E4S
Enterprise for Society

UNIL | Université de Lausanne
HEC Lausanne

IMD
REAL LEARNING. REAL IMPACT

EPFL

Swiss Negative Emissions Fund - paying for Net Zero

E4S White Paper
2022 / 02

Swiss Negative Emissions Fund - paying for Net Zero

E4S White Paper

2022 / 02

Authors: Sascha Nick (EPFL) & Philippe Thalmann (EPFL)

Many experts from the "Evidence-Base Environmental Policy Advice" platform provided input and reviewed preliminary drafts of the report. Their comments and suggestions were of great value.

In order to find solutions to society's biggest challenges, E4S encourages discussions and diversity of opinions on topics of crucial importance. The views and opinions expressed in documents published by E4S are those of their authors and do not necessarily reflect the official policy or position of E4S.

Enterprise for Society (E4S) is a joint venture of the University of Lausanne through its Faculty of Business and Economics (UNIL-HEC), the Institute for Management Development (IMD) and the Ecole polytechnique fédérale de Lausanne (EPFL), under the stewardship of its College of Management of Technology, with the mission of spearheading the transition towards a more resilient, sustainable and inclusive economy. E4S is committed to training the next generation of leaders, inspiring economic and social transformation, and promoting change by strengthening start-ups and boosting innovation.

The project was conducted in the context of a partnership with Fondation Leenaards.

Table of contents

1. Executive summary

In this paper, we propose setting up a fund to finance the removal of all Swiss territorial GHG (greenhouse gas) emissions from 2030. The fund will accelerate decarbonization and help reach annual net zero emissions around 2040, and then progressively remove all past emissions emitted from 2030. The fund will be entirely funded by emitters, based on the "polluter pays" principle, with no taxpayer money involved. The background information and analysis can be found in our December 2021 E4S White Paper ***"Carbon removal, net zero, and implications for Switzerland"***.

The proposed **Swiss Negative Emissions Fund**, fully described in ***section 5***, is a public fund, starting in 2025 and reaching full scale in 2030, with an obligation for all Swiss territorial emitters to pay for removal of "their" CO_2. The compulsory payment into the fund replaces the existing CO_2 levy and ETS, and is due each quarter. Payments can be aggregated at the wholesale, retail or importer level; individuals generally do not contribute directly. The removal of CO_2 from the atmosphere requires the fund to build and scale a diversified portfolio of suitable biological and geological projects, which takes time. As initially the emissions are high and removals only starting, the fund will first accumulate reserves, which will be drawn down later as removal projects develop, and fewer remaining emitters continue paying into the fund.

We model the fund with two scenarios (***section 6***): the baseline adapted from Switzerland's Long-Term Climate Strategy, and a more ambitious climate policy. Our model suggests reaching net zero and respecting the 1.5°C budget would be efficient and affordable, economy-wide. We also propose a pilot fund at 1% scale of the full fund, to test all assumptions, allowing the Swiss Negative Emissions Fund to start with real-life validation.

As we publish this paper, the war in Ukraine gives new urgency to energy security, and requires asking which regimes and wars are financed by European oil and gas imports. We hope this much-needed debate will make defending continued fossil fuel use morally unacceptable and accelerate the deep decarbonization.

Here are the key messages policymakers and organizational leaders should keep in mind:

1. After 51.6% of Swiss voters rejected the 2021 CO_2 Act, the Swiss climate policy is even less on track to deliver the Swiss commitments under the Paris Agreement. The modest territorial reduction of 37.5% relative to 1990 emissions, corresponding to the Swiss NDC (Nationally Determined Contribution - the country commitment under the Paris Agreement, as submitted in December 2020), is far below the EU commitment (-55%).

2. The worldwide remaining 1.5°C carbon budget will be exhausted around 2030. From the perspective of historical responsibility, and given its capabilities, **Switzerland must quickly reach its own territorial net zero, remove any remaining emissions from 2030, and help poorer countries, financially and with knowledge transfer, reach their own deep decarbonization**. This help should not be counted in the Swiss net zero, via Article 6 of the Paris Agreement or otherwise.

