Summary: The pathway to a climate-positive future - strategy and action plan for achieving negative greenhouse gas emissions after 2045

Attaining negative emissions of greenhouse gases will demand supplementary measures alongside extensive emission mitigation. This strategy sets out principles and targets for a policy in the area of supplementary measures and an action plan for achieving them.

All pathways that limit global warming to 1.5 °C with limited or no overshoot project the use of carbon dioxide removal (CDR) on the order of 100-1 000 *GtCO* $_2$ *over the 21st century. CDR would be used to compensate for residual emissions and, in most cases, achieve net negative emissions to return global warming to 1.5 °C following a peak (high confidence).*

From the IPCC Special Report on the impacts of global warming of 1.5 °C from 2018

Introduction

According to the UN's Intergovernmental Panel on Climate Change (IPCC), measures and technologies are needed for net negative emissions of carbon dioxide to limit global warming to a maximum of 1.5 °C. The IPCC states that net negative emissions of carbon dioxide arise when a larger amount of carbon dioxide is removed from the atmosphere thanks to human activity than the residual emissions caused by humans.

Under the Paris Agreement on climate change (the Paris Agreement) the parties are to strive to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century. It is assumed that developed countries will lead the way in these efforts, and many countries around the world have adopted or are moving to adopt net zero em1ss10n targets.

Sweden's climate policy framework from 2017 states that by 2045, Sweden is to have zero net emissions of greenhouse gases into the atmosphere and should thereafter achieve negative emissions. However, attaining this goal will demand supplementary measures alongside extensive emission mitigation, as net negative emissions cannot solely be attained by reducing emissions. The climate policy framework can thus not be implemented without a policy for supplementary measures.

The climate policy framework places Sweden in a small but growing group of countries in the forefront of combating climate change. This strategy sets out how Sweden can work on measures and technologies that produce negative greenhouse gas emissions, i.e. that lead to net removal of greenhouse gases from the atmosphere, and other types of supplementary measures to achieve the goals of the climate policy framework. Few countries have come as far in their preparations to attain net negative emissions as Sweden. If the action plan in the strategy is implemented, together with the drastic emission cuts that are prescribed by the climate policy framework, Sweden's credibility as a trailblazing country on climate issues will be significantly increased. This will clearly show that Sweden intends to act in line with the science to play its part in attaining the goal of the Paris Agreement.

Being a trailblazer takes courage. A policy needs to be developed for what is partly an entirely new area, characterised by major uncertainties and limited experience. However, there are no major risks and no insurmountable obstacles that justify Sweden postponing action. On the contrary, there are weighty reasons in favour of acting and major opportunities to be gained from rapidly putting in place the measures required to bring about net negative emissions.

These reasons are further elaborated on below under the heading *Supplementary measures are needed alongside emission mitigation.* Under the heading *Principles for how the volume of supplementary measures should be built up,* an account is provided of what the build-

ing blocks of a policy to maximise the benefit of supplementary measures could look like.

Sweden is a sparsely populated, forested country; more than two-thirds of Sweden's land area is covered by trees. This means that measures that affect carbon sequestration in forests and in the soil and the opportunity to produce renewable raw materials in a sustainable way are vitally important to Sweden's national net emissions. Although Swedish agriculture does not cover as large an area, there are good opportunities there too to increase production and increase carbon sequestration in ways that contribute towards several simultaneous added values.

The abundant access to biomass as a raw material for the pulp and paper industry has resulted in Sweden having a large number of significant point emission sources of biogenic carbon dioxide. In addition, the use of biomass residues from forest management and forest industries has given rise to several large point emission sources of biogenic carbon dioxide in the energy sector. The potential for negative emissions through the application of bio-CCS (capture, transport and storage of carbon dioxide of biogenic origin) at these sites is high.

Sweden thus has unusually good potential to introduce particular measures and technologies that result in negative emissions of greenhouse gases and should make use of these as far as possible. Some countries have similar opportunities to Sweden and can make use of the same measures and technologies to achieve negative emissions, while other countries will entirely or partly need to choose different paths based on their specific situation. Considering the magnitude of the climate challenge and the urgency with which it must be tackled, all opportunities to achieve negative greenhouse gas emissions in the world must be seized.

The purpose of the strategy

- The overarching purpose of the strategy is to help Sweden to attain the goals of the climate policy framework.
- The strategy is to make it possible to use supplementary measures to attain the goal of net zero emissions by 2045 at the latest, and the goals for 2030 and 2040.

- The strategy is to make it possible for Sweden to attain net negative emissions of greenhouse gases once the net zero goal has been reached, by using supplementary measures.
- The strategy is to help to attain the goals of the climate policy framework in a manner that is efficient in terms of costs and the socio economy and without impairing Sweden's capacity to attain its environmental quality objectives.

Targets for supplementary measures

Targets for supplementary measures should be agreed and decided. The strategy assumes the following targets for supplementary measures:

- In 2030 Sweden is to achieve supplementary measures equivalent to at least 3.7 million tonnes of carbon dioxide per year.
- In 2045 Sweden is to achieve supplementary measures equivalent to at least 10.7 million tonnes of carbon dioxide per year. This level is to be able to increase after 2045.
- Between 2021 and 2045, the volume of annually generated supplementary measures will constantly increase.

It is up to future governments to decide the extent to which supplementary measures are to be counted towards the goals of the climate policy framework.

The target level for supplementary measures in 2045 is based on the maximum permitted use of supplementary measures to achieve the net zero emission goal of the Swedish climate policy framework. In the same way, the target level for supplementary measures in 2030 is based on the maximum permitted use of supplementary measures to achieve the climate goal for 2030. The underlying idea is that the volume of supplementary measures is to be built up continuously over time. Therefore, there is no need for a quantitative target level for supplementary measures by 2040; the important thing is that the volume of supplementary measures continues to grow towards the target level for 2045.

Climate goals in the climate policy framework are expressed as percentages of historical emissions. This means that climate goals expressed as volumes may change as Swedish emission reporting evolves. The target levels for supplementary measures may therefore need to be reviewed in the event of major changes to previously reported historical emissions.

Supplementary measures are needed alongside emission mitigation

Emission mitigation and supplementary measures are both needed

To meet the goal set out in the Paris Agreement and the Swedish climate goals, there is a need for both emission mitigation and supplementary measures. Under the climate policy framework, emissions in Sweden must fall by at least 85 percent by 2045 compared with 1990. Supplementary measures do not replace the need for an extensive transformation of society and for far-reaching emission mitigation but are a complement to such developments.

Some emissions are very hard to mitigate

The goal of net zero emissions in Sweden by 2045 will be very difficult to meet by reducing emissions alone. This is because certain emissions are judged to be particularly hard to eliminate entirely, at least not without also halting the activity that gives rise to the emissions.

Reducing greenhouse gas emissions by at least 85 percent requires ceasing practically all use of fossil fuel in society at the same time as emissions from industrial processes reach levels close to zero, partly by phasing out the use of fossil inputs and by applying CCS technology in industries such as cement production, where fossil carbon emissions cannot otherwise be avoided. The efficiency of the use of energy and materials must be hugely improved, and emissions from electricity supply need to reach zero-levels while electricity use increases in industry and the transport sector.

The greenhouse gas emissions that remain once emissions have been reduced by 85 percent are mainly methane and nitrous oxide

emissions from several disparate sources in society, e.g. from incineration of biofuels, waste water treatment plants, digestion for biogas production and emissions from agriculture. Based on today's knowledge and technology, these remaining emissions are judged to be very difficult and expensive to eliminate entirely.

The largest remaining greenhouse gas emissions in 2045 are expected to be found in the agricultural sector. Agricultural greenhouse gas emissions largely come about as the result of biological processes, and emissions are typically spread across a very large area, making them hard to control and capture. It is true that emissions may be reduced per produced unit of food or agricultural product and by prioritising the production of products with low associated emissions, but emissions cannot be eradicated entirely. Given today's knowledge and technology, Sweden cannot attain zero emissions as long as agriculture continues to exist. Sweden can therefore not attain the national climate goal of net zero emissions by 2045 at the latest through emission mitigation alone.

The conclusion therefore is that supplementary measures are needed to compensate for emissions that cannot be entirely eliminated with today's knowledge and technology. Investment in the field of supplementary measures, in parallel with technological development and a transformation of society to reduce emissions, will mean Sweden is not dependent on highly uncertain future leaps in technology to attain the goal of net zero emissions by 2045 and will simultaneously pave the way for achieving net negative emissions thereafter.

Supplementary measures are needed to go beyond net zero

According to the climate policy framework, Sweden is to have net emissions that are lower than zero once the net zero target has been achieved by 2045 at the latest, i.e. net negative emissions. Net negative emissions will only be possible if supplementary measures are used and deducted from remaining emissions.

The framework does not specify how far below zero Swedish net emissions must be after 2045. Provided that future national climate goals continue to be determined on a scientific basis, and taking global justice into account, it is, however, likely that Swedish climate

goals after 2045 will need to be considerably lower than net zero. In order to attain such goals, a considerable volume of supplementary measures will be needed.

