This should facilitate the application of the material.

Adaptation is *"In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects."* (IPCC, 2018, P.542)

Resilience[6]

"Resilience is [...] defined as the capacity of social and economic systems, as well as ecosystems, to cope with hazardous events, trends or disturbances by responding or reorganising in ways that maintain their essential functions, identity and structure, and, in the case of ecosystems, their biodiversity, while retaining the capacity to adapt, learn and transform. Resilience is a positive attribute when such capacity to adapt, learn and/or transform is maintained."

Resilience is often described simply as the ability of a system to quickly return to its former (pre-shock) state (recovery) after a shock. However, this type of resilience is insufficient to meet the challenges of climate change, as the system is not changed and thus the vulnerability to a new shock remains the same. The IPCC uses the resilience approach of "creative transformation" (Joakim et al., 2015). This means that after a shock, the goal is not to restore the old system one-to-one, but to learn from the experience and transform the system concerned in such a way that a higher level of resilience is achieved and it thus becomes less vulnerable to shocks overall.

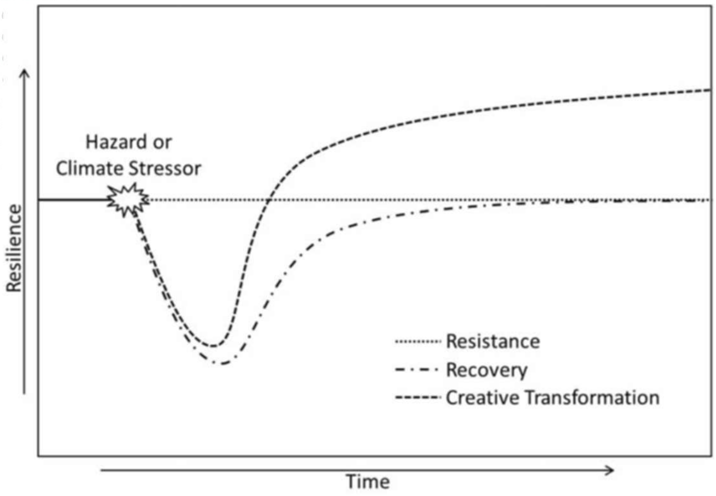

Figure 2: Different dimensions of resilience - Joakim et al. (2015)

Robustness

Robust can refer to different levels. A robust decision (or a robust adaptation measure) is characterised by the fact that it fulfils the objectives of a system over a wide variation of

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[6] In the ClimateFarming material, usually only the term resilience is used. The term resilience is defined as the capacity of a farm to remain functional and achieve farm objectives across a spectrum of different changes and disturbances, including the ability to adapt and transform following shocks or in response to new knowledge.

possible events. A decision (or an adaptation measure) is not robust if even small variations in the conditions prevent the goal from being achieved.

Example robust decisions and adaptation measures: Due to a drought period of several years, an arable farm completely changed its cultivation to drought-tolerant and heat-adapted crops. This enabled him to achieve an optimal harvest result in a drought year. However, if a wet year follows, he will have to accept heavy losses.
His adaptation measure would have been more robust if he had not changed his entire cultivation, but diversified. This way, he would not have achieved an optimal result in the drought phase, but he would also have been less vulnerable to a wet year. Diversification of crops and varieties would therefore have made the adaptation measure more robust.

Example from Kalra et al. (2014, p. 15): "We can manage deep uncertainty by seeking a robust decision -- one that performs well across a wide range of futures, preferences, and worldviews, though it may not be optimal in any particular one. Consider two crops: Crop A provides steady yield in drought or excessive rain, while Crop B provides still greater yield under specific conditions consistent with historical precipitation, but fails otherwise. If we could control precipitation or could reliably predict that this year's precipitation would look like the past, we would do well to plant Crop B and maximize yield. But this decision is likely to be brittle – we can rarely predict precipitation, and we may instead prefer to hedge our bets and plant Crop A if Crop B appears too vulnerable. Robustness becomes important when the consequences of making a wrong decision are high. If crop insurance is available to help protect against potentially poor yields, or if sufficient savings are available, optimizing (and coping with bad years) may be the best strategy. If these tools and resources are not available and the consequences of a few years of low yields are disastrous, then robustness becomes a priority."

A resilient farm is characterised by its ability to remain functional (i.e. achieve farm objectives) across many different climatic and non-climatic changes and events, and to recover quickly even after significant external disturbances. Here, recovery is not meant as a return to the state before the disturbance. Recovery means the ability to learn, which translates into adaptation and transformation of the farm system. The goal is always to achieve a higher degree of resilience.
In other words, higher robustness means lower vulnerability, which is reflected in reduced sensitivity and/or strengthened adaptive capacity.
Transferred to the farm level, this means that adaptation measures support the farm to become less sensitive to climate impacts and extreme events. An example would be the installation of an efficient irrigation system in vegetable production, which makes the farm less sensitive concerning drought events. In addition, the farm can improve its adaptive capacity through smart and forward planning - this means that it can implement future adaptation measures faster and/or more efficiently. An example of this would be clarifying the conditions (e.g. building permit) for an agri-photovoltaic system at an early stage.

Translation to the farm level

The concepts and terminology of the IPCC are only of limited use for adaptation management at farm level. Nevertheless, they are helpful in establishing a consistent use of terms - and thus a common language and understanding.

Climate change impacts, risk and hazards

The three concepts (Impacts, Risks, Hazards) are not easy to understand at first glance and are difficult to distinguish. Fortunately, this is not of high relevance at farm level. To make it as easy to use as possible, the consequences of climate change for the farm and its environment are summarised under the term climate impacts. So when planning adaptation, the guiding question would be: "How can climate change have an impact on our farm and how can we adapt to the impact in order to reduce or prevent losses?". The grouping under climate change impacts is therefore not entirely correct, but simplifies communication in application.

Adaptation and vulnerability

Climate impacts and the resulting risks can neither be fully predicted nor prevented for individual operations. Nor is there much that can be done to influence the resulting hazards or exposure - unless the farm is abandoned at the old location and restarted at a different one. Since this is not an option for most farm managers, this is not an adequate adaptation strategy either. Consequently, the only option for the majority of farmers is to reduce their vulnerability.

Adaptation at the farm level thus aims at reducing the sensitivity of the farm and at the same time increasing the adaptive capacity to respond as flexibly, effectively and efficiently as possible to climatic and non-climatic changes. It is important to note here that many factors that influence the development of farm vulnerability lie outside the scope of action of the individual farm (e.g. political decisions or market changes).

Adaptation management

Variability and adaptation to new conditions is not new to farmers. These experiences were and are important for dealing with climate change and increasing climate variability - but they are not sufficient. This is also reflected in current climate change adaptation efforts.

The majority of adaptation measures to date have been implemented in response to experienced extreme events and trends (Park et al., 2012; Porter et al., 2014), as evidenced, for example, by earlier sowing dates or the cultivation of other crops. These are measures that cause only minor changes to the (agricultural) production system and are implemented as reactions to experienced climate changes. Given the fundamentally new challenges of climate change, this mode of adaptation may prove insufficient (Rickards and Howden, 2012; Noble et al., 2014). A further issue is that individual adaptation measures which are not embedded in an overarching strategy could lead to the consolidation of forms of agricultural production that are fundamentally insufficient to cope with a severe and non-linear trajectory of climate change (Rickards and Howden, 2012). In simple terms, unplanned or misinformed adaptation measures can increase the costs of adaptation when the farm needs to switch to more systemic or transformational adaptation measures, which fundamentally alter the farm and its production mode. In light of these considerations, elaborated climate (adaptation) strategies are needed.

Example of transfer costs: A farm with intensively irrigated vegetable production invests in a more efficient, but very capital-intensive new irrigation system. However, due to declining groundwater levels, the usable amount of fresh water for irrigation is constantly rationed and vegetable production is no longer possible in its original form. Should the farm now consider switching to water-extensive farming or other income-generating activities, the investment in the new irrigation system has increased the transfer costs. This means that the costs of switching from one adaptation measure to the next adaptation measure have increased due to the investment.

Uncertainty

As assessed earlier, uncertainty is one of the main challenges of climate change adaptation - also at the farm level. According to Marchau et al. (2019), uncertainty is limited knowledge about future, past or current events. This applies to climate change. What we know about potential future impacts of climate change is based on climate models and derived climate projections. Projections of how the climate will change in the future are subject to large uncertainties (IPCC, 2014b). How this change in climate parameters will impact different countries, regions or an individual farm is even more uncertain. First, there is inherent uncertainty about the trajectory of the world. In the context of climate change, this implies that assumptions about the change of GHG-emissions are only scenarios of possible futures, not predictions. Second, climate modelling is based on our limited understanding of the physical function of the climate system and its interaction with external and internal forcing. This includes limited knowledge about governing control mechanisms and nonlinear feedbacks in the climate system (Chapin III et al., 2011), e.g. self-reinforcing mechanisms like the thawing of perma-frost, increasing forest fires or the drying of wetlands (Lenton et al., 2008), which entail fundamental release of GHG-emissions. Associated with these self-reinforcing effects is the uncertainty about when possible thresholds are reached and abrupt changes in the climate system occur (Rockström et al., 2009). Third, assumptions and simplifications are used in climate modelling, limiting their representation of the reality (IPCC, 2014b). Since potential climate impacts are mainly derived from climate projections, uncertainties cascade (Refsgaard et al., 2013) and increase owing to the complexity of the human-environment-climate system. As the success or failure in terms of stopping or moderating climate change cannot be predicted, so is it not possible to anticipate with certainty the ability of human and natural systems to adapt to new and changing climatic conditions.

What makes the projections of climate impacts especially uncertain is the complexity of interaction between the climate change responses of the different components of the human-ecological system and following feedback with climate change. Jones et al. (2014)

describe climate change as an interaction of complex environments with conflicting values, making climate change a wicked problem. This implies substantial scientific uncertainties, various framings of the issue by different actors and high ambiguity about how solutions can be designed and implemented. Based on these aspects, agriculture can likewise be perceived as a wicked problem.

The reason for this lies in the complexity of agricultural systems. In agriculture, diverse environmental and social systems (e.g. soil, water, biodiversity, market developments, political decisions, etc.) interact and influence each other.

Complexity

Agricultural production and the individual farm are in a complex interaction with different, interdependent systems (social environment and agroecosystem). These systems in turn consist of different elements (agroecosystem: soil, water, biodiversity, etc.; social environment: markets, politics, partners, etc.) that influence and interact with each other.

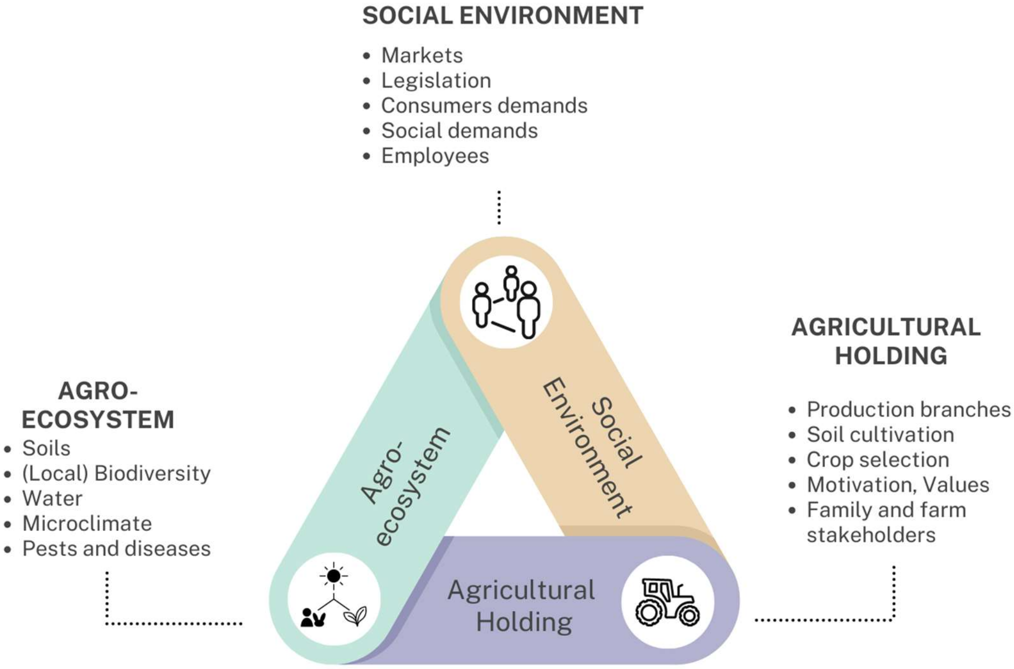

Figure 3: Complexity at farm level - own representation

Thus, even without climate change, there is a high level of complexity at farm level with multiple and often unforeseen interactions and impacts. However, climate change is amplifying this complexity.