3. Carbon removal, including carbon capture and storage (CCS) and negative emissions technologies (NET), is an important part of Swiss climate action, even if limited to around 10% of 2020 territorial emissions, or 5 Mt CO_2 per year. The carbon removal potential implicitly defines how much greenhouse gas emissions must decrease, and sets an objective, "technical" as opposed to "political" carbon price, creating a strong signal to

accelerate climate action. **Timely, properly focused action can deliver significant biodiversity co-benefits, engage the local population, and increase stakeholder acceptance.**

4. The **Swiss Negative Emissions Fund will invest in a portfolio of carbon removal projects in Switzerland**, building essential knowledge, monitoring, governance, infrastructure, public awareness and acceptance, and delivering significant biodiversity co-benefits in Switzerland. Its project portfolio will develop the removal potential of 5 Mt CO_2 per year, and will include both biological projects (wetlands and other ecosystem restoration, reforestation, biochar and soil carbon restoration) and geological projects.

5. The Swiss Negative Emissions Fund could **help Switzerland reach net zero around 2040 on an annual** basis, a full decade faster than current objectives, and eventually remove all GHG emissions in excess of the 1.5°C budget from 2030 onwards.

6. More ambitious decarbonization, as expected, reduces both the annual payments into the fund and their duration, as there is less CO_2 to be removed. It also reduces the removal cost per ton, leading to a much lower total cost of decarbonizing society.

7. As the **fund efficiently delivers lowest-cost carbon removal**, the estimated resulting CO_2 price of CHF 240-290 is too low to incentivize the rapid decarbonization of Swiss society. Other policy instruments are needed, especially regulation, public investment, and voluntary action. It is essential that all sectors deeply decarbonize and pay to remove their remaining emissions - exceptions would shift too much burden on the remaining sectors.

8. **The fund proposal is novel in terms of ambition, implementation and impact**. Conceptually it builds on a long tradition of proven concepts, similar to many existing or proposed "polluter pays" initiatives. Financially it works like a fully capitalized pension fund. The novelty lies in combining the remaining carbon budget, incentives to decarbonize rapidly, operating principles to improve local biodiversity and resilience of food production, and a broad engagement of society.

9. Additionally, we propose to **validate the full-scale fund by starting a pilot fund in 2022**, on a voluntary basis, with several climate-leading organizations, public and private, reaching around 1% of volume of the future national fund. All mission-critical aspects can be tested: financing and financial modeling, project selection and monitoring, governance, knowledge transfer, as well as outreach, awareness and acceptance building.

10. Properly designed, the **Swiss Negative Emissions Fund can unblock today's climate action deadlock, reach net zero funded by polluters, build acceptance**, develop Swiss moral and knowledge leadership, and within months start delivering significant benefits for Swiss ecosystems and the population.

2. Carbon removal, negative emissions, and net zero

Our December 2021 E4S White Paper ***"Carbon removal, net zero, and implications for Switzerland"***[1] makes the case for **carbon removal**, including both carbon capture, utilization and storage **(CCUS)** and negative emission technologies **(NET)**, as an important but small part of climate action in the 2-3 critical decades we have to stabilize our climate and stop biodiversity loss.

Here we summarize the paper's main findings, the basis for our proposed Swiss Negative Emissions Fund:

- IPCC's AR6[2] estimates the **remaining carbon budget** at 300-400 Gt CO_2, to stay within 1.5°C. The 300 Gt limit will be reached around 2027-2028, unless we massively reduce our emissions almost immediately. This extremely short window limits the role of technologies still in R&D, suggesting an emphasis on policy, behavior, and economic measures.
- Climate warming affects humans directly and indirectly, by degrading ecosystem services on which we depend for survival, such as food, medicine, pollination, or nutrient cycling. **Protecting ecosystem services** is one of the main reasons for climate action [3,4]. Many biological carbon removal measures, if properly implemented, can offer significant biodiversity co-benefits, even at relatively small scales.
- For Switzerland, given its density, fragile ecosystems, faster warming already reaching 2°C, limited available biomass, and relatively high emissions from cement and waste incineration, we stress the importance of nature-based climate action with biodiversity co-benefits, especially wetland restoration, biochar and soil carbon projects. Additionally, CCS with local geological storage should be developed for cement plants and incinerators, as well as limited bioenergy with CCS (BECCS). The realistic potential in Switzerland is around 5 Mt per year, corresponding to the last 10% of territorial emissions. Carefully designed and monitored, carbon removal measures could also strengthen the resilience of fragile ecosystems.