According to the IPCC, unless global emissions plummet rapidly in the immediate future, considerable net negative emissions will also be needed at global level after 2050 to meet the temperature goal set out in the Paris Agreement, and this situation will prevail for a long time to come. The earlier that major reductions in emissions and negative emissions come about, the lower the need for negative net emissions will be in the second half of the century to compensate for exceeding the carbon budget for 1.5 °C, but even in such a development scenario, global net emissions would need to be below zero.

Therefore, it is likely that Sweden will have national climate goals that are considerably lower than net zero from the second half of this century onwards and for a foreseeable period thereafter. Thus, in the long term, the volume of Swedish supplementary measures will probably need to remain at a high level for a long time.

Supplementary measures can increase cost efficiency in both the short and the long term

If the national climate goals on the path towards net zero emissions are to be met without adding in supplementary measures, the cost of achieving the goals will rise. The supplementary measures proposed in this strategy are estimated to be associated with considerably lower costs for measures in 2030 than, for example, emission mitigation through further increased use of biofuels over and above what can be demanded to attain the climate target for the transport sector. Also, the cost of measures in the field of biofuels to achieve the climate goal for the transport sector is judged to be higher than the cost of the proposed supplementary measures. However, this is of no practical significance, since the way the goals are designed means that the transport goal must be met without factoring in supplementary measures.

The cost of achieving the Swedish net zero emission goal by 2045 at the latest purely through emission mitigation is judged to widely exceed the cost of achieving the goal by also factoring in supplementary measures, because the former requires major interventions regarding the extent of agricultural production in Sweden, among other

things. The measures that may come to be necessary for achieving the net zero climate target without supplementary measures also risk leading to higher emissions in other countries, e.g. through increased imports of agricultural products, which would seriously reduce the overall actual climate benefit.

The opportunity to meet more stringent climate goals

We are constantly adding to our knowledge on climate change. IPCC's most recent reports from 2018 and 2019 show that global net emissions need to fall extremely rapidly in the immediate decades, through emission mitigation and increased removal, if the temperature goal of the Paris Agreement is to be achieved. The research results also show that even now, at a temperature increase of about a degree compared with preindustrial levels, the effects of a changed climate are more extensive than was previously predicted.

It is feasible that the national climate goals will need to be tightened up to continue to be in line with the goal of the Paris Agreement and Sweden's ambition to be a trailblazer in the area of climate change. If society in Sweden is successfully transformed to attain very low greenhouse gas emissions, supplementary measures may make it possible to respond to tougher climate goals at national or European level.

Principles for how the volume of supplementary measures should be built up

The same climate effect must be attained as for emission mitigation in Sweden

In line with the climate policy framework, the climate effect of supplementary measures must be comparable with the climate effect of emission mitigation in Sweden. In other words, when supplementary measures are used to attain the climate goals, this must not mean lowering ambitions in terms of climate effect. This is a very important starting point for the strategy, which, inter alia, means that it is proposed that only negative emissions (removal of greenhouse gases) and reduced emissions in the land use, land use change and forestry

sector (LULUCF sector) which follow from the effect of measures in this strategy are able to be counted as supplementary measures. Accounted net removals and emission reductions in the LULUCF sector which would have occurred even in the absence of these measures should not be able to be counted towards the climate goals as supplementary measures, because this could lead to a lower mitigation effect in total compared with emission mitigation in Sweden.

The above interpretation is in line with the IPCC's definition of negative emissions, which states that these arise through planned human activity, e.g. in addition to the removal that would otherwise have taken place naturally in the carbon cycle.

For supplementary measures to be comparable with emission mitigation in Sweden, the climate effect must also be comparable over time. When supplementary measures are used to attain any of the climate goals in the national climate policy framework, they must be used and allocated such that they compensate for a higher emission level over time - not only for the specific target year. If supplementary measures were only to be used such that they compensate for a higher emission level in a specific target year, their climate effect would not be comparable with the climate effect of emission reductions in Sweden.

The supplementary measures used must lower the cost of attaining the climate goals

Supplementary measures must be capable of helping Sweden to attain the climate goals in a cost-effective manner that is also effective in terms of the socio economy. In selecting which supplementary measures should be carried out, cost-effectiveness in the short and the long term are elements that should be factored in. The analysis should also consider risks, the permanence of carbon storage, significant ancillary benefits and negative effects.

The instruments applied to achieve the supplementary measures also need to be designed such that they are cost-effective and effective in terms of the national economy. One component in this is to avoid carbon leakage, i.e. production and associated greenhouse gas emissions moving from Sweden to other areas where the production costs are lower as a result of a less ambitious climate policy.

Spreading the risks should be a guiding principle

The different types of supplementary measures are all associated with uncertainty and risks in their implementation. These risks mean that it is highly likely that several of the projects initiated as supplementary measures will fail to deliver negative emissions or emission reductions according to plan.

It is also possible that a whole category of supplementary measures will prove to be a difficult path. This might be the case, for example, if a market for trading verified emission reductions would not come into being internationally, or if geological storage sites for Swedish carbon dioxide would not become accessible.

Changes in EU regulations may mean that what can be counted as a supplementary measure today will not automatically be able to be counted as such tomorrow. This is particularly true if the scope of the EU's main legal provisions in the climate field are changed in terms of emission sources and sinks or accounting rules. Several of these legal provisions do not extend further than 2030.

The type of risks naturally varies between the different supplementary measures. The effects of proposed and other potential measures in the LULUCF sector depend, among other things, on how quickly they can be brought about and how incentives to carry out the measures are affected by other factors, e.g. the market's demand for different products from agriculture and forestry. There are also risks associated with different forms of natural disturbances, some with a link to how the climate develops, which may limit the outcomes of the measures taken.

For bio-CCS, commercial risks are likely to be the major threat to project implementation but there are also technical, legal and political risks or obstacles that may delay or halt bio-CCS projects, even if the proposals of the inquiry seek to reduce these.

The Paris Agreement's rulebook for trade in mitigation outcomes between countries has still not been finally negotiated. This is one of several factors that mean that it is likely to take a number of years before it is possible for Sweden to carry out verified emission reductions in other countries in a way that firstly ensures that the efforts lead to measures over and above those that would have been taken in the host countries in any case, and secondly does not lead to double counting of the emission mitigation attained.

Other technical measures for removal of greenhouse gases are at an early stage of development and are untested on a larger scale. At the moment, there is also a lack of a system or common regulations to report and account for negative emissions using such technologies.

Given the risks inherent in supplementary measures in all areas, it would be unwise to focus on only one type of supplementary measure. Spreading the risk should therefore, at least initially, be a guiding principle for how the volume of supplementary measures is to be built up over time. In the long term, it may become clear that one or more types of supplementary measures should be prioritised over others.

Action today means room for manoeuvre tomorrow

The supplementary measures are generally characterised by high complexity and long lead times. No high-quality supplementary measures can be carried out without being preceded by extensive planning and preparation work. How long the time lag is between a decision on a measure until the result of the measure can start to be taken into account in climate accounting differs markedly, however, between different supplementary measures.

For most of the measures in the LULUCF area, further analyses are needed of where different measures can suitably be carried out, but these analyses should not be so extensive that they prevent the measures from being implemented within a year or two. Once measures are in place, it takes different amounts of time before the full effect is attained. A measure such as re-wetting drained peatland will reduce emissions relatively quickly, while the full effect of afforestation measures will only be attained after several decades.

Bio-CCS projects are associated with long lead times. Pilot-studies permit processes and setting up installations to capture, transport and store carbon dioxide will take several years in total for each individual project.

The lead times for implementing measures in other countries that can be judged to be additional, contribute towards sustainable development and to raising the level of ambition globally, will probably be relatively long, particularly in the introductory phase. Under the Paris Agreement, all parties have their own national climate plans

that will gradually need to be made stricter. Limiting emissions in a country that has also adopted its own climate plan and introduced national instruments for emission mitigation in the climate field therefore requires collaboration between the parties involved, partly to identify how implementing measures will not make it more difficult for the host country to meet its targets or to raise its own ambitions.

Due to the long lead times from decision to result for several of the supplementary measures, it is necessary to act in the immediate future so as not to shrink future room for manoeuvre on climate policy. If, for example, bio-CCS is to be able to play a significant role in climate policy in 2045, the first plants need to be taken into operation in the 2020s, which demands immediate action on the part of the State. The same timescale applies to certain measures in the LULUCF sector.

It is thus important that an investment in supplementary measures is introduced without delay so that it is possible to fully benefit from the opportunities and the room for manoeuvre that the supplementary measures bring.

Stable terms and objectives attract project owners

Most supplementary measures involve projects that will run for a long time, often decades. Projects in the LULUCF sector can also result in a landowner being unable to farm a specific area in the same way as before. Decisions to implement such projects are not made lightly. Projects can also be associated with major investments. This is always the case with bio-CCS, for example.