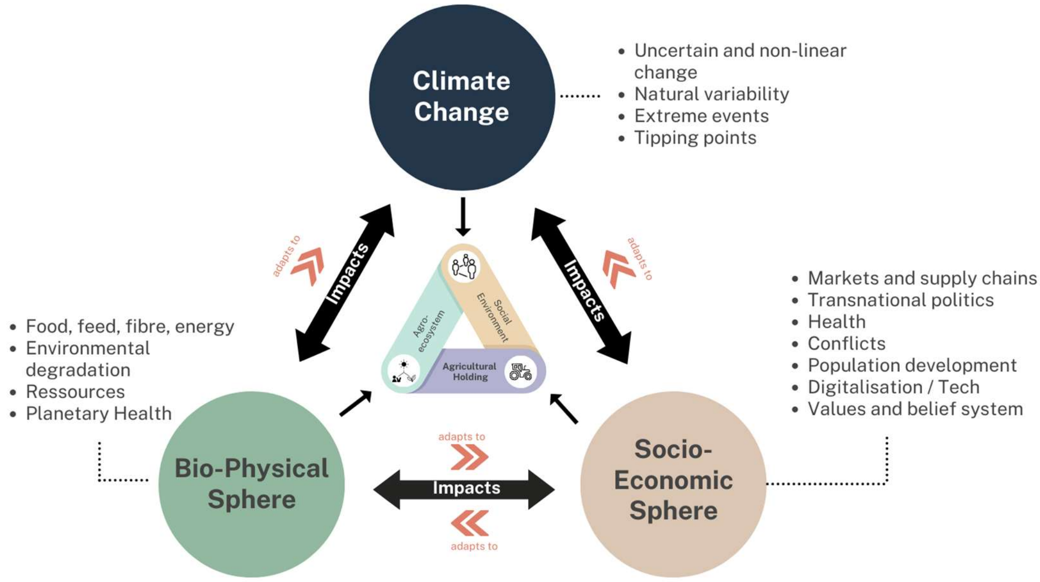

Figure 4: Increasing complexity at farm level due to climate change - own representation

The systems which interact with agriculture are likewise affected by climate change. However, it is uncertain how they will be affected and, more importantly, what the responses (adaptation) of each system will be. As these responses are interdependent and influence each other, it increases uncertainty about potential direct and indirect climate impacts at the farm level. Furthermore, the reactions of the farmers will also have an impact on the connected environmental and social systems. In sum, these reactions will then in turn influence the emission of further climate gases and thus the development of the climate crisis. Accordingly, farmers have to adapt to the whole spectrum of possible climate change impacts, which includes bio-physical, social, cultural, political and economic changes (Rickards and Howden, 2012). As a result of this complexity, agriculture and climate change can be classified as sources of "Deep Uncertainty". More information on deep uncertainty can be found in *“Theoretical Background: Methods and Foundation”*.

The example of agriculture and freshwater can be used to illustrate the problem of interdependent climate change impacts: Climate change is already influencing precipitation patterns and water availability in various regions of the world. This has direct effects on agricultural production, e.g. a lower soil water balance or limited amounts of water for irrigation and animal husbandry. Indirect effects are higher water prices and potential conflicts with other water users. However, land management practices also affect water resources through nutrient leaching, soil erosion and pollution. The negative impacts can be exacerbated by climate change, e.g. through higher erosion rates as a result of heavy rainfall events (especially in winter) and a lack of soil cover, leading to higher nutrient leaching and pollutant inputs. At the same time, there could be a reduced dilution effect due to an overall decrease in precipitation. This would further reduce the available water resources and thus further limit water availability for agricultural use.

In summary, climate change is significantly altering the bio-physical as well as the socio-economic environment in which agriculture is practised. This has and will affect agriculture in many different and uncertain ways. This makes it difficult to plan farm development or adaptation strategies. As a consequence, this uncertainty must be actively integrated into the planning process.

Dealing with Uncertainty

Many adaptation measures for agriculture are known. However, the key question is which measures and strategies increase a farm's resilience over a wide range of possible future developments (Abbasi et al., 2020) and fit a farm's structures, geography and objectives. Ignoring the existence of uncertainty facilitates the planning process but can have serious consequences in the future (Marchau et al. 2019). This can lead to reduced flexibility in the future or low efficiency in adaptation (Abbasi et al., 2020). Simply put, it means that in the absence of planning, a short-term decision can limit long-term climate adaptation options or increase its costs. To prevent this, uncertainty must be integrated into adaptation planning at the farm level.

Planning for the future necessarily includes an assessment of possible but uncertain change (Marchau et al., 2019). To address this problem, corresponding strategies have usually been designed using scenarios. A scenario describes a potentially possible state of the future without making a specific prediction (Jones et al., 2014). After developing plausible future scenarios, these scenarios are assigned with probabilities. Depending on the probability of the scenarios, the decision-makers are able to select a strategy. This approach is also called "predict-then-act" (see e.g. Barnard and Nix, 1979) and is also the basis for traditional risk management. This approach is problematic for adaptation planning, as we can not reliably assign probabilities to certain scenarios. Additionally, the actual future might lie outside of the developed scenarios, making corresponding strategies inefficient and/or ineffective.

Adaptation processes under deep uncertainty require an approach that is based on observation, preparation, learning and continuous adaptation. Flexibility and the capability to react swiftly to new information or changing conditions are core features of a resilient system (Marchau et al., 2019). This approach is also called iterative risk management and is based on a continuous process of assessment, action, observation and reassessment (Jones et al., 2014). The term iterative highlights the process of climate adaptation, with a focus on learning and flexibility and the aim of developing dynamic and adaptive strategies.

Successful adaptation and maladaptation

Ignoring uncertainty as well as feedback and interaction within and between different systems can lead to maladaptation. Many definitions of maladaptation exist, but most have in common that they refer to the negative consequences that result from adaptation policies and strategies (Neset et al., 2019). Fundamental to understanding the problem of maladaptation is an understanding of the temporal and spatial dimensions of adaptation.

Depending on the timing of the evaluation, the paradoxical situation arises that a measure can be assessed as positive or negative at the same time.

Constructed example of maladaptation: The construction of an air-conditioned dairy barn is an effective way to reduce milk yield reductions resulting from increasing heat waves. In the short term, this adaptation measure helps relatively safely to make the farm more resilient concerning heat waves. However, if in the future prolonged droughts have reached such an extent that fodder production in the affected region is significantly constrained and dairy farming becomes unprofitable, the new and costly air-conditioned dairy barn will turn out to be maladaptive - especially if this situation occurs before the cowshed is fully paid for, which is usually a period between 20 and 30 years.

Furthermore, what can and cannot be considered maladaptation depends on how the success of adaptation measures is assessed.
Noble et al. (2014) describe an "adaptation need" as a deviation between the desired future state of a system and the constraints resulting from actual or projected climate change. An adaptation measure is effective if it is able to meet this adaptation need (one could also say a defined objective). This is problematic because adaptation needs are farm-specific and diverse. Moreover, they evolve dynamically and can change over time. Just like climate change and its consequences. This means that adaptation is a continuous process that should develop with climate change, new information, changes in and around the farm as well as social norms and values. Accordingly, the success of climate measures must always be assessed in relation to the farm-specific goals and the temporal dimension.
Besides the effectiveness of adaptation, efficiency is relevant. However, efficiency in adaptation cannot be reduced to the simple ratio of costs and benefits. On the one hand, because various, also non-monetary benefits are pursued (e.g. biodiversity support), and on the other hand, because it is not possible to calculate all potential costs and benefits facing (deep) uncertainty. Moreover, the temporal dimension is also central here. What is not efficient in the short term from a cost-benefit perspective may prove to be a worthwhile investment in the long term, making the operation more robust and resilient.

Example time dimension and efficiency: Establishing an agroforestry system on an erosion-prone site requires - in the short term - investment and labour with low or no (financial) benefits at the same time. In the medium to long term, however, investing in agroforestry helps to reduce the risk of erosion and improve water management in the area, as well as additional financial returns. Furthermore, there are many positive effects that cannot be directly monetised, e.g. for local biodiversity.

In addition to the temporal dimension of adaptation, the spatial dimension is also relevant. The spatial dimension refers to possible side effects resulting from adaptation measures. These are mainly negative effects on other people or natural systems - so-called negative externalities.

Example for negative externalities: Intensive irrigation can stabilize a farm’s yields and income, but it could also lead to negative effects such as declining groundwater levels and associated water scarcity. This in turn would have negative impacts on other water users.

An important question in this context is whether maladaptation can arise only from adaptation measures or can also arise from other management decisions. While the above definition excludes this, it is an important consideration.
In general, the implementation of adaptation measures is not only driven by climate change threats, but combines multiple motivations. In the same way, decisions taken without considering climate change may also affect the future adaptive capacity of the farm. Therefore, it is advisable to consider the context of climate change in all decisions or to integrate it firmly into farm management.

SUMMARY - Climate Change Management

- At the farm-level, following terms are used:
    - **Climate impact**: comprising climate hazards (e.g. new pests and diseases) as well as climate impacts (e.g. yield losses, higher veterinary costs etc.)
    - **(Farm) Vulnerability**: The predisposition of a farm to be adversely affected by actual or projected changes in climate parameters
    - **(Farm) Resilience**: The capacity of a farm to remain functional and achieve farm objectives across a spectrum of different changes and disturbances, including the ability to learn and adapt after shocks or in response to new knowledge.
- **Climate protection and adaptation to climate change are both necessary to tackle climate change**. At the farm-level, both must be considered and related measures should be planned together to exploit synergies
- **Adaptation is the planning and implementation of measures that moderate negative impacts of climate change and take advantage of beneficial developments**
    - Adaptation is supposed to enable a farm to **act preventively** (in order to reduce risks) and to **react flexible** in the face of abrupt and unforeseen climatic and non-climatic changes

- **Core challenge: Uncertainty** concerning climate change and its impacts
    - **Uncertainty must be integrated** in the adaptation process

    - **Adaptation** must be considered **as a continuous process** based on observation, preparation and learning
    - In the absence of adequate planning, adaptation measure can end up being maladaptive
        - **Maladaptation**: Negative consequences of adaptation decisions which hamper the adaptive capacity of a farm or entail negative external effects

- **It is difficult to determine the success of adaptation**, as this depends on the temporal and spatial dimension of the observation. This entails that **no "one-size-fits-all" adaptation measures exist**
    - At the farm level, the individual **farm objectives are decisive for verifying the success of adaptation measures.**
- **Successful climate adaptation is a challenging task and therefore requires a comprehensive approach to be effective and successful in the long run**
- **The ClimateFarming project combines approaches and methods from adaptation management and regenerative agriculture** in order to provide a comprehensive approach to enable successful farm level adaptation planning

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Lesson 3: Regenerative Agriculture: One possible solution

Alena Holzknecht, Janos Wack

In this chapter, we want to give an overview of the origins and different understandings of regenerative agriculture (RA) and how it is related to other alternative agricultural approaches. Further, we will shortly touch topics like carbon certificates/credits and stakeholders in the field of RA, soil health/quality and on-farm greenhouse gas (GHG) mitigation options. Finally, some evidence from research, as well as knowledge gaps in RA will be discussed.

After reading this chapter, the reader should be able to identify a definition of RA that they agree with, or formulate their own. Another goal is to be able to critically evaluate actors in RA and their practices, as well as making their own opinion about current discussions in the field.

Disclaimer: The provided literature does not necessarily represent our understanding of regenerative agriculture, but the authors think it is important to know a variety of sources, including controversially discussed sources to make up your own opinion and to display the current discussions in this sector. Please read with a critical mind, and question methodology of claimed successes.