We conclude that the importance of carbon removal goes well beyond the last 5-10% of current emissions, by implicitly defining goals for sufficiency, efficiency, and renewable energy, i.e. how deep and how fast we must reduce emissions to stay within the 1.5°C carbon budget. Carbon removal also sets an objective, "technical" as opposed to "political" price for emitting CO_2, creating a strong signal to accelerate climate action. Finally, properly designed and monitored nature-based carbon removal offers rapid and significant biodiversity benefits while engaging the local and broader population, which is key to broader acceptance.

3. Swiss climate policy - net zero, and the way forward

After the June 2021 vote

On 13 June 2021, 51.6% of Swiss voters rejected the 2021 CO_2 Act, which would have inscribed in law the Paris Agreement objectives and the Swiss NDC: at least 50% reduction by 2030 and net zero by 2050. The law would have raised the CO_2 levy[1] limit on heating fuels to CHF 210 per ton, and introduced an airline ticket tax of CHF 30 to 120 per outbound flight, depending on distance and ticket class. Half of the ticket tax would have been redistributed to the population, financially benefiting all but a small minority of frequent flyers.

The rejection has been analyzed[5], suggesting subjective decision-making based on very limited knowledge of the general population. For example, only 10% of respondents were aware of the redistribution of the CO_2 levy to the population, which has been in place since 2008.

This suggests both a need to broadly engage the whole society on climate action, and to make policy instruments as simple as possible.

Swiss rapid decarbonization?

Eight months after the June 2021 vote, Swiss climate policy has not yet recovered, and there is still no legal framework to reach the Swiss Paris Agreement goals, in itself legally binding. Most action has been focused on signing agreements under the "Article 6", a COP21 mechanism for international cooperation, allowing rich countries to pay other countries to reduce emissions in their place. We found this approach deeply problematic[1], as it has not yet been proven possible to ensure, at scale, that reductions are real, permanent, additional, not double-counted, and not crowding out host countries' own decarbonization efforts. As of February 2022, Switzerland has signed agreements[6] with Peru, Ghana, Senegal, Georgia, Vanuatu, Dominica, Thailand, Iceland, and Morocco.

Since the vote, not much has happened to reduce Swiss territorial emissions, the immediate focus of the Swiss NDC, nor the broader consumption emissions. Even a credible vision of specific Swiss climate action is lacking, beyond the general goal "Net zero in 2050".

Climate Action Tracker gave Switzerland the overall rating "insufficient" in its latest review for failing to increase its ambition, which is insufficient in terms of policies, actions and fair share of target, and highly insufficient in terms of climate finance[7,8].

From the perspective of historical responsibility, and given its capabilities, Switzerland must quickly reach its own territorial net zero, remove any excess emissions beyond the carbon budget, and help poorer countries to decarbonize, financially and with knowledge transfer. This help should not be counted in the Swiss net zero, via Article 6 or otherwise, for the reasons mentioned above. These considerations of course apply to all high-income countries.

What happens when the remaining carbon budget is exhausted?

The worldwide remaining carbon budget to keep climate warming within 1.5°C with a decent likelihood of 67-83%, defined by IPCC AR6[2] as 3-400 Gt CO_2, will be exhausted around 2029-2030, based on current trajectories. This means that every single ton of CO_2 emitted thereafter will need to be removed from the atmosphere. We interpret this as an obligation for Switzerland to remove all of its emissions from 2030 on. This does not mean that Switzerland must reach net zero by 2030 on an annual basis. Indeed, it is possible to start removal before 2030, and then maintain a high level of removal even as emissions continue decreasing. After a period of such net negative emissions, Switzerland could remove its cumulative emissions from 2030 (*Fig. 1*).

1 In Switzerland, a levy is a tax where most of the revenue is redistributed to the population

This raises two key questions: when should the excess emissions be removed, and who should pay for the removal?

When: Additional CO_2 beyond the allowed carbon budget will cause a potentially dangerous[9] overshoot, with warming beyond 1.5°C. This limits acceptable emissions to low- or no-overshoot pathways, such P1 and P2 in IPCC SR15[4]. **Any "excess" emissions need to be removed quickly, before they accumulate beyond a few years of today's emissions**. As summarized in Table SPM.2 in IPCC AR6, 15 years of today's emissions left in the atmosphere moves us to 2.0°C warming instead of 1.5°C, a life-threatening difference[4].