In order to attract appropriate project owners, the area of supplementary measures should therefore be characterised by stable terms and conditions and clear targets. This aids predictability and reduces the risk for potential project owners.

Stable terms and conditions mean that the direction of governance should not change radically over time. Instruments can and should be gradually developed, but, in other words, this should take place in a way that does not dramatically alter the underlying conditions for the actors affected.

The volume of supplementary measures should be built up gradually

Swedish actors' experience of several types of supplementary measures is limited. Experience is often limited internationally too. This is the case with bio-CCS, for example, and biochar. Technologies and measures where experience is limited today can be assumed to be in a phase in which the learning curve is steep and where development towards greater effectiveness and lower costs may be rapid once experience has increased.

Gradually building up the volume of supplementary measures means experiences from early projects in Sweden and abroad can help to lower the cost and increase the efficiency of subsequent projects. Swedish projects provide relevant experience for the underlying conditions that apply here; equivalent experience cannot usually be fully obtained by studying projects abroad.

If the volume of supplementary measures is built up gradually, certain types of measures can be prioritised ahead of others on the basis of evaluations of early initiatives before volumes have reached high levels.

Development towards technology-neutral governance

The supplementary measures that are feasible today differ wildly in character and find themselves in different phases of technological maturity. The costs of some of them may be thought to fall faster when the experience of measures increases compared with other supplementary measures where the cost scenario is more stable. There are also major differences in the quantitative potential different supplementary measures have and thus what role they can play in a long-term climate transition.

In the short term, there are therefore grounds to apply technol- ogy-specific governance that permits different instruments and pric- ing for different types of supplementary measure. This creates oppor- tunities for measures and technologies that are currently associated with relatively high costs, compared with other options, to contribute to a cost-effective climate policy when experiences of the measures increase, and the costs fall.

In the long term, governance of supplementary measures should be developed towards technology neutrality. Once technological

maturity and experience of supplementary measures have increased, technology-neutral governance facilitates good cost-effectiveness. In the long term, too, it is likely that there will be new technological solutions in early stages of development that may need to be the object of specific development-support initiatives.

Technology-neutral governance needs to consider the fact that the end product of different supplementary measures differs. For example, there is a major difference between carbon dioxide which is permanently and irreversibly stored (e.g. through bio-CCS) and carbon dioxide that is stored for the long term but where this is temporary or reversible (e.g. through afforestation), even if both can be counted as negative emissions. This difference can justify differentiated compensation for negative emissions.

In addition to development towards technology-neutral governance, a move towards geographically neutral governance that does not take national boundaries into account may ultimately become relevant in the longer term.

There is no ceiling for the volume of supplementary measures

The climate policy framework contains rules that limit the volumes from supplementary measures that may be counted towards the climate goals. On the other hand, there is no limit on the volume actually created.

This strategy contains targets for the volume of supplementary measures expressed as minimum levels. In the future, however, it may prove to be the case that higher levels are needed or desirable. The proposals in the action plan seek to clear the minimum levels but they also create underlying conditions for going further in the long term where necessary and generating a larger volume of supplementary measures.

Harmony with the development of the EU's climate policy

The EU's climate policy is developing rapidly. At the end of 2019 the EU Heads of State, except for one Member State, backed the goal of a climate-neutral EU by 2050. The Communication from the Commission on The European Green Deal from the same period

contains a wide-ranging roadmap for work in the coming years towards a tougher environment and climate policy for sustainable economic growth in Europe. Negative emissions are part of the European Commission's long-term climate strategy, but actual governance in this area is absent at EU level, except for the LULUCF sector. It is likely that a European policy for negative emissions of greenhouse gases will eventually be developed. It can also be noted that international climate measures are not included in the proposals drawn up so far.

Formally tightening up the EU's climate target or organised voluntary overperformance compared with the goals of Member States with high ambitions, would probably hasten the development of EU-wide governance of negative emissions.

The Swedish supplementary measures need to be planned, defined, carried out and managed so that they can work well with the EU's regulations, now and in the future.

Direction of supplementary measures up to 2030 and possibility space up to 2045

The volume of supplementary measures should be built up in line with the proposed targets for supplementary measures and principles above. The impact assessment presented in section 20 forms a basis for this strategy and its action plan together with the conclusions and assessments made in the other sections of the report.

Direction up to 2030

Up to 2030 the direction should be towards creating supplementary measures equivalent to at least 3.7 million tonnes of carbon dioxide per year with a rough distribution between the main types of measures set out in table 1 below. The direction may need to be modified in conjunction with the control stations proposed to reflect experience won and external developments.

Table 1 Direction for supplementary measures up to 2030

Type of supplementary measure	Mtonnes CO_2 equiv./year
Increased carbon sink in forests and land	1.2[1,2]
Capture and storage of biogenic carbon dioxide (bio-CCS)	1.8
Verified emission reductions in other countries	0.7
Total	**3.7**

[1] Equivalent to the entire effect of proposed supplementary measures compared with the measures not being carried out.
[2] Inclusive use of biochar as a carbon sink, which, however, is not judged to result in any major boost by 2030.

The total volume of verified emission reductions in other countries should amount to a total of at least 20 million tonnes of carbon dioxide equivalents in the 2020s. Of this, 0.7 million tonnes are calculated as supplementary measures in the specific year 2030 in line with the direction above. The remaining volume is calculated partly as supplementary measures for the period 2021-2029 as the quantity of supplementary measures must be built up gradually, and partly as results-based climate financing.

If any of the other types of supplementary measures fail to deliver in line with the direction, the gap can be compensated for by a larger proportion of verified emission reductions in other countries being counted as a supplementary measure instead of as climate financing. This opportunity brings valuable flexibility, increasing the likelihood of meeting the target level despite the risks of loss of units in the LULCF sector, for example due to disturbances in the form of storms, insect infestation and forest fires, or in bio-CCS due to unpredicted obstacles.

The volume of annually generated supplementary measures will be built up gradually from 2021 to the target level of 2030 as a minimum. The volume is likely to increase gradually rather than linearly, because many of the measures proposed in the action plan have stepped rather than linear effects.

Direction and possibility space up to 2045

The direction is for Sweden to achieve supplementary measures equivalent to at least 10.7 million tonnes of carbon dioxide per year by 2045. There are to be opportunities to increase that level after

2045 should this be needed. The volume of annually generated supplementary measures should be built up gradually from 2030 to the target level of 2045 as a minimum.

It is not appropriate to propose a detailed distribution between different types of supplementary measures in 2045 at this point because future trends in the cost of measures, alternative technologies and surrounding changes cannot be predicted. Locking in distribution based on the knowledge we have today therefore risks making the effect of supplementary measures as tools in climate policy more expensive and less effective. However, it is possible to produce an argument regarding the possibility space in 2045 with intervals for the different types of measure, given the direction up to 2030 and the content of the action plan (table 2).

Future control stations for the supplementary measures should be used to judge where in the possibility space it is desirable to end up and to steer development in that direction.

Table 2 Possibility space for different types of supplementary measures in 2045, given the direction up to 2030 and the action plan

Type of supplementary measure	Mtonnes CO_2 equiv./year
Increased carbon sink in forests and land	2.7[1]–?
Capture and storage of biogenic carbon dioxide (bio-CCS)	3–10
Other technologies for negative emissions	0–?
Verified emission reductions in other countries – negative emissions	0–very great[2]

[1] Refers to proposed supplementary measures in this strategy .

[2] In a world that is in transition in line with the temperature goal of the Paris Agreement, the prices of verified emission reductions in other countries are not judged to differ markedly compared with the costs of carrying out measures for negative emissions in Sweden .

Up to 2045, additional measures in the LULUCF sector may come about and be included as supplementary measures in addition to the areas in which the inquiry proposes instruments, e.g. additional measures in agriculture, measures on forest land and the use of biochar as a carbon sink.

The effect on the carbon sink due to measures on forest land, e.g. increased protection of forests or measures to increase growth, is hard to assess because the effect on the carbon sink depends on both how growth develops and on the market's demand for forest raw material, which affects the total harvesting level. Further analysis is

needed of how the additional contribution from different measures on forest land is to be calculated and counted if they are included as supplementary measures. One particular measure may negatively affect opportunities for implementing other measures locally, while at the same time the measures may also supplement each other in a broader sense.

Action plan to achieve the purpose of the strategy and the targets for supplementary measures

The action plan seeks to fulfil the purpose of the strategy and attain the proposed targets for supplementary measures through a detailed policy in line with the direction up to 2030. The proposed policy must also make it possible to achieve supplementary measures equivalent to 10.7 million tonnes of carbon dioxide per year in 2045 and thereafter.

The Government and the Parliament need to create sufficient incentives for supplementary measures to ensure that these are carried out to the desired extent. Under today's climate policy there are largely no incentives for measures that bring about increased removal of carbon dioxide from the atmosphere. Nor are there any instruments that give market actors incentives to contribute towards funding supplementary measures as an alternative to mitigating their own em1ss10ns.