This chapter includes excerpts from two Master Theses on Regenerative agriculture:

- **A Master Thesis by Lærke Daverkosen & Alena Holzknecht**
- **A Master Thesis by Janos Wack**
  (originally written in German, translated by CEFE)

Preface

To tackle the problems and challenges that agriculture is facing as described in the previous chapter, many different approaches will be necessary. Some examples of modern solutions that are being discussed and partly implemented at different scales are e.g. intensive irrigation, genetic engineering, digitalization and smart agriculture, specialised intensive agriculture, soilless agriculture, controlled environment agriculture, or alternative pollination with humans or robots. Many of these are capital intensive, require hi-tech solutions or approach problems by treating the symptoms of malfunctioning systems, which may only alleviate a certain pressure locally or momentarily. They also in most cases lead to an increased dependency on external inputs, the topic of which has been covered in *Problems and Challenges*. Without overarching structural adjustments, other, possibly unexpected problems, may arise

It is important to recall that we are dealing with different contexts that all have their own inherent challenges on an environmental, social, and economic level. Giller et al. (2021) underline that the large variety of context-specific policies, agroecosystems, food and farm systems tackle different issues. Hence, no one specific set of practices or meaningful problem definition can be made to address all challenges alike. In some contexts, some of the solutions above, or a combination thereof, may make sense.

We do not claim to explore the topic of RA in its integrity due to its bare complexity and the fact that the conversation around it is evolving quickly in both the scientific and mainstream field. However, there are a few main subjects at the core of our understanding of RA that address the manyfold and multi-dimensional challenges in agriculture today in a holistic way. This helps to adapt to climate change by taking into account a wide variety of environmental, social, and economic factors and translating them into action that results in higher resilience and quality of life on the and around the farm.

History of regenerative agriculture

The word regeneration stems from Latin genero [to produce or procreate] and re- [back or again]. Used in biology, the term is applied for the process of restoration and growth (Hermani 2020). In an agricultural perspective this can be translated into the restoration of the soil, which means that the application of RA practices depends on the current state of the cultivated land. The word regeneration emphasizes a reorientation from not only reducing harm and damage, but actually creating net-positive environmental and societal outcomes (Robinson & Cole 2015).

Usually, the son of the US organic pioneer J. I. Rodale is credited with the first mention in the early 1980s. However, the term has also been used by Gabel (1979 cited after Giller et al. 2021), so the origin is not clear. Robert Rodale, son of organic pioneer Jeremy Rodale, wrote about Regenerative agriculture in his article Breaking New Ground: The Search for a Sustainable Agriculture (Rodale 1983). He envisioned an agriculture beyond the present system and “beyond sustainability, to renew and regenerate our agricultural resources (Rodale 1983)” (Mang & Reed 2012; Hermani 2020). This should be achieved through a core focus on restoration, as “one that, at increasing productivity, increases our land and soil biological production base […] it has minimal to no impact on the environment beyond the farm or field boundaries (Rodale 1983)”. Even though Rodale was the first to coin the term regenerative, pioneers of permaculture had already introduced an ecological approach of emphasising the regenerative potential of ecological systems by changing the human relationship to nature in 1978 (Mang & Reed 2012).

Throughout the 1990s, the term regenerative agriculture became almost invisible in agricultural literature and research. This absence occurred parallel to the development of first organic certifications and the institutionalisation of organic agriculture (Hermani 2020). In 1994, five principles were formulated, with the points "protect and revitalise the soil", "biodiversity" and "integrate animals" (Lyle 1994 after Hermani 2020) being particularly relevant to today's understanding of regenerative agriculture.

At the beginning of the new millennium, individual pioneers began to use the term again and to farm according to corresponding ideas. Since 2010, an increasing number of actors are communicating their vision of regenerative agriculture in public. The foundation of “Regeneration International” in 2015, an international foundation based on the ambitious goal “to reverse global warming and end world hunger by facilitating and accelerating the global transition to regenerative agriculture and land management (Regeneration International 2019)“ was an important milestone for the increased attention to RA which has been detected both in mainstream and academic literature within recent years (Hermani 2020). Furthermore, RA has gained political attention and was listed as a “sustainable land management practice (IPCC 2019)” in IPCC’s special report on Climate Change and Land in 2019.

Definitions

The term "regenerative agriculture" is neither protected nor does it have a uniform definition (Elevitch et al. 2018), which allows a wide scope for interpretation. On the one hand, the lack of a unified definition can lead to strong simplifications by equating RA with e.g. carbon farming (Newton et al. 2020). On the other hand, there is a demand in the scene to take as holistic an approach as possible at the individual ecosystem level, which rejects a uniform definition (Soloview and Landua 2016). While some definitions include certain agricultural practices or principles (e.g. crop rotation), others define the term by excluding practices (e.g. tillage, herbicide use). In addition, the different definitions can be divided according to the focus on the practices used (e.g. no-till), the outcome of the action (e.g. improving soil quality) or a mixture of both approaches (Newton et al. 2020). This is especially relevant when talking about certifications, as the monitoring of successes depends on how exactly you define such. Organic agriculture for example is defined according to inputs: Pesticides, herbicides, synthetic fertilisers, etc. are inputs that are not allowed. However, for certification it does not matter which tillage practises an organic farm adheres to. Nevertheless, many approaches of RA have the goal of improved soil quality in common (Schreefel et al. 2020). Schreefel et al. (2020) also propose a concrete definition for the international standardisation of the term based on an analysis of previous scientific publications and definitional approaches:

> "An approach to agriculture that uses soil conservation as a starting point for regeneration and contribution to multiple provisioning, regulating and supporting services, with the aim that this improves not only the environmental but also the social and economic dimensions of sustainable food production (Schreefel et al. 2020)."

The authors of the publication above intended to initiate a broad discussion and to develop benchmarks in the next steps. Within the next few years, a uniform scientific definition could be found internationally.

Another definition was proposed by Daverkosen and Holzknecht et al. (2022):

> “We define RA as an ever-developing, complex, and context-dependent agricultural approach aiming to restore and regenerate degraded land and contribute to climate change adaptation with mitigation co-benefits. In RA, the soil is the entry point to rethink food systems with the aim of enhancing biological, physical, chemical, as well as cultural ecosystem services in response to ecological conditions and the climate crisis, on a local as well as a global level (Daverkosen and Holzknecht et al. 2022)”.

Regenerative agriculture is thus to be understood as a concept that is still under development, and may stay so depending on the self-conception of other actors. It is a concept that is not universally defined in a field with many stakeholders, interests, and understandings. In addition, it takes place in an almost infinite number of different contexts that all have their own inherent challenges on an environmental, social, and economic level. This underlines that its definition can evolve and differ in context of its user.

Hermani (2020) names two main strands within RA, a techno-economic and an agroecological-ruralist movement. The first is often characterized by large agribusinesses that are not aiming for a paradigm shift in agriculture and aspire to keep up their production. The latter is pursuing a more fundamental (and maybe radical) restructuring of food systems. This argument is carried forward to divide between a camp that is aiming for a holistic, ecosystem-centric view vs. the application of single practices. On the other hand, there are large actors like e.g. the Syngenta Group who have their own understanding of RA and thus shape how it is perceived in public.

Many US-American corporations like General Mills, Cargill, Lush cosmetics, Unilever, and One Planet Business for Diversity (OP2B), a business corporation including Nestlé, Danone and L’Oréal, are using RA as a promotion strategy. Starting from about 2017, RA has become a new buzzword for many companies, with a rather reductionist approach of applying single practices in an unaltered system, often without clear and binding standards (Beste 2019; Hermani 2020; Giller et al. 2021). While they are applying practices that are considered regenerative, the implementations miss out on interactions and complexity that will be elaborated later on. Keeping definitions open and dynamic can be a way of contributing to a continuous development of the understanding, practicing, and expansion of RA (Soloviev & Landua 2016), however it can also be a two-edged sword, enabling the co-option of the term by large corporations.

There are however some common denominators that most RA stakeholders agree on. According to Elevitch et al. 2018, Newton et al. 2020 and Schreefel et al. 2020, regenerative agriculture should produce the following outcomes:

- Support soil health

- Increase infiltration and retention of water

- Increase and preserve biodiversity

- Store carbon

- Creating more resilient agroecosystems

Other stated outcomes and co-benefits are improved watersheds and water resources, enhanced ecosystem services and health, closed nutrient loops, reduced GHG emissions, same or higher farm productivity, improved animal welfare, better social and economic wellbeing of communities and rural livelihoods, improved food access, security and nutritional quality, circular systems and reduced waste (Rodale Institute 2014; Elevitch et al. 2018; Al-Kaisi & Lal 2020; Newton et al. 2020; Giller et al. 2021).

Corresponding concepts have so far mainly been developed and publicly presented by practitioners. On an international level, there are several popular farmers who present their regenerative concepts and farms in lectures, films or books (e.g. Brown 2018; Perkins 2019; Savory 2013). Based on the successes described there, these have a strong influence on the scene and its understanding of the term. Possible farming systems that map the envisioned goals of regenerative agriculture can include conservation tillage, organic farming, agroforestry, multi-paddock grazing, permaculture, and rewilding (Burgess et al. 2019). Within these, many individual practices can be applied (Table 1 shows some examples).

Operational category	Practical measures
Management & planning	- Holistic Management - taking into account the farm context and regional conditions - Farm planning with a focus on water as a resource (Keyline-Scale of permanence) - Community-supported agriculture
Inputs & material flows	- Circular economy at farm and regional level - Use of compost - Compost tea - Biochar, Terra-Preta - Fermentation products - Woody biomass and fresh branch chippings - Targeted use of mycorrhiza - Soil analysis and fertilisation according to Albrecht/Kinsey
Overarching land use	- Increase plant diversity

	- Reduction of synthetic inputs (sprays and fertilisers) - Horse work - Agroforestry - Management pattern according to keyline design - Natural Sequence Farming - Rewilding
Arable and vegetable farming	- Wide crop rotations - Leave crop and root residues on the surface - Occasional ploughing, no-till farming, minimum tillage, direct seeding - Permanent soil cover: cover crops, undersowing, catch crops, mulch systems, green manures - Permanent living roots in the soil - Mixed crops - Use of perennial crops (e.g. perennial cereals) - Integration of animals in arable farming - Biointensive vegetable production ("market gardening")
Animal husbandry	- Essential element - Animals as shapers of ecosystems - Increasing the diversity of livestock - Holistic grazing management: adaptive rotational grazing management, mob grazing, holistic planned grazing - Pasture cropping

Table 1: *Overview of possible practical measures of a regenerative economy Structured according to possible fields of application within a farm (Own compilation and outline;. Sources: Brown 2018; Burgess et al. 2019; Fortier 2014; General Mills 2021; LaCanne and Lundgren 2018; Merfield 2019; Newton et al. 2020; Perkins 2019; Rodale Institute 2014; Savory and Butterfield 2017; Shephard 2013)*

Rodale Institute (2014) argues that through RA farming becomes a "knowledge intensive enterprise", instead of a "chemical and capital-intensive one (ibid)", which calls for a shift in mindset and in whole food systems rather than the isolated application of practices that could sequester C. The strongest and most unifying principle that differentiates RA from other alternative agricultures is however the focus on soil organic carbon (SOC) for carbon (C) storage and improved soil health.

Synthetic inputs

The original term of regenerative agriculture from Rodale Institute did not include a specific viewpoint on synthetic inputs. While many argue that synthetic fertiliser, pesticide, and insecticide use cannot be part of regenerative systems, proponents of more reductionist approaches of RA argue that minimum soil disturbance and thus C sequestration is only possible with synthetic inputs (e.g. Giller et al. 2015; Regenerative Organic Alliance 2018). In response to the discordance about synthetic inputs, the Rodale Institute that initially coined the term regenerative agriculture, now refers to it exclusively as regenerative organic agriculture (Rodale Institute 2014). Furthermore, there are currents that see methods like CRISPR/Cas9 as a potential for RA.