Who pays: There is a time and stakeholder dimension to this question, as carbon removal could be paid by:

1. **Today's polluters**, as proposed in this paper, who would fully take charge of their environmental liability, as with fully funded depollution or pension schemes
2. Today's taxpayers, increasing the already significant fossil energy externality, where polluters do not bear the cost of their actions, further reducing incentives to decarbonize
3. Tomorrow's polluters: similar to #1 above, but likely to re-create all the problems of pay-as-you-go pension schemes, as pollution profiles change and the biggest polluters go out of business (even faster so if there is a growing liability to continued operation)
4. Tomorrow's taxpayers: in addition to the fairness ("polluter pays" vs. "everybody else pays") and externality arguments listed above, tomorrow's taxpayers will have the additional burden of coping with the effects of climate change and degraded ecosystem services

4. The case for a Swiss Negative Emissions Fund

Why is a Swiss Negative Emissions Fund needed?

Before examining the details of our proposal, let us define what we are trying to achieve, why and how:

1. Unblock Swiss climate action, by providing novel and bold proposals, following the June 2021 vote
2. Reach Swiss climate neutrality in 2030, with cumulative negative emissions covering residual GHG, thus ensuring Swiss cumulative territorial emissions are compatible with the remaining carbon budget
3. Remove explicit and implicit externalities and make polluters pay for removing their emissions which exceed the remaining carbon budget
4. Build acceptance for NET, by developing local projects with direct benefits for the population and ecosystems
5. Build NET capacity in Switzerland: knowledge and training, infrastructure, monitoring and governance, technologies, best practice, ecosystem resilience, food system resilience, public health, new jobs
6. Build Swiss credibility and moral leadership internationally, by taking climate responsibility seriously

Expected results

The proposed Swiss Negative Emissions Fund is designed to:

- Remove more CO_2 every year, reaching its full potential of at least 5 Mt around 15 years after launch
- Develop Swiss geological storage capable of storing >1Mt CO_2 p.a., and the associated transport and monitoring infrastructure
- Restore fragile ecosystems, especially peat-forming wetlands such as bogs and fens, at a significant scale, comparable to their extent in 1800
- Restore soil health at a scale to significantly improve Swiss food production resilience
- Make climate action tangible to a large part of the Swiss population
- Significantly accelerate the deployment of sufficiency, efficiency, and clean energy measures to reach the needed 90% deep decarbonization, based on the resulting carbon price and broad awareness
- Make any gaps in deep decarbonization visible to policymakers and the general population, and pave the way for additional policy instruments to close such gaps and reach net zero as committed

Externalities and lack of climate action

Why focus on carbon removal, if we know this is at best one of the good 10% solutions[1], not *the* solution to climate action? First, to be effective, carbon removal requires deep decarbonization: sufficiency, efficiency, and clean energy, together reducing emissions by 90%. Second, the very reason that sufficiency, efficiency, and clean energy are developing far too slowly is the **externality of abundant and cheap fossil energy**, where the costs are not borne by the polluters, but by taxpayers (health care, public investment), citizens and especially vulnerable people (pollution, noise, accidents, health insurance costs), future generations (habitability of the Earth, future food supply, financial liabilities), and ecosystems (biodiversity and habitat loss, pollution, climate change, ecosystem service degradation).

Why is carbon removal the best place to start eliminating this externality? In short:

- The cost of carbon removal is the average cost of a portfolio of removal projects, current and future, each with its cost per ton, quantity, timeline, and risk.
- Charging this cost to polluters defines a carbon price based on a technical calculation, which is not the result of a political compromise, so less influenced by special interests.
- Even an optimal portfolio of removal projects is expensive, leading to a high carbon price, and the resulting payment to the fund will create a strong incentive to decarbonize as fast as possible.
- Rapid decarbonization and timely removal of overshoot emissions drastically mitigate the externality of abundant and cheap fossil energy.

Fund or mandate to remove carbon?

Finally, why do we propose a fund, instead of simply mandating immediate carbon removal of any emitted CO_2 from a certain date? The main reason is a mismatch in timing: total emissions are highest now, decreasing at least by half in 2030, and around 90% in 2050, assuming the Paris Agreement commitments are met. On the other hand, carbon removal is negligible now; biological and geological methods need time to develop, which is another reason to start rapidly. Today, removal costs are very high, and will decrease for each method as we learn.

Would a time-delayed removal mandate for polluters, i.e. a future liability, work better? It might, but it would increase the risk of default, possibly even creating an incentive to close companies with large liabilities, transferring these to taxpayers.