The action plan is divided into five sections. The first section is about creating fundamental, general conditions for supplementary measures irrespective of the type of measure. This is followed, in order, by sections on increased carbon sinks and reduced emissions in the LULUCF sector, bio-CCS, other technologies for negative emissions and, to conclude, verified emission reductions in other countries. All sections comprise two parts -firstly a descriptive element about the most important prerequisites and assessments in the area, followed by proposed measures set out in bullet point form.

The action plan should be implemented as swiftly as possible.

Create the underlying conditions for developing supplementary measures

Underlying conditions and assessment

Supplementary measures often involve investment-intensive projects that will run for a long time. For such projects to come about, the field of measures needs to be characterised by stable terms and conditions and clear targets with the aim of reducing the project risks for actors involved. A politically backed quantitative target for supplementary measures by 2045 facilitates long-term planning and long-term action for potential project owners. One target on the path towards supplementary measures by 2030 helps to create trust that the long-term target will be realised.

Supplementary measures are a tool for attaining the climate goals in the climate policy framework. Targets set and determined for supplementary measures would mainly be aimed at attaining the climate goals and should thus be ranked equally with the climate goals.

The field of supplementary measures needs to be constantly evaluated and developed in the same way as other parts of climate policy. Work to evaluate and develop the supplementary measures should be carried out integrated with, and within the framework of, the system on climate policy applied in general, in line with the climate policy framework.

Calculation, reporting and verification of negative emissions need to be developed to enable Sweden and the EU to follow up the climate targets and report negative emissions of greenhouse gases in a transparent manner.

Sweden currently lacks a system for gathering data and calculating and reporting negative emissions to monitor national goals apart from existing reporting in the LULUCF sector. This should be addressed.

The international reporting guidelines and climate reporting tables need to be expanded to enable transparent reporting of negative emissions to the United Nations Framework Convention on Climate Change. For example, there are no guidelines for estimating how much carbon dioxide is bound in concrete, which means that there is no category for reporting such data in the climate reporting tables. Nor are today's reporting guidelines unequivocal.

Sweden has an opportunity to, and should, report data on negative emissions in the annual Swedish climate report to the EU and the United Nations Framework Convention on Climate Change, even if this information cannot be reported in the tables provided. That stated above regarding data collection and reporting also applies to carbon capture and utilisation (CCU).

The following measures should be taken:

Set targets for supplementary measures

- The Parliament should confirm the targets for supplementary measures proposed in, and which form the starting point for, this strategy. The targets should be ranked as subordinate to the national climate goals and therefore not constitute intermediate objectives within the environmental quality objective system.

Implement control stations for supplementary measures

- The climate policy action plans that the Government must submit to the Parliament every four years should set out how work on the supplementary measures is progressing. These control stations should also report whether any new type(s) of measure will be able to be counted as supplementary measures. Furthermore, the climate policy action plans should contain proposals for steering development in the field of supplementary measures in the desired direction.
- The Government should base the control stations for supplementary measures on data from relevant agencies. The Government should therefore task the Swedish Environmental Protection Agency with compiling such data in partnership with the Swedish Energy Agency, the Swedish Board of Agriculture and the Swedish Forest Agency, as part of the Environmental Protection Agency's existing mandate to produce data for the climate policy action plans.

- The climate reporting that the Government annually presents to the Parliament as an appendix to the budget bill should account for how work on the supplementary measures is progressing. The report should also include how all types of supplementary measures have been developed over time. The Government should task the Swedish Environmental Protection Agency with compiling data for the report in partnership with the agencies concerned.

Develop comprehensive and transparent reporting of supplementary measures

- The Swedish Environmental Protection Agency should be given the task to create a system for collecting data, and for calculating and reporting negative emissions for following up supplementary measures and the national climate goals. The system should encompass negative emissions of greenhouse gases, including capture, transport and storage of biogenic and atmospheric carbon dioxide, utilisation of biochar as a carbon sink, and CCU. Following up emissions and uptake in the LULUCF sector is already covered by existing systems but these need to be developed further to identify the effect of proposed measures in the sector. This part of the mandate should be carried out in consultation with the Swedish Board of Agriculture and the Swedish Forest Agency.
- Monitoring verified emission reductions through investments in other countries should be carried out in collaboration between the Swedish Energy Agency and the Swedish Environmental Protection Agency.
- Sweden should work to see that the EU creates transparent systems for reporting negative emissions of greenhouse gases. The reporting should distinguish between short-term and long-term or permanent carbon storage.
- The Swedish Environmental Protection Agency should be given the task to produce a proposal for how, when and in what form information about negative emissions is to be reported internationally and to the EU.

- Sweden should work to ensure that the international reporting guidelines with associated methodology guidelines and the tables used in climate reporting are developed within the process of the UN Framework Convention on Climate Change and the Paris Agreement such that negative emissions can be reported appropriately and transparently.

Increased carbon sink in forests and land

Underlying conditions for measures in the LULUCF sector

Underlying conditions for measures in the LULUCF sector vary to a very great extent between different countries. In Sweden, just under 70 percent of the land area comprises forest land (28 million hectares), which can be compared with the global average of just over 20 percent. This creates an opportunity for measures that may have a relatively major impact on the carbon sink in the forest, and on the forest as a resource for renewable raw materials. Compared with other countries of the same size, the amount of agricultural land in Sweden is relatively small (less than 3.5 million hectares of arable and grazing **land** according to Sweden's climate reporting). At the same time, there is also scope to create underlying conditions for higher carbon sequestration on such land through measures that may provide several additional values without affecting the domestic supply of food and other products.

The biogenic carbon flows found in the LULUCF sector differ considerably from fossil carbon flows in that they are volatile, can flow in both directions and are part of a circular flow. An uptake of carbon stored in biomass at one occasion may contribute emissions at a later stage when the carbon is released, e.g. when biomass is burned or naturally decomposed. The carbon flows in the sector are also highly influenced by natural factors, but human activity is of major significance on forested and agricultural land.

There are several potential measures in the LULUCF sector capable of increasing carbon sequestration and reducing greenhouse gas emissions respectively, but the effect of the measures on total greenhouse gas emissions - when in time the effect is achieved and how long-lasting it is - varies hugely due to the inherent inertia of the biological systems affected. This means that certain measures

should be put in place early in order to achieve a real effect on carbon sequestration and greenhouse gas emissions by 2030, 2040, 2045 and thereafter, while other measures can be carried out on an ongoing basis since they have a more direct impact on emissions. One difficulty is distinguishing which measures can also provide a long-lasting effect on the carbon stock into the future.

Measures to increase the carbon sink and reduce emissions in the LULUCF sector that produce additional values and meet other objectives, e.g. preserving biodiversity and reducing nutrient leaching, should be prioritised. Measures that contribute towards several values and objectives are generally judged to be more lasting than measures that solely help to increase the carbon sink, because in such cases there are more drivers capable of ensuring that the measures are retained.

The inquiry's proposed measures in the LULUCF sector

The proposed policies mainly concern measures on agricultural land and agricultural land taken out of production, where agricultural land means arable land and all forms of grazing. On agricultural land, the proposed policies have been judged to lead to an increase in the use of catch crops and cover crops on 400,000 hectares and agroforestry on 50,000 hectares. The proposed policies are also judged to lead to that 40,000 hectares of agricultural land taken out of production will be used for energy crop cultivation (e.g. Salix and Poplar) and that 100,000 hectares will be used for afforestation, while approximately 50,000 hectares of land in a later stage of natural overgrowth should be managed to promote growth. The assessment of the effects of the measures is based on that they are implemented gradually such that the full area is attained in 2030, apart from carbon-capture crops, where the full area will be attained in 2040.

The inquiry also proposes policies that create incentives so 100,000 hectares of forest land and 10,000 hectares of former agricultural land on peatland previously drained for farming and forestry, may be gradually re-wetted up to 2040. With all proposed measures, it is important that the underlying conditions for attaining other environmental objectives and the objectives of the National Food Strategy are not impeded but rather strengthened.

Provided that the measures above come about in the next ten years, they are judged in combination to be able to contribute to reducing emissions of just over one million tonnes of carbon dioxide equivalents in 2030 and almost three million tonnes of carbon dioxide equivalents in 2045. Re-wetting and catch crop initiatives are the most important for these estimated effects.

Land use affected

The estimate of available land area is based on land use trends in the agriculture sector today and how land use may change. The future demand for land to produce food and other products is hard to assess, however, and may change rapidly, which means that measures that block agricultural land for other use over a long period have been included to a lesser extent than would be possible if the entire available potential were to be included.

The measures in terms of catch crops, cover crops and agroforestry are judged to be able to be integrated with existing land use without it being affected to any major extent. Energy crop cultivation and afforestation mainly concern measures on land that has already been taken out of production but also involve land that may be taken out of production in the future to a certain extent. Re-wetting covers forest land where forestry is conducted to a limited extent, often former arable land. Land where farming is carried out or has recently been carried out may also be considered for re-wettmg.