Excursus: Soil health

According to Mitchell et al. (2019), the concept of soil health is based on the perception of soil as a living biological entity, impacting plant growth and being intertwined with the wellbeing of animals, humans and ecosystems. It is associated with soil organic carbon dynamics and the supply of nutrients in the soil-plant-atmosphere continuum and has a focus on long-term food security. Giller et al. (2021) mention that soil health has gained more attention in conjunction with RA, and while it can be something favourable to strive for, they call it a problematic term that is abstract and needs to be specified to be measurable.

A brief history of alternative agricultures

Throughout the last century, various movements towards alternative agriculture and food systems have emerged. Different issues are taken on, some more fundamentally and all-encompassing and others within the existing industry. RA inherited large parts of its meaning today from agroecology, the organic movement, and recent findings in soil science. The question arises whether and how RA is different from other agricultural systems, how do they overlap and why this concept is met with such enthusiasm recently. Evaluating the relevance of RA in the landscape of alternative agricultures requires the knowledge of their history and evolution.

Many of the above-mentioned practices are also found in conventional or other farming systems and are generally considered good agricultural practices (Giller et al. 2015). Often, other alternative agricultural systems are openly included. For example, Terra Genesis International includes the design perspective from permaculture and agroecology (Hermani 2020). Agroecology is often incorporated due to its high potential in sequestering C aboveground, and when integration of animal or closed nutrient cycles are included in the definition it often relies on holistic management practices (Soloviev & Landua 2016). Giller et al. (2021) argue that the reframing of other alternative agricultures through RA leads to confusion instead of clarification in the public debate and deflects from more essential challenges. However, RA might have the potential to bridge the ideological gap between different agricultural camps, and to unite them under the premise of soil health and C sequestration. Some of the below-mentioned farming systems may be seen as one among others within RA, with increased SOM as their intersection. Bossio et al. (2020) point out that RA, organic farming, agroecology, climate smart agriculture, agroforestry and permaculture are not mutually exclusive systems and can have significant positive impacts on SOC in certain geographies.

Organic agriculture

Organic agriculture as defined by the International Federation of Organic Agriculture Movements (IFOAM) General Assembly (2008) “relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects”. This means that it refuses synthetic inputs like synthetic fertilizers, pesticides, herbicides, and additives as well as genetically modified seeds. The focus lies on site-specific ecosystem management to prevent pests and diseases and maintain soil fertility (FAO 2021c) and is based on the four principles of health, ecology, fairness and care (IFOAM 2021).

In a recent position paper, Organics Europe (2023) describe the similarities of regenerative and organic agriculture, but also clearly state that the use of the term “regenerative” is problematic as it is not legally protected. Further, RA in many definitions does not prohibit synthetic inputs and GMOs which makes it easier for industrial agribusinesses to misuse the term. On the other hand, the focus of RA on outcomes like increasing SOC or biodiversity, is not found in organic standards and could inspire organic farmers to improve their practices. Core principles of organic agriculture like fairness and food sovereignty and justice are rarely part of the understanding of corporate regenerative agriculture, which may be a major differentiation between the two concepts. They conclude that if regenerative will be used in policies and market environments, be based on the EU organic regulations.

Agroecology

The term agroecology first appeared in scientific publications in the 1930s and initially described a scientific discipline. In the 1980s different agricultural practices came up under the same name, often connected to social movements that emerged opposing industrialized agriculture after the Green Revolution. Agroecology stays present in different contexts and scales around the world and today refers either to a scientific discipline, an agricultural practice or a socio-political movement (Wezel et al. 2009).
Agroecology is characterized by bottom-up, regional and context-specific concepts, regarding autonomous producers with practical (traditional) knowledge as the agents of change (Gliessman 2020). Agroecology puts emphasis on enhanced functional biodiversity in the spatial and temporal dimension to maintain production and profitability. This also involves utilizing ecosystem functions to the highest degree possible and enhancing biological regulation (Francis & Wezel 2015; Gliessman 2020).

Regenerative agriculture resembles agroecology in many ways although it has a smaller focus on the socio-political topics that are discussed in agroecology. Regenerative agriculture on the other hand focuses more on climate mitigation and building soil.

Permaculture

The term permaculture is a portmanteau of the words permanent and agriculture and was coined by David Holmgren and then Professor Bill Mollison. Holmgren defines permaculture as “consciously designed landscapes, which mimic the patterns and relationships found in nature, while yielding an abundance of food, fibre, and energy for provision of local needs (Holmgren 2002a)”. Thus, there are two main elements: first, the imitation of natural ecosystems for a human use, and second, the optimisation of the system so that yields can be accomplished with minimal effort and ecosystem functions are extended beyond their ordinary output (Krebs & Bach 2018). Further, permaculture sees land use systems as intricately linked with social systems and draws upon the ethical principles of care for earth, care for the people and fair share (Holmgren 2002b).

Permaculture in its practical execution has many analogies with other alternative farming systems. that strive towards a resource-efficient, pesticide-free farming approach with biological regulation, high biodiversity and local nutrient cycling (Krebs & Bach 2018).
Specific to permaculture is the focus on the design process, rather than on distinctive techniques (Morel et al. 2019).

Conservation Agriculture

The 1930s Dust Bowl in North America was the cause of massive soil and water degradation that was intensified by large-scale mechanised tillage. It triggered no-till, minimum tillage, ridge tillage and similar approaches to tackle soil erosion and C efflux by wind (Mitchell et al. 2019). In the 1960s and 1970s, highly effective herbicides, injection of fertilisers and direct seeding were introduced to agriculture that alleviated the need for tillage. On top of that, the US-government started incentivising no-till systems and herbicide-resistant GMO crops came onto the market in the 1990s, further disseminating the movement towards reduced tilling (Giller et al. 2015).

Today, especially in the Americas and Australia, conservation agriculture is popular on large, highly mechanised farms. According to the European Conservation Agriculture Federation ECAF, about 3.3% of arable land and permanent cropland in Europe is managed as conservation agriculture, where Belgium has the lowest adoption rates with 0.03% and Finland has the highest rate with 21.3%, but most European countries lie below 10% (ECAF 2021), and about 40% in the US in corn, soy, wheat and cotton cultivation (Wade et al. 2015).

Conservation Agriculture is based on three main principles: minimum soil disturbance (or no-till), the maintenance of a continuous soil cover, and crop rotations with a diversification of plant species. By doing so, it is claimed that overall soil quality is improved: biological processes are nurtured that help to increase soil OM, soil aggregation, water retention, and nutrient use efficiency and reduce soil erosion and water evaporation. Advantages besides soil protection are lower production costs in comparison with conventional tillage agriculture through savings in fuel and labour. Wack (2021) also found that as a result of regenerative cropping strategies, there was additional workload and less flexibility, even though minimal tillage was practised. Conservation agriculture leads to an accumulation of SOC close to the surface as the soil is not mixed, however the overall effects on soil C sequestration remain vague. When legumes are part of the crop rotations, they could help to sequester C at greater depths (Giller et al. 2015).

While traditionally conservation agriculture and organic agriculture oppose each other on account of an extensive use of herbicides in conservation agriculture, there are also organic minimum or non-inversion tillage systems that deal with stresses without synthetic inputs.
The distinction of conservation agriculture and regenerative agriculture is not always clear. Some authors state that the latter is the combination of the first and holistic grazing, sometimes with organic principles. Others argue that while conservation agriculture wants to preserve the current state of the soil, regenerative agriculture wants to improve it (Hermani 2020). Burgess et al. (2019) conclude that conservation agriculture can be seen as one among other systems within regenerative agriculture.

Holistic Management / Holistic Grazing

Holistic management and holistic grazing are concepts that were established by the biologist Allan Savory in the 1970s, even though similar ideas have already come up in the 1920s (Nordborg & Roos 2016). He gained substantial prominence in 2013 after giving his TED talk How to fight desertification and reverse climate change. Savory's claims were widely applauded but also harshly criticised for exaggerating and lacking scientific evidence. Holistic management is also oftentimes advocated by proponents of RA. Grazing management in general has three goals: first, higher productivity and species diversity by letting key species rest, second, lower grazing selectivity and third, more uniform animal distribution (Briske et al. 2008; Nordborg & Roos 2016). Holistic management is a decision-making and planning framework "to work with the web of complexity that exists in nature [to balance] key social, environmental, and financial considerations (Savory Institute 2021)" that is centered around holistic grazing. Holistic grazing is based on the approach of rotational grazing, a grazing management method where it is assumed that grazing livestock packed in herds and moved often to imitate 'natural grazing' of wild herbivores that try to evade predators can regenerate degraded land.

Holistic grazing or management is often mentioned as a management technique or tool within regenerative agriculture. Sometimes, the terms regenerative grazing or ranching are used.

Agroforestry

According to World Agroforestry (ICRAF), "agroforestry is the interaction of agriculture and trees, including the agricultural use of trees (ICRAF 2021)". Trees provide many benefits in natural ecosystems, above all ecological stability. The specifications in combination with agriculture can be manyfold, including trees on farms, agriculture in and along forests and tree-crop production, e.g. cocoa or coffee. Agroforestry promotes the formation of a system that consists of a wide variety of niches that stabilise the ecosystem and render it biologically diverse (Leakey 2017b). Trees can provide livestock fodder, fuel, food, fertilisation, timber, medicine, shelter, shade or other ecosystem services. Beyond this, they are also of socio-cultural, aesthetic and religious value. Moreover, animal husbandry is oftentimes integrated into agroforestry systems (ICRAF 2021).

The multipurpose use of trees can provide long-term concepts for climate change mitigation, reduce loss of biodiversity, increase food security (Ramachandran Nair 2014) as well as restore degraded soils and sequester C below and above ground, making it a next-best alternative to C sequestration in native forests (Ollinaho & Kröger 2021).
However, like in RA, there is a risk of co-option of the term by large-scale agribusiness and drivers of forest degradation (Ollinaho & Kröger 2021). In summary, agroforestry can be interpreted as its own concept for land use, or as a measure among many in regenerative agriculture.

Climate-Smart Agriculture (or Climate-Resilient Agriculture)

Climate-smart agriculture represents a set of strategies and guiding actions to transform agricultural systems in order to ensure food security in a changing climate. It is an iterative process that aims at overcoming challenges connected to climate change and finding ways of sustainable transitions (Lipper et al. 2014; Steenwerth et al. 2014). There are three main objectives in climate-smart agriculture: "sustainably increasing agricultural productivity and incomes; adapting and building resilience to climate change; and reducing and/or removing GHG emissions, where possible (FAO 2021a)". Thus, climate-smart agriculture is outcome-based and focuses on climate change adaptation and mitigation. (Lipper et al. 2014). This underlines the many similar goals as RA, but traditionally digitalisation and process-orientation are not a focus in RA.

Carbon Farming

There are several, sometimes conflicting, definitions of Carbon Farming. According to the European Commission (2021), "Carbon farming can be defined as a green business model that rewards land managers for taking up improved land management practices, resulting in the increase of carbon sequestration in living biomass, dead organic matter and soils by enhancing carbon capture and/or reducing the release of carbon to the atmosphere, in respect of ecological principles favourable to biodiversity and the natural capital overall". The financial incentives can come from public or private sources and reward land managers either for their management practices increasing the storage of atmospheric carbon or the actual amount of carbon sequestered. Toensmeier (2016) describes Carbon Farming as "a system of increasing carbon in terrestrial ecosystem[s] for adaptation and mitigation of climate change, [to] enhance ecosystem goods and services and trade carbon credits for economic gains." Toensmeier's publication The *Carbon Farming Solution* is one of the prominent books in linking carbon sequestration research to RA practices (Hermani 2020). Thus, strictly speaking, Carbon Farming is not an agricultural approach, but a business model in which farmers get remunerated for the service of carbon sequestration. This incentivizes farmers to implement practices that mitigate and sequester carbon, including active (IPCC 2019) or co-beneficial (Toensmeier 2016) adaptation to climate change. Some expanded definitions include carbon offsets, where carbon sequestration is rewarded by e.g. higher product prices or by selling credits to emission entities (Toensmeier 2016). Carbon offsets have the potential to enhance practices that increase carbon sequestration, and co-beneficially improve other ecosystem services, but have often proven to e.g. encourage monoculture plantations instead, causing decreases in biodiversity, substituting natural landscapes, and potentially decreasing carbon sequestration dependent on the substituted land use (Lin et al. 2013).