The fund bridges the timing gap, and at the same time eliminates the incentive to default.

Are we proposing something new?

Yes and no.

Let's start with "no". There is a long tradition of the "polluter pays" principle, sometimes traced back to Plato[10], and first introduced in law[11] in 1810 in a very limited form. It has since become a major principle of environmental liability in the EU[12], and the basis of key US environmental laws: Clean Air Act, Clean Water Act, "Superfund" (clean up of sites contaminated with hazardous materials). In Switzerland, the principle is used both at a large scale (the Decommissioning Fund for Nuclear Facilities, since 1985, and the Waste Disposal Fund for Nuclear Power Plants, since 2002) and by almost all communes with a garbage bag tax, first introduced in 1975, and made compulsory by the Federal Court in 2011.

We are building on a subset of this large tradition, specifically "polluter pays for later cleanup", where the payment is not only a financial incentive to pollute less or a compensation to people hurt by the pollution, but is invested in reversing the pollution itself. This makes the Swiss Negative Emissions Fund very different from current Swiss climate policy instruments. For example, ⅔ of the heating fuel levy is redistributed, and ⅓ is invested in measures to reduce future pollution, thus no money is allocated to remove the CO_2 on which it is levied. Similarly, the EU ETS aims to reduce the total amount emitted, and no payments are due nor invested in reversing the pollution when polluters satisfy their requirements.

The principle of net zero, where GHG emissions must be matched by negative emissions for climate warming to stop, is the ideal application case of "polluter pays for later cleanup", as the polluters, the quantity and timing of emissions, and the cost and timing of negative emissions can all be identified.

One high-visibility proposal to remove emissions from fossil fuel, the "carbon takeback obligation", is discussed in the next chapter, including how the Swiss Negative Emissions Fund can improve several aspects of this proposal.

Financially, the fund we propose is very simple and similar to a fully funded pension scheme.

So, are we proposing something new? The Swiss Negative Emissions Fund brings the novelty of combining the remaining carbon budget, the incentive to decarbonize rapidly, a set of operating principles to improve local biodiversity and resilience of ecosystem services including food production, a broad engagement of society in particular local communities around removal projects, and capacity building, especially research and education.

We believe this combination could lead to net zero in an efficient, fair, affordable, and socially acceptable way.

Carbon takeback obligation

The carbon takeback obligation[13], first conceptually proposed in 2009[14], and widely discussed before COP26, would require oil and gas companies to capture and store CO_2 from the combustion of their products. The "takeback" requirement would progressively increase from 1% of their production in 2023, to 10% in 2030 and 100% in 2050.

The model[15] based on a MESSAGE-GLOBIOM IAM emulator, calculates an equivalent carbon price, multiplying the above removal requirement percentage with the removal cost per ton, initially $40-60 per ton (low to account for "cheapest, high-purity CO_2 capture opportunities"), reaching $200-600 in 2050, as large-scale expensive direct air capture and storage (DACS) would be needed.

Given the low percentage of removal, the 2030 price would only reach $6-13 per ton, much lower than today's carbon prices and insufficient to create any meaningful incentive. To encourage early decarbonization, the authors propose[15] "applying economy-wide, demand-side policy instruments equivalent to an effective carbon price of $110/t CO_2", from 2020, worldwide. By coincidence, this would create a worldwide carbon price exactly at the level of the Swiss heating fuel CO_2 levy.

Other than inevitable governance issues (the obligation is at the company, not country level, creating a hard-to-enforce liability), it requires removing 10-25 Gt CO_2 per year from 2050 to geological storage, mostly achieved through DACS. This is almost twice the level we analyzed[1] as unrealistic. It also downplays the importance of nature-based solutions (NBS) due to their potential reversibility. Yet NBS are especially important when considering biodiversity implications of climate action.

Building on a similar conceptual basis, our proposed implementation aims to solve the above problems. Replacing a company liability with a national fund (a) includes all polluters, not only oil and gas companies, (b) develops a more diversified and robust portfolio of removal projects, (c) creates local biodiversity and food resilience co-benefits, (d) removes the incentive to default, (e) separates the timing of payments and removals, and (f) in conjunction with a CBAM, allows countries to implement at different speeds.