Measures to the extent proposed by the inquiry cover less than 1 percent of the total land area used for forestry and slightly more than 14 percent of agricultural land. Regionally, however, the proportion may be greater as, for example, the majority (over 80 percent) of the approximately 230,000 hectares of agricultural land taken out of production in the past 20 years and that may be available for afforestation is found in Gotaland and Svealand. This is also where the most suitable land for re-wetting is found (forest land and agricultural land).

Instruments to increase the carbon sink

To put in place measures that lead to enhanced carbon sequestration on existing agricultural land and agricultural land no longer used for food or feed production, advice in agriculture and forestry needs to be stepped up at the same time as making sufficient funding available for these measures in upcoming Rural Development Programmes and in some cases through additional national financing programmes.

It is also important that existing funding for other measures that increase or maintain the carbon stocks in agricultural land, e.g. for ley that currently covers large areas, is retained in future programme periods of the Rural Development Programme. In the long term, measures on agricultural land that is proposed to be counted as supplementary measures can be broadened such that other crops that are beneficial for carbon sequestration are also included. Adding biochar for long-term carbon sequestration with simultaneous soil improvement could also be included.

Outreach activity, effective advice and increased opportunities for financial support are needed to initiate extensive re-wetting of drained peatland. Funding that currently exists in the Rural Development Programme and in the wetlands initiative for creating or restoring wetlands must be supplemented.

In general, the measures proposed to increase carbon sequestration and reduce emissions in the LULUCF sector are cost-effective because they usually result in several other environmental benefits in addition to increased carbon sequestration and lower greenhouse gas emissions. For example, catch crops produce a reduction in nutrient leaching, while re-wetting benefits biodiversity. The underlying conditions for measures, and thus also the costs, vary considerably within the sector, and some measures, e.g. afforestation, may also bring an income for the landowner. Examples of costs of measures include the cost of re-wetting, which comes in at between SEK 100 and SEK 700 per tonne of carbon dioxide equivalent depending on the land concerned, and the cost of catch crops and cover crops, where the cost comes in at between SEK 200 and SEK 700 per tonne of carbon dioxide. No simultaneous benefits have been valued in this case.

Other measures to strengt;hen and preserve the carbon sink

There is also potential to increase the carbon sink on forest land through measures that increase growth and forest management measures that also prioritise other environmental values and by exempting larger areas of productive forest land from timber production to attain other environmental objectives such as the environmental quality objective *Sustainable forests.*

In a national perspective, the total effect on the forest's carbon balance from growth-increasing measures and measures that increase the protection of forests will mainly be determined by how harvesting develops in relation to total growth. The harvesting level in turn depends on demand for Swedish forest raw material. Increased demand for forest raw material in Sweden may also lead to more harvesting in another country if this demand cannot be met with Swedish forest raw material.

Another opportunity to increase carbon sequestration is to increase production and use of long-lived wood products, e.g. by increasing the use of wood in buildings. Increased use of long-lived wood products also leads to reduced fossil emissions in that they can replace more fossil-intensive alternatives.

Permanently changing land use from forest land and arable land to settlement can lead to major emissions of greenhouse gases and lost carbon sinks. The effect on emissions and carbon sinks can be reduced either by development being steered to land where the impact on the greenhouse balance is lower or through limiting the area developed each year.

There is also a great need to safeguard the existing carbon stocks already sequestered in biomass and in land, in the light of ongoing climate change bringing increasing risks of damage of various types, e.g. storms, drought, insect infestation, root rot and fires. There is a need to increase knowledge of different types of damage to boost preparedness in the event of outbreaks.

Besides the climate-related damage ref erred to, there is also a major need to reduce the damage from grazing wild animals in the forest. This damage has a negative impact on carbon sequestration, timber production and biodiversity, and also leads to maJor economic losses in forestry.

Knowledge is good but can be improved

Knowledge about the proposed measures and of the impact of these measures on the greenhouse gas balance is already good. For several of the measures, however, it is essential that preparatory work is conducted by the agencies concerned to identify which measures should be carried out on which land so as not to negatively impact on other environmental objectives. For example, this involves developing recommendations on where it is appropriate to increase bushes and trees on agricultural land, and on where afforestation is appropriate and which varieties of tree should be used.

Several of the proposed measures already exist today in the portion of agriculture eligible for financial support. In conjunction with producing the new Rural Development Programme, however, compensation for these measures needs to be reviewed at the same time as developing support schemes for measures that are not currently included. Forms of support for measures that do not naturally fall within the Rural Development Programme, or where the support is not sufficient today, should also be developed.

The Government should therefore commission several agencies to contribute expertise and further develop work in their respective areas.

An important element in terms of supplementary measures in general and supplementary measures in the LULUCF sector in particular is developing reporting and monitoring systems so as to enable evaluation of the impact of proposed measures and instruments. Such a system should complement existing systems for reporting greenhouse gas emissions to the EU and the UN Framework Convention on Climate Change.

High quality requirements for the contribution from the LULUCF sector

Increased removal or reduced emissions from supplementary measures in the LULUCF sector must be calculated and reported under Regulation 2018/841 of the European Parliament and the Council (the LULUCF Regulation).

It should be possible to count supplementary measures in the LULUCF sector towards the national climate goals as the additional

effect of each individual measure proposed here, compared with the situation had the measure not been carried out, provided that the additional effect on removal and emissions can be estimated in a reliable manner. This restriction means that only the effect of supplementary measures is counted towards the national target, not the entire accounting effect possible under the EU's LULUCF regulation.

This is in line with the intentions of the Cross-Party Committee on Environmental Objectives (SOU 2016:47) to enable contributions from increased carbon sinks calculated in line with internationally approved rules, e.g. that only the effect of additional measures in the area may be counted.

However, it would be irrational for Sweden to report potential debits in the EU while contributions from supplementary measures are used to achieve the national objectives. Potential debits from the parts of the sector that are not affected by the supplementary measures must first be balanced. The contribution from supplementary measures in the LULUCF sector can thus be limited by the LULUCF Regulation's requirement that the LULUCF sector must not have any net emissions.

To attain the goal of the LULUCF Regulation, all accounted flows in the respective activity are included, both changes due to the supplementary measures proposed here and changes carried out for other reasons.

The contribution from the proposed supplementary measures in the LULUCF sector is thus affected by the outcome for the whole LULUCF sector in relation to the goal of the LULUCF Regulation 2021-2030. The same approach should apply for 2040 and 2045 relative to the potential rules which will apply within the EU at that ume.

In some cases, it may be difficult to distinguish the effect of proposed measures from other factors that also affect changes in emissions and removals. This mainly concerns measures that are already being carried out to a certain extent. One solution in such cases might be to calculate the detected effect of relative emissions or removal compared to emissions or removal the year the measure being introduced. In some cases, changes in the carbon sink arising for reasons other than the inquiry's proposals can then be included. Considering the often-low use of the proposed measures today, and the good opportunities for transparent monitoring, the view of the inquiry is

that this contribution to an increased carbon sink or emission mitigation due to factors other than the inquiry's proposed instruments is minor and does not reduce the importance of the measures for the carbon balance.

The following measures should be taken:

Create conditions for financing climate measures

- Sweden should continue to work to ensure that climate measures that increase carbon sequestration and mitigate greenhouse gas emissions can also be supported in the future and afforded greater weight within the remit of the EU's Common Agricultural Policy.

Produce advice and support for proposed supplementary measures

- The Swedish Board of Agriculture should intensify existing advice, including the support that can be applied for, in order to put in place additional measures that lead to enhanced carbon sequestration on existing agricultural land and agricultural land no longer being used for food and feed production. For this, the Swedish Board of Agriculture will be allocated an equivalent of SEK 10 million per year in 2021-2030.
- The Swedish Board of Agriculture should be given the task to review and investigate the potential design of existing and new measures to benefit carbon sequestration on agricultural land in the Rural Development Programme. This mandate should also include reviewing the levels of compensation. Measures that increase the opportunity to attain several environmental objectives and that strengthen additional values in the agricultural landscape should be prioritised.
- The Swedish Board of Agriculture should, in consultation with the Swedish Environmental Protection Agency, be given the task to draw up criteria for the type of land suitable for agroforestry and the species of tree most suitable for the measures without impeding the achievement of other environmental objectives and the objectives of the National Food Strategy.

- The Swedish Forest Agency, in consultation with the Swedish Board of Agriculture, the county administrative boards and the Swedish Environmental Protection Agency, should be given the task to draw up criteria for which former agricultural land is suitable for afforestation and which the species of tree are most suitable for the measures without impeding achievement of other environmental objectives and the objectives of the National Food Strategy.
- The Swedish Forest Agency and the county administrative boards, in consultation with the Swedish Board of Agriculture and the Swedish Environmental Protection Agency, should be given the task to develop criteria to assess the suitability and prioritisation of different types of re-wetting projects. This is in line with the proposals for re-wetting drained peatland laid out in the in-depth evaluation of the environmental objectives in 2019. The focus should be on producing a basis for identifying appropriate land for re-wetting to steer the measures to the land that provides the most climate benefit and the most benefit for other goals, e.g. biodiversity, at the lowest cost, and for the landowners concerned to be offered free advice and financial compensation for implementation, maintenance if required, and lost land value. The funding that currently exists for creating or restoring wetlands in the Rural Development Programme and in the wetlands initiative must be increased by an average of SEK 125 million per year. The compensation should be placed within the remit of existing or planned measures and administrative systems.
- The Swedish Forest Agency should be given the task to review potential forms of support, including the size of the compensation, for afforestation, i.e. planting trees on agricultural land taken out of production, and for optimised management of natural regenerated forest on former agricultural land.