While there is no universal practice to create a positive carbon budget, identification of context-specific practices is necessary. The basic strategy is to maintain continuous soil cover, replace harvested nutrients, enhance soil structure and rhizosphere processes, and improve eco- efficiency by reducing general losses (e.g. soil erosion, carbon loss, or nutrient leaching) (Lal et al. 2018). Examples of such practices include integration of perennials and woodland, increased crop diversity, cover cropping, no-till or conservation tillage, agroforestry, improved fertiliser use, addition of organic amendments and biochar (Lal 2004; Bates 2010; IPCC 2019). In general, the practices mentioned in carbon farming and RA are similar, but carbon farming has a more narrow, thus more detailed focus on quantification of C sequestration for the individual practices. Further, carbon farming also increases the risk of a so-called carbon tunnel vision, a term coined by Jan Konietzko (Stockholm Environment Institute 2022), that puts the sole focus of the sustainability transition on carbon, instead of considering interrelated topics like biodiversity loss, overconsumption, resource scarcity, health, etc..

Today, a variety of start-ups and big ag companies, as well as the EU and governmental institutions are launching carbon crediting schemes (see 4. Stakeholders and certifications).

Excursus: Soil organic carbon (SOC)

Soil organic C comprises about 58% of soil organic matter (SOM), which consists of a wide range of heterogeneous dead and living organic compounds of varying size with different stability and decomposition levels. Naturally, SOC increases through carbon additions via photosynthesis of growing plants, decaying plant, animal and microbial matter and decrease through losses from decay, mineralization and erosion (Singh et al. 2018; Ramesh et al. 2019; De Moraes Sá et al. 2020).

As SOC stocks in agricultural land have been reduced considerably through land-use changes, there is a potential to restore SOC by improved management practices (Singh et al. 2018). However, the maintenance of higher SOC requires improved management in the long term, as SOC stocks can decrease again if such are ceased. Further, the storage capacity of SOC depends largely on climate, topography, and soil characteristics. A basic strategy for terrestrial C sequestration for climate mitigation in agriculture consists of 1) increasing C inputs and 2) maximizing the mean residence time of carbon in the soil (Lal et al. 2018).

Further, a new equilibrium at high SOC levels can be reached after some years with improved management practices and fertile soils in the same climate may be closer to the carbon saturation potential than largely degraded soils (Six et al. 2002).

The importance of Soil Organic Carbon (SOC)

The importance of SOC lies in its potential as a land-based solution to climate mitigation through a combination of preventing carbon emissions, removing atmospheric CO_2 and delivering ecosystem services. This can be achieved through a combination of improving crop lands so land conversion for food production and thus carbon loss from soils become unnecessary, as well as active carbon storage in agricultural land (Bossio et al. 2020).

Agricultural practices to increase SOC include perennial cropping systems, reduced or no tillage, mulch application, managed grazing, crop-livestock integration, and cover cropping. Another option to increase organic carbon contents is adding biochar to the soil which can persist from 100 to 1000 years. Most documented soil health co-benefits of RA are due to improvements in soil organic matter (SOM) content (Toensmeier 2016). SOM serves many functions within the soil and an increase will positively affect biological, physical, and chemical properties of the soil, such as nutrient supply, soil structure, water holding capacity, and microbial soil life (Watts & Dexter 1997; Johnston et al. 2009). Additional benefits from increased SOM include increased soil fertility and climate change resilience, reduced soil erosion and habitat conversion. Further, increased SOC does not require additional land area, minimizes water footprints and related practices are readily implementable as they do not necessitate land use changes (Bossio et al. 2020). Bossio et al. (2020) call these SOC enhancing opportunities “no-regrets opportunities”, as they have a variety of positive outcomes on different environmental and social levels.

Bossio et al. (2020) found that soil C represents 25 % (or 23.8 Gt CO_2-equivalent yr-1) of the potential of natural climate solutions. Forty percent of this potential can be found by protecting existing soil C pools, whereas 60 % are represented by rebuilding depleted carbon stocks. Agriculture and grasslands account for 47 % of this mitigation potential, whereas the rest can be accounted to forests and wetlands. Other land-based opportunities for carbon sequestration besides improved agricultural management are afforestation, reforestation, and carbon storage in harvested wood products (IPCC 2019), as well as trees in croplands (agroforestry), peatland and coastal wetland restoration, avoidance of forest and grassland conversion, and the use of biochar. Regenerative agriculture is one opportunity in a long row of actions needed to achieve climate change mitigation and adaptation goals. Only a quick implementation and combination of the above-mentioned practices and other measures to rapidly decrease global GHG emissions will make it possible to keep global warming below 1.5°C.

Mitigation & Decarbonisation

A large impact on climate change mitigation can be made by reducing agricultural emissions, as well as reducing land-use change by increasing/ preserving soil fertility. In a study by the World Resources Institute using the GlobAgri-WRR model, a potential of reducing agricultural emissions by >70% in 2050 was calculated. This can be effected by addressing a variety of sectors within the food industry, e.g. reducing food loss and waste, shifting diets, increasing food production without expanding agricultural land, protecting and restoring natural ecosystems, and reducing GHG emissions from agricultural production (Ranganathan et al. 2020). The latter can be done by e.g. improved quality of livestock feed to reduce CH_4 emissions, reducing losses of nitrogen from animal manure to minimise N_2O emissions, reducing N_2O and CH_4 emissions through livestock manure management, but also managing nitrogen supply by soil and plant testing, minimising the length of fallow, and avoiding Nitrate based fertilisers (Department of Energy, Environment and Climate Action 2023). IPCC (2019) also underlines that many food system responses that target climate mitigation are at the same time climate adaptation measures. Examples for this are biochar application, agroforestry, increased SOM content, improved water management, crop diversification, residue management, crop-livestock systems, and improved animal health and parasites control. Paustian et al. (2016) for example provide decision support tools for cropland GHG mitigating practices that can be helpful to find fitting on-farm measures.

Stakeholders & Certifications

To understand the scene around regenerative agriculture, it is helpful to know who is actively using the term and which sector they come from. Many consultants, organisations and processors call their agricultural approach “regenerative”, as it is an unprotected term and can be used independently from their legal status.

Political initiatives for climate mitigation and land restoration are numerous. For example, in 2015 the European Union set the goal at the conference of the parties (COP21) of reducing GHG emissions by 80 – 95 % (relative to emission level in 1990) before 2050, together with the voluntary plan “4 per 1000” to increase C stocks with a rate of 0.4 % per year in topsoils of the world (Lal et al. 2018; Al-Kaisi & Lal 2020). The EU also initiated a process towards carbon removal certification in 2021, further described in *Carbon certifications/credits*. The urgency of climate mitigation and need for drastically faster emission reductions and carbon sequestration strategies are emphasized by the new IPCC report (IPCC 2021). Every tonne of CO_2 emissions adds to global warming and it will require at least net zero CO_2 emissions, along with strong reductions of other GHG emissions to limit human-induced global warming (IPCC 2021). Since 2021 the EU is working on a proposal for high quality carbon removals.

Large corporations like Nestlé, General Mills, Unilever, PepsiCo, but also non-food companies like Patagonia, Ecosia and The North Face, just to name a few, invest in so-called regenerative enterprises and carbon trading. This may release large financial resources that could accelerate its transformation. Nestlé, for example, plans to allocate 3.2 billion Swiss francs to its own climate neutrality in this sector by 2050 (Reuters Money New 2020), and Cargill wants to “support farmer-led regenerative agriculture practices and systems across 10 million acres of agricultural land” in the US until 2030 (Cargill 2023). Moreover, this new form of agriculture is also seen as a lucrative investment. In the US, in the field of regenerative agriculture, a choice could already be made in 2019 between 70 investment funds with a total investment of over $47.5 billion. However, the basis of food production and at the same time the focus of regenerative land use - the soil - is repeatedly becoming an object of speculation. Investors expect high returns from such investment opportunities (Electris et al. 2019).

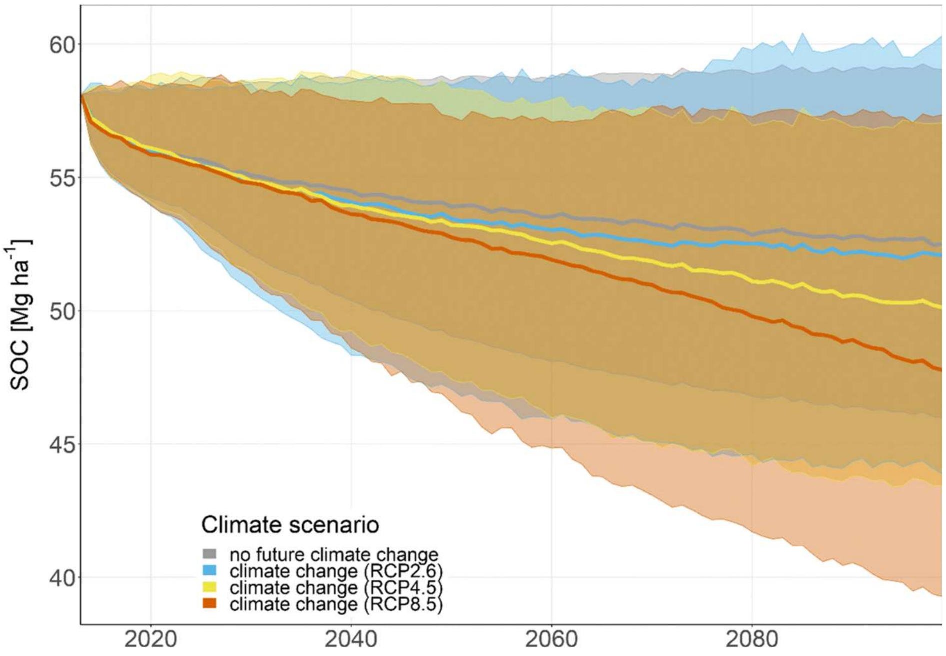
In Australia and the US, regenerative agriculture has already entered university teaching. E.g., at Southern Cross University, a bachelor's programme is offered with a corresponding focus. The course is supported by the Regenerative Agriculture Alliance. The content ranges from general theories and practices to soil management, agroecology, landscape planning and human ecology. There are full Bachelor's and Master's programmes at the private Maharishi University. In addition, many other institutes as well as individual actors conduct research, networking platforms or/and carry out educational work. The non-profit umbrella organisation "Regeneration international", founded in 2015, is the largest lobby for regenerative agriculture with over 200 partners. Leading positions are occupied by high-ranking personalities from the agri-food sector. However, the quality of the research conducted to date is often controversial and is usually not integrated into the recognised scientific community, but represented or at least accompanied by interest groups (e.g. Briske et al. 2008).

Carbon certifications/credits

Carbon credits can be an opportunity for farmers to implement environmentally friendly management practices and being remunerated for it. Carbon crediting or certification schemes could thus be a powerful tool to upscale climate mitigation action in farming. However, there is scientific disagreement on whether increasing soil carbon is a legitimate climate mitigation practice (e.g. Bradford et al. 2019, Ranganathan et al. 2020), and whether carbon certificates are the right way to go (e.g. Wiesmeier et al. 2020).

Figure 2: Projected mean soil organic carbon (SOC) stocks for German croplands under current organic carbon input levels and the 95% confidence interval for the ensemble of climate projections and SOC models. The climate scenarios covered three climate change scenarios based on different representative concentration pathways (RCPs) and a scenario of no future climate change. Source: Riggers et al. (2021)

In a study about increasing SOC stocks in German croplands, Riggers et al. (2021), argue that increasing temperatures will result in warming-induced SOC losses (see Figure 2), which may be partly be counteracted by increasing plant growth, but that an increased organic input of about 9 Mg C/ha/year would be required to increase annual SOC stocks by 0.4%, as suggested by the 4 per 1000 Initiative. While an overcompensation of the climate change-induced SOC losses by improved management may be feasible at farm level, it seems unrealistic on a national level (Riggers et al. 2021). Further, a theoretical compensation of 8-15 Mio. tons of CO_2 per year in Germany contrasts an approximate 106 Mio. tons of CO_2 per year from agriculture, thus only about 10% of agricultural GHG emissions could be compensated by an increase of SOC (Don 2022). However, other benefits of soil carbon are almost fully agreed on (see also: The importance of Soil Organic Carbon (SOC) above).