Future Swiss climate policy

As shown in the simulations based on our financial model, all excess emissions from 2030 can be removed at a cost of CHF 240-290 per ton CO_2, much more affordable than eliminating the last greenhouse gas emissions but too low to create by itself the financial incentive to decarbonize to an extent allowing the remaining emissions to be removed. In other words, the **fund's cost efficiency means additional policies are needed**.

If carbon pricing were the only instrument used, our baseline scenario modeled on Switzerland's Long-Term Climate Strategy – which has a goal of annual residual emissions of around one ton CO_2e per capita – would require an economy-wide price[15] of around CHF 1000 per ton CO_2. Excluding individual sectors would lead to even higher prices in the remaining sectors[17].

To retain the "polluter pays for cleanup" principle, we need additional instruments, such as regulation (standards, limits on fossil fuel imports,

land use etc.), public investments (helping people transition to 1.5°C lifestyles), and voluntary measures. The additional measures and the resulting lower carbon price should facilitate acceptance.

Swiss climate action and geopolitical implications

We examined geopolitical conditions for deployment[1], and concluded that while CCS and DACS require a robust global cooperation, well beyond current UNFCCC agreements to prevent leakage and work at all, biological projects (reforestation, ecosystem restoration, soil carbon, biochar) can be meaningfully implemented by individual countries, due to their local benefits to ecosystems, resilience of food production, ecosystem services, climate adaptation, as well as direct benefits to the population. To a smaller extent, this is also true of BECCS due to electricity and heat generation, if kept small-scale and based on excess biomass from forests, waste, or agriculture.

This corresponds well to Swiss specificities and the types of carbon removal projects we recommend.

CCS could play a significant role in Switzerland over the next 20-30 years, but only as part of a broader global agreement to prevent leakage. This could take the form of the EU Carbon Border Adjustment Mechanism (CBAM) eventually extended via a "climate club" to include other regions with similar carbon pricing.

Such an extension beyond the EU is challenging for several reasons. The World Bank Carbon Pricing Dashboard[18] lists 65 carbon pricing initiatives worldwide, national or sub-national, covering 21.5% of global GHG emissions, with prices ranging from $1 to $137 per ton (generally low outside Europe), as of 01-2022.

The war in Ukraine makes the fossil fuel dependency on a small number of exporters painfully obvious. The large associated financial flows create problems on both sides. The open-ended annual fossil fuel import cost to the Swiss population is comparable to peak annual decarbonization costs. On the receiving side, these payments often finance wars and human rights abuses.