Invest in research and development to increase the cost-efficiency of measures

- An investment in R&D on the effects of re-wetting on greenhouse gas emissions should be carried out, whereby the Swedish Forest Agency should be granted SEK 9 million in 2021-2023 to allocate through targeted calls for proposals.
- Research is needed on how different climate-induced damages to forest can be limited. An investment in research and development (R&D) on how forest damage can be limited should be carried out, whereby the Swedish Forest Agency should be granted a total of SEK 6 million for the years 2021-2023 to allocate through targeted calls for proposals.
- The Swedish Environmental Protection Agency, in consultation with the Swedish Board of Agriculture, the Swedish Forest Agency and the county administrative boards, should be given the task to review how the effect on the greenhouse gas balance from exploitation of land is to be calculated and develop proposals for how this can be mitigated.

Other measures to strengt;hen and preserve the carbon sink

- Under its terms of reference, the Forest Inquiry 2019 (M 2019:02) is to propose the measures needed to be able to comply with international commitments on biodiversity and climate. The proposals must take into account existing knowledge and needs analyses on protecting forests and increased demand for forest raw material. Once the need for measures for preserving biodiversity has been established, the measures that also contribute towards an increased carbon sink should be realised as soon as possible.
- The Swedish Forest Agency should be given higher appropriations for advisory activities on sustainable growth-increasing measures, measures for enhanced nature conservation on productive forest land, and damage prevention together with climate-friendly measures aimed at safeguarding the carbon sink and timber production. A specially earmarked budget of SEK 10 million per year for 2021-2030 is proposed for this.

- In the budget for 2020, the Government allocates the Swedish Forest Agency funding for 2020-2022 for managing forest damage and to support work to combat spruce bark beetle infestations. After 2022, the Swedish Forest Agency should also be granted higher funding to monitor and combat existing and new pests.

Capture and storage of biogenic carbon dioxide {bio-CCS)

Underlying conditions and assessment

Sweden is well-placed for bio-CCS. Today there are about seventy facilities in Sweden whose emissions of biogenic carbon dioxide alone exceed 100,000 tonnes. The combined emissions of biogenic carbon dioxide from these exceed 30 million tonnes. The greatest biogenic point emission sources and the greatest combined biogenic carbon dioxide emissions are found in the pulp and paper industry. Electricity and district heating production, including waste incineration, also accounts for significant point emissions of biogenic carbon dioxide. Emissions from both these industries primarily derive from incineration of waste products from forestry and pulp manufacture and biogenic waste. There are also a few industrial facilities outside the pulp and paper industry with major emissions of biogenic carbon dioxide. The realisable potential for bio-CCS in Sweden amounts to at least 10 million tonnes of biogenic carbon dioxide per year from a 2045 perspective. Bio-CCS is well suited to be a cost-effective mea- sure to attain the long-term climate goal of net zero emissions by 2045.

Biogenic carbon dioxide ought to be able to be captured at a cost of SEK 400 to 600 per tonne in facilities with favourable conditions for bio-CCS, mainly in the pulp and paper industry and combined heat and power (CHP) production. The cost of transporting carbon dioxide from Swedish plants to a storage site is estimated at between SEK 150 and SEK 300 per tonne. Storage and monitoring the storage site should be feasible at a cost of SEK 100 to SEK 200 per tonne of carbon dioxide.

From a geological perspective, there is storage space for carbon dioxide from Swedish CCS (including bio-CCS) for the foreseeable future, in Sweden or nearby. Carbon dioxide storage in Norway or

another North Sea country is a fully realistic alternative for Swedish CCS projects in a technical and financial sense.

It is likely that there is significant potential for carbon dioxide storage in Sweden, but knowledge of potential domestic storage sites is poor. Developing a storage site for carbon dioxide in Sweden would take a very long time, partly for that reason. For storing carbon dioxide in Sweden to be an option in the future, we need to have better knowledge about how storage sites can be identified. However, at the moment Sweden should not prioritise establishing a storage site on Swedish territory.

For bio-CCS to be able to take place at Swedish emission sources in the immediate future, it needs to be possible to store carbon dioxide outside Sweden's borders. We therefore need to facilitate carbon dioxide storage abroad. The legal obstacles that currently exist to cross-border transport and storage of carbon dioxide should be lifted. Swedish agencies should also investigate with agencies in potential storage countries the need for bilateral agreements and what these might involve, to ease transport to and storage in another country.

Transport by sea is the only realistic alternative for transporting carbon dioxide to a storage site when conducting CCS including bio-CCS in Sweden for the foreseeable future. The distance to a potential storage site affects the cost scenario but not in a decisive way; as long as a plant is located on the Swedish coast, or on Lake Malaren or Lake Vanern, it could be a candidate for CCS, including bio-CCS. In the current situation, the State should refrain from by itself carrying out an investment in transport infrastructure for carbon dioxide.

Swedish bio-CCS is judged to have very limited consequences for biodiversity at the quantities relevant to reach the goal of net zero emissions, even if the removal of biomass increases somewhat compared with today's situation. When producing instruments for bio-CCS at European level, it must be ensured that no incentives are given for bio-CCS that risk leading to unsustainable land use. At the same time, it is important not to create obstacles to sustainable biomass use.

Although experience of CCS including bio-CCS is limited in practice, the knowledge situation is relatively good, which means that CCS, including bio-CCS, can be carried out in Sweden with no need to await the results of ongoing or planned research initiatives. In order to further improve the knowledge situation, research can be

directed towards systemic questions linked to CCS including bio-CCS, e.g. instruments, acceptance, value chain integration and consequences for biomass use and the energy system in the event of extensive application of CCS including bio-CCS in Sweden. Basic research and applied research in partnership with Swedish industry to lower the cost and reduce the energy-intensiveness of CCS including bio-CCS are also highly important.

Today there is a lack of national or EU-wide incentives for full-scale bio-CCS. An incentive structure needs to be introduced capable of promoting technological development and demonstration activities, at the same time as creating long-term economic conditions for full-scale bio-CCS projects. Governance to develop complicated and capital-intensive value chains such as bio-CCS needs to be sustainable, predictable and long-term.

Bio-CCS results in net removal of carbon dioxide from the atmosphere, which is a benefit that can be attributed an economic value for society in general but does not result in any benefit specifically for operators that apply bio-CCS. Emissions of fossil carbon, on the other hand, cause damage to society but are an unwanted side-effect of production that is a benefit to the operator. When designing instruments for bio-CCS, attention needs to be paid to the major difference between these two cases in principle. While it is reasonable that an emitter pays for the damage the emissions cause, it is reasonable that a business that creates negative emissions through bio-CCS receives payment for the benefit generated.

In parallel with Sweden developing national instruments for the introduction of bio-CCS, Sweden needs to work to ensure that EU-wide instruments come into being. Sweden should be sensitive to other Member States and the European Commission and act pragmatically and strategically based on Swedish interests when instruments are being designed at EU level.

No agency has currently been appointed to take overarching responsibility for CCS issues in Sweden. Nor has any agency been designated responsibility for coordinating the work of agencies on CCS including bio-CCS. This is a deficiency that should be tackled. Because CCS including bio-CCS is a technology chain that has not yet been established or become well-known in Sweden, it is also important to improve opportunities for effective information sharing between agencies, private actors, academia and society.

The following measures should be taken:

Create underlying conditions for transport and storage of carbon dioxide

- Sweden should drive the question of whether all transport of carbon dioxide for storage is to be included in the EU's Emissions Trading System. At the same time, Sweden should apply to opt in all transport of carbon dioxide for storage in the Emissions Trading System for its own part. The system should furthermore include an approved method of monitoring the carbon during transport, and an opportunity to separate biogenic and fossil carbon in transport and storage using the mass balance method, without everything being considered to be fossil carbon.
- Sweden should ratify the amendment in the London Protocol that means that under certain circumstances, transport of carbon dioxide for geological storage with another party to the protocol is exempt from the export ban prescribed by the protocol. At the same time, Sweden should work to hasten other parties' ratification of the amendment so that it can enter into force. When Sweden has entered into a bilateral agreement on transport and storage in another country, Sweden should take the action required such that the amendment to the London Protocol can be applied provisionally until it enters into force.
- Sweden should take the initiative to urge the parties to the Helsinki Convention to amend the convention or adopt a resolution on the interpretation of the convention which permits geological storage into the seabed, such that the CCS Directive becomes compatible with the convention.
- Sweden should work to ensure that the decision on the moratorium on geoengineering made at the Tenth meeting of the Conference of the Parties to the Convention on Biological Diversity in Nagoya is amended such that bio-CCS and other non-fossil CCS are not covered by the moratorium.
- Sweden should propose that an addition be made to the definition of transport of carbon dioxide in Commission Regulation (EU) No. 651/2014 of 17 June 2014 declaring certain categories of aid compatible with the internal market in application of Articles 107 and 108 of the Treaty (Block Exemption Regulation) and in the

guidelines for state aid to environmental protection and energy such that state aid may also be granted for transport of carbon dioxide for storage other than through pipelines. Furthermore, Sweden should propose that the opportunities to provide state aid in line with the General Block Exemption Regulation and the guidelines for state aid for capture and storage of carbon dioxide be extended.