Funding can come both from private carbon markets or public funds like the EU's Common Agricultural Policy (CAP). The increasing trade in carbon credits between agriculture and other sectors is currently experiencing an enormous upswing internationally. More and more companies are pushing for the desired climate neutrality of their activities through compensation measures in the agricultural sector, see also above.

It is also problematic that, as discussed above, the term regenerative is not protected and companies can basically make up their own frameworks on what stands behind it. This results in a large risk of greenwashing and is especially hazardous when certificates are issued. The EU is currently preparing a framework to create a standardised market for carbon certificates in agriculture as part of the European Green Deal, based on the so-called QU.A.L.ITY criteria (quantification, additionality, long-term storage, sustainability) (European Commission 2022).

The definition of a minimum standard for carbon certification based on a uniform standard is crucial. Wiesmeier et al. (2020) made a proposition for seven principles to ensure good quality of carbon certificates that partly overlap with the EU's QU.A.L.ITY criteria:

Principles to ensure good quality of carbon certificates

- **Fairness**: Some soils can store more carbon than others, and especially soils with low SOC content due to depleting past management have highest potentials. The requirement of fairness ensures that this is accounted for when issuing certificates.
- **Reversibility**: Once measures are ceased, SOC levels are likely to decrease to before-levels again. To insure C storage, measures have to be implemented in the long term. One option are permanent, close-to-nature structures like trees or hedges.
- **Permanence:** Only carbon that is stored for the foreseeable future is relevant for climate mitigation.
- **N_2O emissions:** Soil organic matter (SOM) also contains nitrogen, which is important for plant nutrition. However, if the nitrogen is not used by growing plants, parts of the SOM becomes readily available for microorganisms and the nitrogen is transformed into N_2O emissions, a strong GHG.
- **Additionality**: Only carbon that is stored on top of business-as-usual practices can be certified, otherwise there would be no additional effect of the carbon credits. Thus, carbon that would be stored "anyways" (without crediting) is not valid for carbon credits! An important question arises: How do we define such baselines?
- **Leakage**: Measures that are implemented for carbon storage must not lead to GHG emissions elsewhere without accounting for them. E.g., reduced productivity may lead to land-use change somewhere else to account for the lacking yields.

In North America, a certification for regenerative organic farms (ROC, Regenerative Organic Certification) was created by the Rodale Institute in 2018 as the first uniform, transparent standard. This is seen as a further development of organic farming and assesses farms according to bronze, silver or gold standards based on a complex catalogue of criteria. The basis for the assessment are soil health, animal welfare and social justice (ROC 2021). Another certificate developed under scientific supervision is awarded by the Savory Institute for animal products from pasture farming. This aims to measure the impact of pasture management on ecosystem functions (soil health, biodiversity, water cycle, mineral cycle, energy flow and community dynamics) using defined indicators. The existence of the two certifications underlines the strongly advanced development of regenerative agriculture at the international level compared to Europe. However, the question arises whether it is desirable to offer more certifications on a market like Europe where organic certifications are more widespread than in the US, and the consumer target group may be similar. Further, certification schemes necessitate a costly infrastructure to ensure their validity which is usually carried by the farmers themselves.

Scientific evidence

In order to determine the success of the measures, various indicators are proposed which will not be discussed further here (e.g. Luján Soto et al. 2020). A rising enthusiasm for RA emphasises that agronomists need to engage in the public debate and learn to better communicate their appraisals on the topic (White & Andrew 2019; Giller et al. 2021). There have been few scientific publications dealing with the topic of RA up until recently, but are becoming more and more due to its rising popularity with practitioners and large media attention. The scientific evaluation of the concepts mentioned in RA however is demanding. This is due to, among other things, the desired degree of complexity of farming systems, which are viewed holistically, understood dynamically and designed iteratively.

While farmer-to-farmer communication of success stories can be a very potent means of catalysing change (Rosenzweig et al. 2020), there is often a large gap between scientifically proven facts and models on the one hand and promises and statements by individual practitioners on the other. Therefore, many researchers are sceptical about the promises of regenerative agriculture and react cautiously (e.g. McGuire 2018). Based on such claims, some scientists reject RA completely, while others acknowledge the exaggeration without turning down the general message, and call for researchers to view it as an opportunity to investigate new approaches towards agricultural systems (Toensmeier 2016; Hermani 2020). Figure 3 by Moyer et al. (2020) illustrates an example of such a propagated potential of regenerative agriculture by the Rodale Institute. In this case, a bar chart shows that the carbon sequestration potential of regenerative methods on a global scale is expected to exceed annual global CO_2 emissions by 46% (Figure 3).

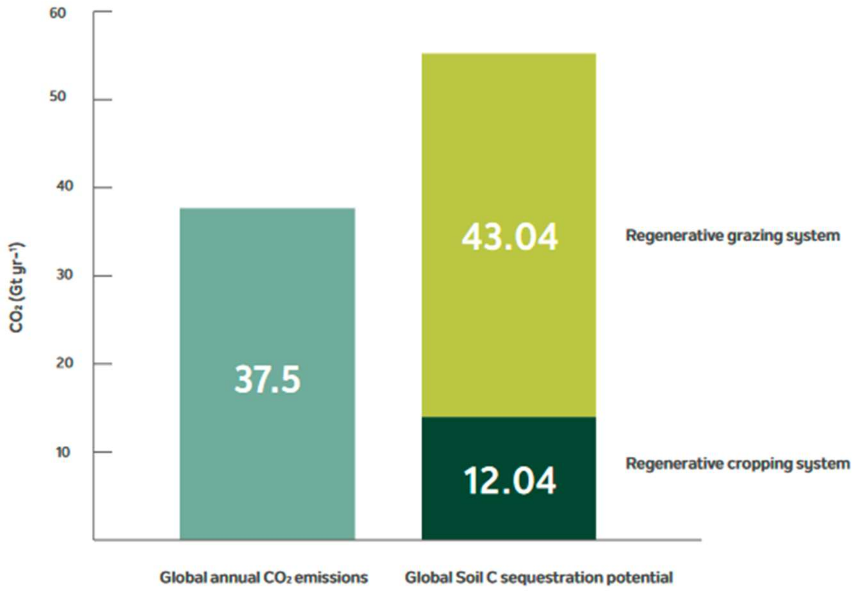


Figure 3: Carbon sequestration potential of global adoption of regenerative agriculture. Source: Moyer et al. (2020)

Due to the increasing attention for regenerative agriculture, a reflective engagement of researchers is thus crucial. According to Giller et al. (2021), the philosophical ballast must be clearly separated from the agronomic reality. The Center for Regenerative Agriculture and Resilient Systems at California State University, for example, aims to support a turnaround in the food system through practice-oriented research and networking of relevant actors by processing research results and making them publicly accessible.

According to Merfield (2019), individual projects are often shaped by commercial interests. Research into individual methods, such as agroforestry or conservation tillage, on the other hand, takes place on a large scale and is recognised for its quality. For example, on the "sciencedirect" platform alone, more than 26,000 publications can be found for the year 2020 under the keyword "no till" . Even on hitherto less widespread practices such as the use of compost tea, there is a wide range of research, and here too there are various approaches such as for production and use. An effect of compost tea could be found in various studies with regard to plant growth and plant health. Some publications about the carbon sequestration potential of certain management practices like hedgerows, cover crops or the influence on roots have been published lately by researchers of the German Thuenen Institut (e.g. Poeplau et al. 2021a, Poeplau et al. 2021b, Drexler et al. 2021). In a preliminary comparison, Montgomery et al. (2022) links regenerative practices with higher levels of vitamins, minerals and phytochemicals in crops compared to conventional farming. A meta-analysis by Jordan et al. (2022) analysed practices that are often mentioned when talking about RA and found overall that reduced tillage and ley-arable rotations, but not cover crops increased SOC concentration. More results from publications about soil carbon are presented in the chapter about carbon credits above. Nevertheless, the need for more research is highlighted (De Corato 2020), as well as the. need for a close liaison between farmers, land managers, policy makers and the academic community worldwide (Singh et al. 2018).

Conclusion

In summary, it can be said that regenerative agriculture as such is a highly dynamic scene that is currently receiving a lot of attention. This form of land use promises many advantages and solution strategies for pressing problems. Therefore, the demands for a scientific examination of the topic, including the development of appropriate methods, are also increasing. For as long as the benefits still have to be derived from presentations by individual pioneers, it is important to clarify whether these can be confirmed by independent research projects. However, the previous studies of individual measures or even system comparison trials give an idea of the potential of regenerative agriculture.

SUMMARY - Regenerative agriculture

Regenerative agriculture is an unprotected term that has many different understandings, which makes it necessary to define it when used. As our understanding of regenerative agriculture fits the requirements of transformative climate adaptation, it is used as a conceptual framework within the ClimateFarming method.

The term *regenerative agriculture* was first coined in the 1980s but a sole origin is not clear. It came back into use around 2015 and shortly thereafter different stakeholder groups started to use the term, leading to misunderstandings, especially for consumers.

In our understanding, regenerative agriculture can be defined as “*an approach to agriculture that uses soil conservation as a starting point for regeneration and contribution to* ***multiple provisioning, regulating and supporting services****, with the aim that this improves not only the* ***environmental*** *but also the* ***social*** *and* ***economic dimensions*** *of sustainable food production (Schreefel et al. 2020)*”, or as
„*an* ***ever-developing, complex,*** *and* ***context-dependent*** *agricultural approach aiming to restore and regenerate degraded land and* ***contribute to climate change adaptation*** *with mitigation co-benefits. In RA [regenerative agriculture], the soil is the entry point to* ***rethink food systems*** *with the aim of enhancing* ***biological, physical, chemical,*** *as well as* ***cultural ecosystem services*** *in response to ecological conditions and the climate crisis, on a local as well as a global level (Daverkosen and Holzknecht et al. 2022)*”.

In this sense, regenerative agriculture also largely overlaps with concepts like permaculture, agroecology, organic agriculture, climate-smart agriculture or carbon farming. The promoted practices are often similar and could simply be considered *good agricultural practices*. While generally regenerative agriculture does not rule out synthetic inputs like fertilizers, pesticides or herbicides, many proponents argue for organic principles or strive to reduce the use of synthetic inputs to a minimum.

Soil health and soil carbon storage are seen as central in many definitions, and also comply with the goals of climate protection and adaptation. While scientifically it is controversial whether soil carbon can or should be quantified for carbon certificates, many certification systems have emerged in the last few years. These must be critically evaluated.

Climate protection and adaptation go hand in hand. While their starting points are different- protection aims to prevent further climate change, adaptation aims at adjusting to the change that is present or to come- their ultimate goal is the same: enabling a pleasant life for all in the light of climate change.

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Online resources

Regeneration International: https://regenerationinternational.org/why-regenerative-agriculture/

Rodale Institute:
https://rodaleinstitute.org/why-organic/organic-basics/regenerative-organic-agriculture/

The Carbon Underground:
https://thecarbonunderground.org/our-initiative/definition/

Climate Farmers:
https://www.climatefarmers.org/definition-of-regenerative-agriculture/

Savoury Institute: https://savory.global/holistic-management/

Project Drawdown:
https://drawdown.org/sites/default/files/pdfs/DrawdownPrimer_FoodAgLandUse_Dec2020_01c.pdf

European Commission (on the CAP): https://agriculture.ec.europa.eu/common-agricultural-policy/cap-overview/cap-glance_en

Some certifications

Land to market programme: https://www.landtomarket.com/

EOV: https://savory.global/land-to-market/eov/

ROC: https://regenorganic.org/resources/

Resources and further reading

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Lesson 4: Connecting: Regenerative Agriculture and the Climate-Farming-Cycle

Alena Holzknecht, Janos Wack

In this chapter the threads that have been spun in the last chapters about problems and challenges in agriculture, climate change management, climate adaptation and regenerative agriculture are to be connected. Why is changing agricultural practice to more regenerative ways of farming part of the solution to cope with climate change and the challenges it brings? What do we need for climate adaptation? Why do we see the key of a future farming system in climate adaptation and how do we translate that into practice in the form of regenerative agriculture? Why does the ClimateFarming cycle fit these goals?

So far you have been presented with the global challenges of…

- agriculture as a greenhouse gas (GHG) source, sink and affected by climate change and maybe by players in the field of carbon-dioxide removal
- planetary boundaries that are being crossed, and thus humanity leaving the safe operating space for issues like nitrogen and phosphorous flows, land-system change and biosphere integrity
- soil degradation as a serious threat to global food security
- dependance on external inputs in agriculture like fertilizers or fossil fuels that can have fluctuating market prices or limited availability
- nutrient efficiency, that has decreased over the last decades, getting to a point where adding more (synthetic) nutrients will not necessarily provide higher yields
- animal welfare, that has a serious problem in a farming system that often is highly specialized and where animal husbandry and crop production are often strictly separated; livestock systems will also be highly impacted by increasing temperatures and precipitation variation
- physical factors of climate change like heat and drought waves, changing precipitation patterns, decreasing freshwater resources, etc. that challenge the patterns and rhythms that agricultural production is accustomed to
- biodiversity loss that threatens the stability and resilience of ecosystems
- pets and diseases, new and old, that spread faster and have an easier job attacking plants and animals that are weakened by other climate change-related factors
- food security that is suffering under more and more unpredictable weather, soil degradation, and many of the factors above
- these challenges and interrelationships are exacerbated by the fact that the 1.5°C-target will no longer be achieved

All these factors are interconnected and in some way or another and depend on each other. Focusing on resolving one or several of the issues above in an isolated way while disregarding the others, will most likely not lead to the anticipated result. This is the reason why holistic thinking is the foundation for a resilient, productive farm and food system in times of climate change and the high demand for multi-functional land use.

Similar Starting points

While there is no uniform definition of Regenerative agriculture (RA), common themes with climate adaptation are multifunctionality, complexity and holistic or ecosystem thinking as phrased in two of the definitions presented in chapter 2.

> “An approach to agriculture that uses soil conservation as a starting point for regeneration and contribution to **multiple provisioning**, **regulating and supporting services**, with the aim that this improves not only the **environmental** but also the **social** and **economic dimensions** of sustainable food production (Schreefel et al. 2020).”

> “We define RA as an **ever-developing, complex,** and **context-dependent** agricultural approach aiming to restore and regenerate degraded land and **contribute to climate change adaptation** with mitigation co-benefits. In RA, the soil is the entry point to **rethink food systems** with the aim of enhancing **biological, physical, chemical,** as well as **cultural ecosystem services** in response to ecological conditions and the climate crisis, on a local as well as a global level (Daverkosen and Holzknecht et al. 2022)”.

> According to IPCC (2014), “adaptation is the process of adjustment to actual or expected climate and its effects. It is **not a one-time emergency response**, but a series of **proactive measures** to deal with the nexus of hazard (e.g. drought, sea level rise), exposure (e.g. less water in the South), and vulnerability (e.g. poverty or lack of education) [...].”

Both the concept of climate adaptation and of regenerative agriculture have similar premises:

- Climate change is one of the largest challenges for humanity, and that we need to not only prevent but also deal with its consequences.

- Dealing with complex processes and issues where easy solutions won't work.
- Long-term impacts > short-term benefits.
- Embracing complexity and trying to understand interconnections between multiple factors.
- Process-orientation, stepwise implementation of measures, constant learning, feedback loops.
- Being confronted with high uncertainties.
- Many actors are involved on different levels (farm - markets - governance - etc.).
- Demanding to step away from business-as-usual.

However, the principles of both climate adaptation and regenerative agriculture can be misinterpreted and result in creating more problems like investing in resource-intensive cooling or irrigation systems that keep up the production of products that don't (or won't) fit in the ecosystem (see chapter 3 on maladaptation). For this reason, guidelines and superordinate processes are needed to minimize the probability of such maladaptation problems and at the same time keep the required effort as low as possible (e.g. the ClimateFarming cycle).

Claims and needs

RA wants to be holistic, contextualized, flexible, multifunctional and supportive towards natural resources. At the same time adaptation needs to be holistic, contextualized, flexible, multifunctional and supportive towards natural resources. These two concepts are two sides of a coin. Both are considering a changing climate a "baseline" we have to deal with rather than doubting it. Thus, by implementing regenerative agriculture on a systemic level, the requirements of climate adaptation can be met in the farming sector itself but also touching so many other climate-relevant topics. For example, extreme weather events are happening and will continue to do so, but their impact can be hampered by creating landscapes that can take up and store more water and thus e.g. prevent flooding. Biodiversity will most likely continue to decrease, but its collapse can be averted by creating more diverse landscapes and using no more disruptive chemicals. Agricultural productivity (in the conventional way, i.e. yield/ha in highly specialized crops or high production animals) will probably decrease in some places, but by considering seasonality, localisation, diet changes, food waste, etc., this does not necessarily need to result in lower quantity or quality of food resources.

Thus, the focus lies on long-term stability rather than short-term benefits. Moving beyond short-term planning, the creation and fostering of self-evolving systems and an integrative approach to natural processes is central in regenerative agriculture. At the same time, this corresponds to the basis for successful long-term adaptation to climate change.

Pursue similar Goals

Both concepts approach the goal of resilience by taking into account all possible factors in the equation, through a holistic (or systemic) understanding of their interconnectedness. One of the four EU's adaptation principles is "more systemic adaptation", as climate change will be felt at all levels of society, and thus considerations about climate resilience need to be mainstreamed and become part of every decision taken (European Commission 2021). The same goes for decisions in a regenerative agricultural mindset.

So how can theory be translated into measures? The complexity of such multilayered issues demands a dynamic, iterative process of Assessing – Planning – Implementing – Monitoring/Assessing – Re-planning, and so forth. Similar approaches are used e.g. in the ClimateAdapt tool (European Commission and European Environment Agency 2021) or the Farm management flow chart (Kay et al. 2016), which is described in the next chapter.This process is central in developing effective measures and requires knowledge and often new skills as the most important inputs. It is important to respect the characteristics and context of the individual farm (system) and integrate these in planning and doing. Further, make use of multi-functionality for maximizing synergies and addressing several challenges alike.

Measure-Examples

Depending on the understanding of regenerative agriculture, its principles are difficult to prove scientifically, as their purpose is to embrace complexity, and natural science often requires the exclusion of background "noise" factors in order to use deductive methods for finding patterns. In simpler terms, it is hard to prove a specific measure brings a desired impact, if also a range of other measures are implemented at the same time and many factors (like soil, climate, etc. that are out of control of a farmer or researcher) also impact the outcome.

We mostly rely on anecdotal evidence of farmers demonstrating higher resilience, good soil-structure, lower pressure from pests and diseases, etc. by implementing a wide variety of measures that are well-suited to their context and interconnected in their services and provisions and thus "feed" and support each other. While integrated farm management systems are more difficult to measure and evaluate, more complex studies are underway as researchers find ways to deal with multidimensional systems. There is evidence for individual measures (and some combinations of thereof) that are included in some definitions of regenerative agriculture, especially practices like reduced tillage, cover crops and perennial cropping systems.

Two somewhat well-researched measure examples are the application of biochar and the establishment of agroforestry systems. Both of them can be examples of a development towards regenerative farm management if implemented in the right context. It has been proven that biochar and agroforestry meet the requirements of a holistic regenerative farm system through their multi-functionality and ecosystem approach. Moreover, they can be highly relevant for climate adaptation with mitigation co-benefits (e.g. Lehmann et al.. 2021, Schmidt et al. 2021, Quandt et al. 2023, Rolo et al. 2023). Measures like biochar application and agroforestry thus pick up the theoretical foundations described above and show that they can be transferred into practice. Finally, the question that remains is where and how such measures can be implemented, which is where the ClimateFarming Cycle can be of great help.

Example: Biochar

Similarly to the term regenerative agriculture, there was a considerable increase in scientific publications containing the word “biochar” in their title in the last 10 years (see e.g. [The State of Carbon Dioxide Removal report]() 2023) . Adding biochar to soils is often mentioned as a regenerative practice and many different benefits have been found like higher water storage capacity, increased root growth, more active microbial activity, etc. – all of which also are climate adaptation strategies. Another important factor is that it has a long-term impact, so it could help to store more carbon in soils.

Example: Agroforestry

Agroforestry has been practiced for many centuries, so its impacts can be measured in quite old managed ecosystems as well as in newly established ones. Some opportunities of agroforestry are increased biodiversity, more soil fungi, higher water holding capacity, a cooling effect on landscapes, they can act as windbreaks and may even bring higher yields on the same area if managed well. Just like biochar, they also usually have a long-term impact that is important to be relevant for climate mitigation.

The ClimateFarming Cycle

In order to condense all the considerations mentioned above and more into a practical approach, the ClimateFarming cycle was developed. It is based on insights from farm strategic management and several decision-support frameworks aiming at supporting climate adaptation. Further information concerning the theoretical background can be found in Tolle (2021).

It is an efficient process caused by a semi-standardised method that addresses individual farms, sites and persons. By assessing the state of the farm and its many facets as a first step, including all involved parties at the farm and giving impulses for finding new ideas or seeing opportunities from a new angle, it helps to stepwise develop a strategy for climate adaptation. The measure catalog is the practical link between the farm survey and theoretical approach and the implementation of the strategy. This should cause an extended version of regenerative agriculture, where even more factors are taken into account than often mentioned. By focussing on the farm context and an intensive iterative planning and evaluation process, the uncertainties and dynamics of climate change are considered and fully integrated. The semi-standardisation provides higher efficiency and less arbitrary decision making, resulting in more transparency.

Some thoughts on implementation

There are limitations to the ClimateFarming method. It is a time and knowledge intensive process that needs dedication to function properly. For now, there is also a lack of practice-orientation, which can partly be alleviated by involving external consultants for specific services. Impacts are difficult to measure, and the results are highly dependent on the users (both farmers and consultants). The measures might cause changes that go beyond the impacts of combining measures that require a deep understanding of the ecosystem to assess them.

There is also always a conflict between the daily farm routine vs. long-term plans, strategies and measures, and specific time slots need to be reserved for the initial process but also regularly afterwards to re-evaluate. Another conflict is the demand for easy solutions on the one hand (e.g. “climate farming”) vs. complex problems that require diverse and context-dependent analysis and solutions on the other hand (climate change) where general guidelines are not applicable.

The consequence is that the support of such a process is a highly challenging task for consultants. This requires generalists that can involve different specialists when needed. How many farms will go through this potentially tedious process to implement their climate strategy?

But what is the alternative? The alternative is business-as-usual, which in reality is not an alternative anymore. Climate impacts are here & now, and the agricultural sector cannot afford to stand back and watch.

The overall goal of this project is to make (academic) knowledge and theories more accessible and practice-oriented *without* degrading their value for addressing the complex challenges of climate change and agriculture. Based on the previous content, simple, one-dimensional solutions will only, if even, bring short-term beneficial effects.

By implementing the ClimateFarming Cycle on demonstration farms, theory is further brought into practice, providing constant feedback on the method. It also makes the theoretical background perceptible and shows its impact on a farm. Therefore, this network of demonstration farms makes scaling of the ClimateFarming Cycle and thus climate adaptation scalable.

SUMMARY - Connecting: Regenerative agriculture and the ClimateFarming Cycle

Both the concept of Regenerative agriculture and climate adaptation have similar starting points and premises, e.g.

- acknowledging climate change as a complex challenge that must be met with proactive measures,
- valuing long-term impacts over short-term benefits,
- process-orientation, feedback loops and constant learning,
- demanding to step away from business as usual,

as well as similar needs:

- contextualisation and flexibility,
- multifunctionality

and similar goals:

- holistic and systematic approach,
- understanding interconnectedness.

Therefore, we see potential in applying the ClimateFarming Cycle, to translate climate adaptation principles to real-life farm conditions.