- The Geological Survey of Sweden (SGU) should be given the task to identify what decision-making data for a Swedish storage site for carbon dioxide needs to contain and how such data could be produced. This includes setting out what surveys, amounts of data and modelling are needed and estimating what interventions involve in the form of resources and time.
- The Swedish Energy Agency should be given the task to work with Norwegian agencies to specify what a bilateral inter-governmental agreement on transport to and storage of carbon dioxide in Norway should contain, including what is needed to fulfil the requirements under the London Protocol for exports of carbon dioxide. The Swedish Energy Agency should complete this task in consultation with the Swedish Environmental Protection Agency and SGU and in dialogue with industry. The mandate should also include establishing whether there is interest in the Netherlands and the UK in carrying out equivalent analyses together with the aforementioned Swedish agencies.

Continued support for technological development and demonstrations in the field of bio-CCS

- The already existing investment aid instrument for negative emissions should continue to encourage the development of technology and demonstrations in bio-CCS. It is likely that targeted support for technology development and demonstrations in bio-CCS will have to remain in place in some form up to at least 2030, even if the interventions that need support may change in nature by then. The future size of the appropriation should be determined taking into account experiences from calls for proposals and initiatives carried out.

Apply reverse auctioning to support full-scale bio-CCS

- The Swedish Energy Agency should be given the task to run what are termed reverse auctions of negative carbon dioxide emissions through bio-CCS to support full-scale bio-CCS.
- The reverse auctions are to result in differentiated guarantee prices for stored biogenic carbon dioxide for the actors that win auctions (normally the lowest bidder). The compensation paid out should be the difference between the agreed guarantee price and the value of any EU funding and national funding to promote bio-CCS that an actor receives. To have funds paid out, it should be required that the project owner has applied for relevant support from the EU.
- Payments could partly be made in advance, which can be seen as a form of investment aid. Procurement should be limited in terms of maximum total cost and maximum cost per tonne of geologically stored carbon dioxide. The binding period should be 10 to 20 years to enable the parties involved to conduct long-term planning.
- The total amount of stored biogenic carbon dioxide procured through reverse auctions should at an initial stage be limited to a maximum of 2 million tonnes per year (an estimated 3-5 plants). Once bio-CCS has reached this quantity and level of maturity in Sweden, experiences of reverse auctions should be evaluated as part of a review of the forms of continued governance of bio-CCS.

Other governance of bio-CCS

- In the long term, the economic instruments proposed above could also be opened up to other technologies for negative greenhouse gas emissions that entail permanent storage with the aim of making governance more cost-effective. No other such technology, however, is currently judged to be sufficiently mature and have potential in Sweden.

- Current taxation rules mean that it is often beneficial to use steam instead of electricity for carbon dioxide capture. This can lead to plants with their own electricity production that apply CCS/bio-CCS switching to steam turbines with lower maximum output than today, which can lead to a deterioration in the power balance on cold winter days. The Government should review whether there are grounds or opportunity to make self-generated electricity used to capture carbon dioxide tax exempt, or to take other steps to reduce the risk of a poorer power balance as a result of switching turbines.
- It should not be possible for carbon dioxide storage that contributes towards greater extraction of oil or natural gas though what is termed enhanced hydrocarbon recovery (EHR) to be counted as a supplementary measure for attaining the Swedish climate goals, irrespective of the origin of the carbon dioxide. Only projects within CCS including bio-CCS where carbon dioxide storage takes place permanently and without contributing to EHR, should be eligible for state aid.

Work for instruments to promote bio-CCS at EU level

- Sweden should work to ensure that the EU develops a common long-term instrument to promote bio-CCS. A separate technology-neutral instrument with EU joint financing to achieve permanent negative greenhouse gas emissions may be the most accessible route in the immediate future, because the alternative does not demand renegotiation of the EU's main legal provisions in the climate field. Another option is to change the EU's Emissions Trading System (ETS) such that bio-CCS gives rise to emission credits that may be used within the ETS. However, it is not desirable for this to lead to reduced pressure away from fossil fuel use in the ETS. The change therefore needs to be carried out in combination with a measure that adjusts the number of emission allowances in the ETS.

Clarify and develop the distribution of responsibilities within the State

- The Swedish Energy Agency should be made responsible for coordinating issues concerning CCS including bio-CCS by an addition to the agency's instructions that means that the agency coordinates work on CCS issues at the agencies concerned and is made responsible for CCS issues that do not fall within the remit of any other agency. This responsibility for coordination does not mean that the Swedish Energy Agency takes over any area of responsibility from another agency or is superior to another agency.
- The Swedish Energy Agency's instructions should be changed such that the agency is given the task to work to facilitate the well-planned, resource-efficient and environmentally sustainable expansion of CCS including bio-CCS in Sweden. The agency should also be given the task to assist actors in CCS or bio-CCS with information and guidance on e.g. legal questions and aid that can be sought nationally or from the EU.
- The Government should commission the Swedish Energy Agency to set up a national centre for CCS including bio-CCS as part of the agency. The national centre should be tasked with promoting the appropriate application of CCS including bio-CCS in Sweden, building networks for increased knowledge exchange, providing a platform for dialogue and collaboration between agencies, actors and stakeholders, enabling coordinated action from the actors' side and contributing to increasing understanding of CCS including bio-CCS in society.
- The national centre for CCS including bio-CCS should be tasked with encouraging interested operators to carry out site-specific studies of the prerequisites for bio-CCS. The studies should, for example, be able to provide details of the approximate cost of capturing different volumes of carbon dioxide, the potential transport solutions that exist and what they might cost. They should be able to be financed by the already existing investment aid instrument for negative emissions. It should be possible for the operators concerned to apply for aid and have it paid out to them.

- The Swedish Energy Agency should be given the task to investigate how coordination of different permit and inspection issues concerning CCS including bio-CCS could facilitate capture, transport and storage of carbon dioxide from Swedish emission sources. This includes the issuing of permits under the ETS. The investigation should include producing a plan for guidance with support and advice to operators and permit and inspection authorities on permit and inspection issues regarding CCS including bio-CCS, such that the permit and inspection procedures become as effective as possible and, where possible, work to ensure that the procedures run in parallel. Furthermore, the task should cover whether a particular agency should have coordinating responsibility for permission and inspection of CCS including bio-CCS facilities and which agency should have such responsibility in such cases.

Other technological measures for negative emissions of greenhouse gases

Underlying conditions and assessment

The realisable potential of other negative emission technologies is uncertain, as several of the alternative technologies are under development and largely untested. It is therefore difficult to judge which technological measures may be relevant for carbon dioxide removal in Sweden before the middle of this century. Several of the technologies are judged to result in long-term sequestration of carbon dioxide.

The inquiry has studied several different technologies: biochar as a carbon sink, binding carbon dioxide in crushed concrete, binding carbon dioxide in slag from waste incineration, DACCS, enhanced weathering, fertilising the oceans and CCU.

The inquiry judges that the use of biochar as a method for long-term carbon sequestration and simultaneous soil improvement is the technology among those studied that has the greatest realisable potential to contribute to negative emissions in Sweden in the middle of this century, bearing in mind, however, that the information available may be insufficient. In Sweden small-scale production and use of biochar is already in progress. Biochar is predominantly used

as a soil conditioner in parks and when planting trees. Carbon sinks from the use of biochar are not, however, included in Sweden's climate reporting.

Biochar production plants have previously received investment funding from the climate investment aid programme Klimatklivet, and such aid may also be provided during the current programme period. Compensation may be paid both for substitution of fossil fuels and for carbon sequestration. It is also possible to receive investment aid through the Rural Development Programme for production facilities for biochar that replaces fossil fuels. In the long term, aid could be given to the use of biochar for carbon sequestration and soil improvement within the remit of the Rural Development Programme.

Quality requirements should be set when granting state aid to biochar projects, including that the composition of the biochar must be stable for aid to be able to be granted for higher carbon sequestration. The anticipated carbon sink must be calculated on scientific grounds. Furthermore, a requirement should be set whereby only sustainably produced raw materials may be used in production and whereby the area of use is such as to contribute to a carbon sink, e.g. use in soil, arable land, animal feed and subsequent spreading as fertiliser on arable land, animal bedding and subsequent spreading on arable land and mixing in construction material.