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Extra: Theoretical Background: Methods and Foundation

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Strategic Farm Management

Strategic farm management (Barnard and Nix, 1979; Kay et al., 2016) is an iterative process. It is used to formulate individual farm objectives, allocate resources within the farm and monitor farm results. In the process, possible development strategies of the farm are produced. In principle, this process can be compared to approaches dealing with adaptation planning (e.g. Adaptation Action Cycles; Park et al., (2012)), as essential elements are similar. Strategic farm, management involves:
1. (problem) analysis and description
2. definition of guiding principles (qualitative) and goals (quantitative, measurable)
3. assessment of internal and external conditions (e.g. SWOT analysis)
4. based on this: collection and planning of possible solutions
5. implementation of the planned measures
6. monitoring, control and re-planning (target-performance comparison)

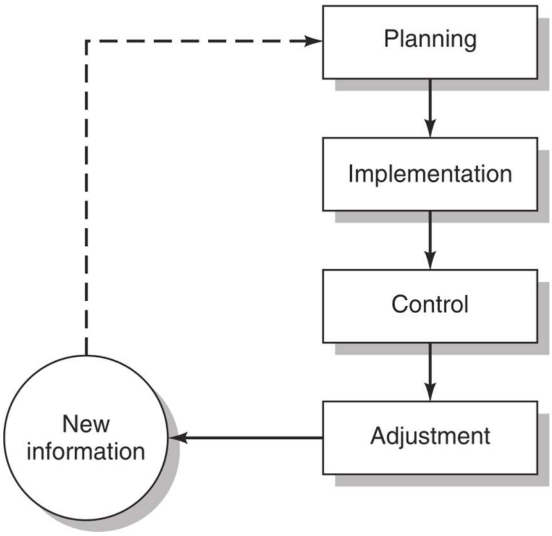

Figure 1: Farm management flow chart, taken from Kay et al. (2016)

However, classical strategic farm management lacks the tools and mechanisms to deal with “deep” uncertainty. To address this problem, classical strategic farm management is extended by approaches based on “Decison-making under Deep Uncertainty” (DMDU).

Decision-making under Deep Uncertainty (DMDU) and the Dynamic Adaptive Pathways Approach (DAPP)

Accumulated uncertainties, referred to as uncertainty cascade (Refsgaard et al., 2013), pose a significant challenge to climate change adaptation planning in general, and for agriculture specifically. Climate change can be termed as a source of deep uncertainty (Jones et al., 2014).

The DAPP method is an approach based on the insights of the DMDU. Originally developed in the context of water management, the method can also be used as a basis for adaptation processes in other sectors (Haasnoot et al., 2019). DAPP was developed by Haasnoot et al. (2013) and is based on the combination of elements of *Adaptive Policymaking* and *Adaptation Pathways*. This approach addresses the issue of Deep Uncertainty by enabling the user to "Proactively plan for flexible adaptation over time [...]" depending on how "[...] the future actually unfolds" (p. 73, Haasnoot et al., 2019). DAPP uses a so-called pathway approach, where an adaptation pathway is a sequence and combination of different adaptation measures over time. Different possible adaptation pathways are presented in a so-called pathway map. These pathway maps open up a decision space for the user in which each pathway is potentially capable of achieving a predetermined goal. However, there are differences between pathways in efficiency, side effects and robustness (Marchau et al., 2019).

The DAPP is used as the foundation for the ClimateFarming Cycle as it corresponds with the challenges of climate adaptation at the farm-level. According to Haasnoot et al. (2019), the DAPP is especially useful when:

- The planning horizon comprises fundamental uncertainties.
- A high variation of adaptation actions exists, allowing for different and flexible
- solutions.
- Measures can be implemented relatively fast and the system has sufficient time to
- adapt.
- The lifetime of measures is relatively short compared to the planning horizon.
- Decisions can entail significant path dependencies.
- Indicators exist to signal changing trends.

Above this, the pathway approach is particularly valuable because it visualises complex interactions and dependencies of the different adaptation measures in the pathway maps and thus makes them tangible for the user. The advantages of this approach are used in Step 4 of the ClimateFarming-Cycle, the *farm climate strategy*. Due to the visualisation, it motivates the user to think and plan short- and long-term measures together. This reduces the potential for maladaptation and the associated monitoring enforces the perception of adaptation as a continuous process. Actively addressing uncertainty also encourages consideration of potentially more severe climate change impacts (Haasnoot et al., 2019).

Additional Method 1: TOWS-Analysis

The TOWS-Analysis translates the findings of the SWOT-Analysis into possible response strategies (Weihrich, 1982). These can already be concrete adaptation measures to specific climate impacts, but do not have to be. This method is worthwhile in a complex farm system, e.g. a farm with various production branches.

A TOWS matrix is comparable to a SWOT matrix, but contains four additional blocks which focus on the interactions of the individual SWOT elements (*SO = Strentgh/Opportunity; ST = Strength/Threat; WO = Weakness/Opportunity; WT = Weakness/Threat*). To focus on the interaction of the different SWOT aspects helps to identify chances for the farm development *(S/O)*, shows options how to respond to external *Threats* with internal *Strengths (S/T)* or how to address internal *Weaknesses* by external *Opportunities (W/O)*. Lastly, the interaction of *Weaknesses* and *Threats (W/T)* can reveal which combination of negative factors are especially problematic and need to be addressed by adaptation.

Example SWOT/TOWS-Analysis:
SWOT: An example farm identifies increasing drought as an acute *Threat*. In addition, the farm members note that all farm sectors are vulnerable to drought, showing a *Weakness* of the farm. In the SWOT analysis it also becomes clear that the profitable direct marketing of beef is a *Strength* of the farm. At the same time, it becomes apparent that there are two agricultural lateral entrants in the neighbourhood of the example farm who are interested in and experimenting with vegetable production, what is categorised as *Opportunity*.
TOWS: From this combination of factors, the farm members consider that a new branch of the farm, which is less susceptible to drought, must be integrated into the farm (*Threat:* Increasing drought + *Weakness:* High susceptibility to drought). Based on the strong direct marketing (*Strength*) and the availability of additional labour (*Opportunity*), the idea arises to establish irrigated vegetable cultivation with direct vegetable marketing as a new branch of the farm. This is intended to further diversify the farm and compensate for farm losses in other production branches, especially in times of drought.

Example combination of SWOT/TOWS analysis with findings of the climate impact exploration: As a possible response strategy to the vulnerability of an example farm to drought, the TOWS analysis suggested the establishment of a new production branch: irrigated vegetable production with direct marketing. Of course, the farm members were aware that irrigation could potentially become problematic if precipitation decreases and with it groundwater recharge or rainwater collection possibilities. However, the regional climate projection showed that, according to climate models, a significant decrease in average precipitation per year is not to be expected, even in the long term. However, there is the possible prospect of a seasonal shift - less precipitation in the summer months, more precipitation in the winter months. From this information, the farm members concluded that irrigated vegetable production has the potential to reduce the farms vulnerability towards drought and to cope with possible climate impacts, also in the long-term. However, a prerequisite for this is good water management and the expansion of rainwater storage, especially in the winter months.

Additional Method 2: SWOT-Analysis and contingency measures

Using SWOT-Analysis and contingency measures is not pivotal for the success of Step 4 and the ClimateFarming Cycle and can be skipped if necessary. However, it is emphasized that it is a worthwhile method to evaluate the developed farm climate strategy, as it motivates the farm members and the consultant to critically analyse the developed plan and how to improve the farm climate strategy even further.

The SWOT-Analysis of the farm climate strategy serves to identify uncertainties, new vulnerabilities and opportunities arising from the farm climate strategy. The analysis is the basis for the formulation of contingency measures. Contingency measures have the purpose to increase the resilience of the farm and its plans by hedging its success or exploiting arising opportunities. Three categories exist, namely *defensive*, *corrective* and *opportunity actions*. According to Walker et al. (2019), these actions are defined as follows:

- Defensive Action (DA): Measures taken to support or hedge the success of the farm climate strategy or to address external challenges which threaten the success of the farm climate strategy

Example defensive action: If a farm climate strategy foresees the construction of an agrophotovoltaic installation, the farmer could convene a community meeting in the affected municipality in advance in order to provide information about the project at an early stage and to obtain support from the population.

- Corrective Action (CA): A corrective action changes the farm climate strategy in response to new knowledge or changed conditions without changing its overall objectives.

Example corrective action: Advances in robotics enable better weed control in organic farming. As a result, soil cultivation and crop selection can be changed.

- Opportunity action (OA): A action taken to take advantage of opportunities and increase the effectiveness or resilience of the farm climate strategy

Example opportunity action: Due to a change in the legal situation regarding the promotion of agroforestry systems, certain tree species are promoted and others are not. Re-planning the agroforestry plantation with the eligible trees would be a corrective measure (of course, this only applies if these tree species still suit the location, climate and farm).

The implementation of contingency measures is informed by the monitoring from step 5.

Additional Method 3: Adaptation Tipping Points and Opportunity Tipping Points (ATP and OTP)

In DAPP, the individual adaptation measures that make up an adaptation pathway have different Adaptation Tipping Points (ATP). An ATP marks the point at which a measure is no longer able to achieve the specified objectives of a system (Kwadijk et al., 2010). The formulation of ATP is supposed to inform the decision-maker about the change to a new or additional adaptation measure.

This approach is problematic for the farm-level, as it is difficult to make reliable estimates of ATP due to the complex interaction of various factors. The use of ATP is further complicated by the fact that in agricultural production several measures are usually implemented simultaneously and existing measures are not replaced but rather complemented by new and additional measures. For example, drought-tolerant varieties are not replaced by the introduction of reduced tillage, but complemented.

As this is not only an issue at the farm-level, ATPs were complemented by OTPs (Opportunity Tipping Point; Haasnoot et al., 2018). In contrast to ATP, OTP signals when the introduction of a new or complementary measure makes sense. This approach is - most of the time - more helpful in agricultural adaptation planning.

The tipping point concept helps to become more independent of (climate) scenario selection and its accuracy. The focus is on the conditions under which a certain adaptation measure fails (ATP) or should be implemented (OTP), not the selected scenario.

Example ATP: The adaptation measure "sowing of deep-rooted legumes and drought-resistant grass varieties in grassland stands" is considered. This climate measure could mitigate drought-related damage to a certain extent, but would need to be complemented by other measures (e.g. agroforestry to provide shade and supplement the forage supply) as the intensity of droughts increases.

Example OTP: The adaptation measure "agroforestry" is considered. The introduction of government support for agroforestry would be an OTP that initiates the implementation of the agroforestry measure.

SUMMARY - Theoretical Background: Methods and Foundation

Strategic Farm Management (Barnard and Nix, 1979; Kay et al., 2016) is a cyclical process and consists of the phases of.

  - Analysis (problem definition)
  - Goal formulation
  - Planning
  - Implementation
  - Monitoring, control and replanning (target-performance comparison)
- In principle, this process can be compared to approaches dealing with adaptation planning (e.g. Adaptation Action Cycles; Park et al., (2012)), as essential elements are similar.
  - It is an ongoing process of analysis, implementation, monitoring and reassessment. There is a focus on learning, adaptability and flexibility.
- Strategic farm management needs to be complemented by DMDU (Decision-making Under Deep Uncertainty) approaches to deal with the problem of increasing uncertainty.

Decision-making Under Deep Uncertainty:

- Definition from U.S. Climate Resilience Toolkit (2023):
  "Deep uncertainty occurs when decision makers and stakeholders do not know or cannot agree on how likely different future scenarios are.
  - *If there's not an agreement or knowledge or confidence in these future scenarios.*

  - ○ *When decision makers or stakeholders do not agree or do not know what consequences could result from their decisions.”*
- Various approaches and methods exist that help decision-makers to make decisions in situations of deep uncertainty, comprised under “Decision-making under Deep Uncertainty (DMDU)” (Marchau et al., 2019)

The **Dynamic Adaptive Pathways Approach (DAPP)** provides the methodological basis for the climate farming cycle.

- DAPP is integrating uncertainty in the planning process via the ability of the plan to be modified over time with the availability of new knowledge or changed conditions (Marchau et al., 2019).

Additional Methods exist which can be integrated in the ClimateFarming Cycle in order to improve its results

- Additional Methods 1: TOWS-Analysis (Step 2)
- Additional Methods 2: SWOT-Analysis and Contingency-Measures (Step 4)
- Additional Methods 3: Adaptation Tipping Points and Opportunity Tipping Points (ATP and OTP)

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