Additional initiatives in applied research, tests and evaluation of Swedish biochar projects are needed to determine the extent to which the use of biochar as a carbon sink can contribute towards the supplementary measures.

The potential for carbon capture and utilisation (CCU) is uncertain. Only a fraction of today's emissions of fossil and biogenic carbon dioxide is used, and largely all carbon dioxide caused by humans is released into the atmosphere. CCU has the potential to partly replace fossil fuels and fossil-based material with products based on carbon-dioxide, and partly to create a market basis to improve carbon dioxide capture technology. For carbon dioxide use to be able to be viewed as negative emissions, the carbon dioxide must be biogenic (bio-CCU) or atmospheric, and be stored for the long term. Currently, however, there is no established definition in climate reporting of what long-term carbon sequestration means. In most cases, the captured carbon dioxide reaches the atmosphere relatively

quickly and CCU is thus viewed as circular use of carbon dioxide to delay emissions. However, there may be some potential in long-term carbon storage in construction material, but more research is needed in this area.

There are advantages of long-term, technology-neutral financial incentives for negative emissions with similar features and permanence, as it is unclear which technologies are capable of contributing towards cost-effective measures long term. In the long term, too, it is likely that there will be new technological solutions that may need to be the object of specific development-support. The voluntary climate compensation market can contribute towards developing new negative emissions technologies.

The following measures should be taken:

- It should continue to be possible to receive investment aid for biochar facilities through Klimatklivet and the Rural Development Programme.
- It should be investigated whether, in the long term, aid could be provided for the use of biochar for carbon sequestration and soil improvement within the remit of the Rural Development Programme. If such aid is introduced, the necessity of and the forms of investment aid for biochar facilities should be reviewed.

Verified emission reduction by investment in other countries

Underlying conditions and assessment

The rulebook of the Paris Agreement on voluntary cooperative approaches and transfer of mitigation outcomes between countries have not yet been finally negotiated, and it will take time before the forms of such cooperation have been developed in detail. The Paris Agreement means a major change compared with the situation under the Kyoto Protocol, in that all parties have now adopted their own nationally determined contributions, (NDCs) reflecting the country's or the region's contribution to meeting the goal of the Agreement. The nationally determined contributions, however, are currently overall insufficient, and the Paris Agreement presupposes that

the NDCs will gradually increase in ambition. The gaps that must be bridged to reach the emission levels demanded by the global 2 °C and above all 1.5 °C scenarios are very large.

It is important that the mitigation of greenhouse gases that Sweden contributes towards, in bilateral agreements or jointly with several other countries and international organisations, are performed in such a way that they are additional, contribute to sustainable development and can help to raise the climate ambitions of the host country, too. Such effects can be attained through choice of country, programme and type of measure, the conditions set in relation to the host country's own policies and by the number of units resulting from the measures carried out being calculated in relation to a strict reference scenario.

It will not be easy to set requirements on improvements in all the above areas in every case of international cooperation on mitigation of greenhouse gases, but the ambition should be to achieve results in as many areas as possible.

The agreements entered into with the focus to increase the level of ambition as set out above should simultaneously strive at being as cost-effective as possible.

At the start of the 2020s, the demand for units resulting from mitigation outcomes in other countries under the Paris Agreement is judged to be relatively limited overall, with few explicit investor countries and host countries. International air travel is judged to account for the greatest demand for units and thus also to set the price in the market for offset projects, at least initially. Prices are judged to be relatively low, but still higher than when at their height during the first commitment period under the Kyoto Agreement. The situation may change if, for example, the EU countries were to jointly choose to also include international greenhouse gas mitigation outcomes as part of a more stringent EU target for 2030. Were this to be the case, the prices of measures in other countries would nse.

One of the starting points for the Swedish climate framework is that it is being carried out in a world that is in transition in a manner in line with the temperature goal of the Paris Agreement. The costs will rise in deep greenhouse gas mitigation scenarios based on the 1.5 °C goal being reached and would become harmonised across the world in scenario developments with a cost-optimised approach. The

costs converge by 2050 in some scenarios, while in other modelling they converge as early as by 2030.

The prices of units from mitigation outcomes in other countries, in a world in transition, are estimated to come in at about the same level or higher than the estimated marginal costs, at that time, of equivalent supplementary measures in Sweden, e.g. in the form of bio-CCS and carbon sequestration in agricultural land.

At the same time, it cannot be ruled out that new potential measures may be developed in other countries and that these measures will be more cost-effective than supplementary measures in Sweden, e.g. new measures or technologies for negative emissions in the form of DACCS or biochar.

In the 2010s, Sweden has invested in a relatively large volume of emission units mainly from CDM (Clean Development Mechanism) projects under the Kyoto Protocol in order to contribute towards Sweden's national targets for 2020. The units have gradually been cancelled and subsequently partly reported as results-based climate financing of emission mitigation, as part of Sweden's climate financing undertaking under the United Nations Framework Convention on Climate Change.

No major coordination is judged to have taken place between these initiatives and other financing initiatives in nearby areas, mainly financing using aid funding of measures to reduce greenhouse gas emissions in least developed countries. Sweden's current undertaking on climate financing amounts in total to approximately SEK 6 billion per year from 2020 onwards - an undertaking that may increase in scope towards the mid-2020s, if not earlier. A smaller proportion of these initiatives is estimated to go to measures that lower emissions, mainly as a side-effect, and a larger proportion to climate adaptation measures, also as a side-effect of aid projects with several simultaneous benefits. The proportion of results-based climate financeing, where the emission effect per krona input is calculated, is low. Most of the projects are carried out in least developed countries.

If, within the remit of its climate financing undertaking, Sweden also chooses in the future to contribute to emission mitigation programmes in middle income countries with relatively high and growing emissions, Sweden has an opportunity to contribute towards greater dissemination effects of measures in regions where, globally speaking, it is particularly urgent to rapidly turn the current emis-

sion trend around. Also linking the initiatives to Article 6 of the Paris Agreement will enable the actual climate effects of the mitigation measures to be calculated in line with internationally agreed principles. It is looking more likely that results-based financing will be attained, which in turn means that opportunities to attain a greater effect per krona invested will improve compared with the measures being financed by other means.

The programmes proposed by the inquiry will partly seek to contribute towards the supplementary measures to the extent that may be needed, but will also seek to increase Sweden's climate financing of emission mitigation measures, mainly in middle income countries.

Through the proposed programme, this part of Sweden's contribution to climate financing will be results based and carried out mainly in countries with high and growing emissions.

The following measures should be taken:

Direction up to 2030

- Sweden should set up a programme for international mitigation of greenhouse gas emissions under Article 6 of the Paris Agreement, to be implemented in the 2020s. The new programme needs to result in units from emission mitigation outcomes equivalent to at least 20 million tonnes of carbon dioxide equivalents in the 2020s, to work in the manner the inquiry proposes. To attain such a result, a budget equivalent to an average of SEK 400 million a year needs to be allocated during the 2020s. It is proposed that the programme contribute to:

  the proportion of climate funding of measures to mitigate emissions increasing, becoming results-based and also covering middle income countries to a greater extent.

  achieving the targets of the supplementary measures.

- The initiatives should provide incentives to raise the level of ambition in line with the temperature goal of the Paris Agreement, have high environmental integrity and contribute towards sustainable development in the host countries as laid down in Article 6 (1) of the Paris Agreement. It is proposed that the pro-

gramme be designed such that it helps host countries to increase the level of ambition in their NDCs. This focus on raising ambitions should influence the choice of host countries in which greenhouse gas mitigation measures are implemented, which types of programme or measure are selected for funding, the conditions set in relation to the host country's own policies and by the number of resulting units from the measures carried out being calculated in relation to a strict reference scenario.

- It is assumed that the host countries for the initiatives will adjust their emission reporting so that no mitigation of emissions is counted twice. This adjustment needs to be made whether Sweden subsequently uses the units acquired as part of the country's climate financing or as part of the supplementary measures.
- The Swedish Energy Agency, the Swedish Environmental Protection Agency and the Swedish International Development Agency (Sida) should jointly be given the task to provide proposals for how climate financing initiatives via emission mitigation and international initiatives for supplementary measures can best be coordinated, partly in the light of the inquiry's proposal for a new programme for international initiatives in middle income countries. The Swedish Energy Agency should be given the task to coordinate this mandate.

Direction of international initiatives up to 2045 and beyond

- The international initiatives to contribute towards further emission mitigation also need to continue after 2030. Initiatives for further emission mitigation will be key, while initiatives to achieve negative emissions need to successively increase in scope.
- Where global ambitions are raised in line with the temperature goal of the Paris Agreement, i.e. the development presumed by the Swedish climate framework, the long-term initiatives to mitigate emissions in other countries to achieve the climate target for 2045 need to mainly be targeted towards measures for negative emissions with high permanence.

- Continued initiatives for emission mitigation in other countries, alongside measures for negative emissions, should be transferred to the area of results-based climate financing and not be counted as supplementary measures in the Swedish climate framework when Sweden is to attain net zero emissions by 2045 at the latest and net negative emissions thereafter.