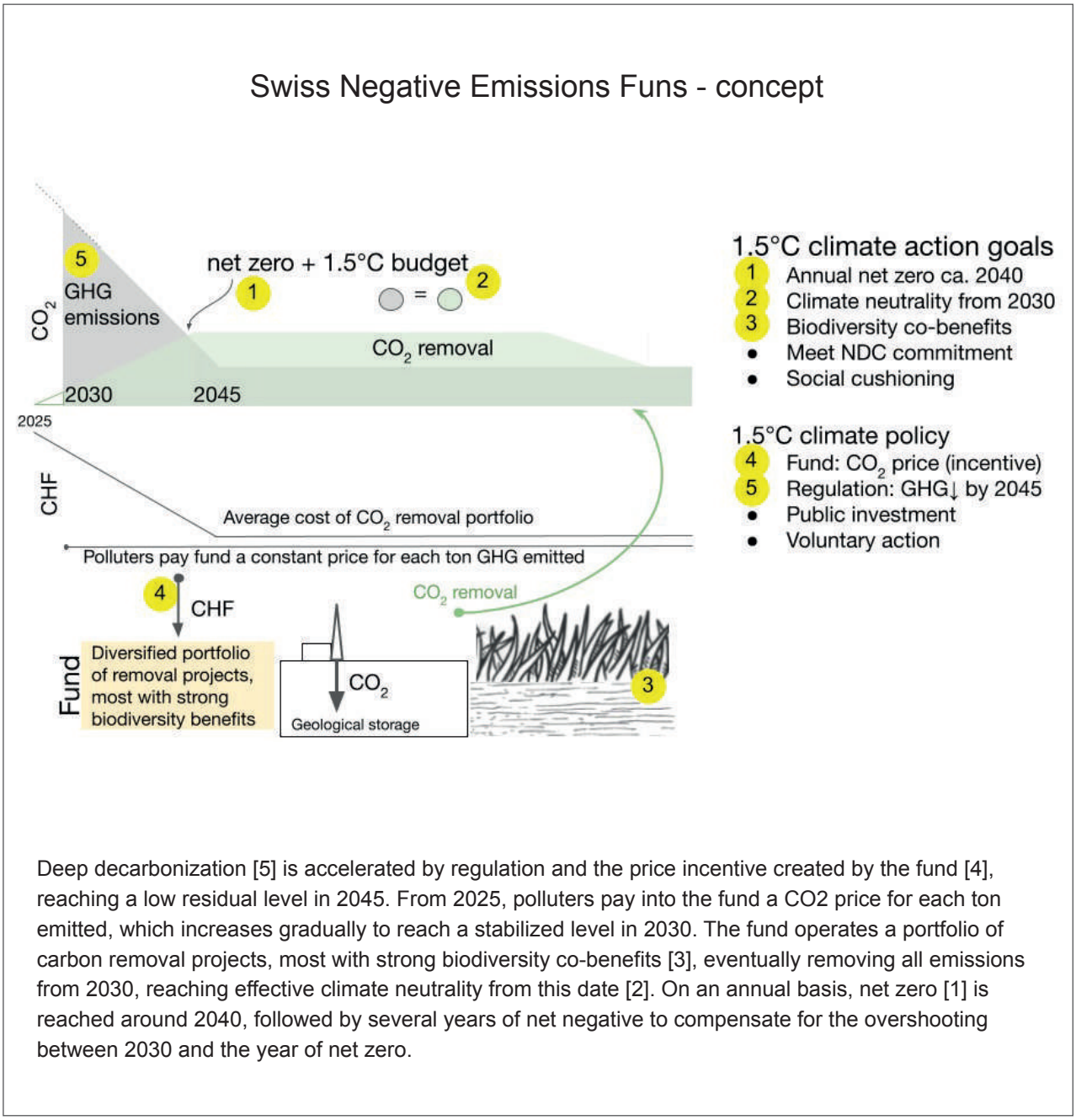
Finally, the Swiss Negative Emissions Fund is not directly compatible with EU ETS: large Swiss polluters who reduce their emission to limit their contributions to the Fund could sell excess emission rights to European participants, creating carbon leakage (lower emissions in Switzerland would lead to more emissions in the EU).

Should Switzerland create its own CBAM towards the EU or other countries? Probably not towards the EU, due to the relatively low carbon intensity of the remaining Swiss industry, but certainly it should join the EU CBAM towards third parties.

A more interesting option would be to establish a European Negative Emissions Fund based on the Swiss model we propose - as it becomes increasingly clear that the EU ETS will not help decarbonize all the way to net zero, and certainly not fast enough to stay within the carbon budget. There seem to be no viable proposals for funding net negative emissions in the EU, as the focus is on granting credits for CO_2 removal[19], which simply allows emitters to emit as much CO_2 as was removed.

5. Proposed implementation of the Swiss Negative Emissions Fund

The proposed Swiss Negative Emissions Fund collects and manages advance payments for future carbon removal costs, similar to two existing Swiss funds: the Decommissioning Fund for Nuclear Facilities (started in 1985) and the Waste Disposal Fund for Nuclear Power Plants (started in 2002), both based on the polluter pays principle, with cost re-calculation and validation every 5 years[20].



Deep decarbonization [5] is accelerated by regulation and the price incentive created by the fund [4], reaching a low residual level in 2045. From 2025, polluters pay into the fund a CO2 price for each ton emitted, which increases gradually to reach a stabilized level in 2030. The fund operates a portfolio of carbon removal projects, most with strong biodiversity co-benefits [3], eventually removing all emissions from 2030, reaching effective climate neutrality from this date [2]. On an annual basis, net zero [1] is reached around 2040, followed by several years of net negative to compensate for the overshooting between 2030 and the year of net zero.

Fig.1: Visual description of the Swiss Negative Emissions Fund, facilitating climate goals, integral to climate policy

Financial flows and governance

In our proposal, we include a 5-year transition, during which all Swiss territorial GHG emissions are progressively subject to payment to the Swiss Negative Emissions Fund, from the day the fund starts, as defined below:

- **Emitters have the choice of either immediately removing the carbon themselves, or paying into the fund**. "Immediately" means within the reporting quarter.
- Emissions are declared every quarter, with payment to the fund within 30 days after the end of the quarter, similar to VAT today. The declarations will be periodically audited.
- GHG and GWP (Global Warming Potential): All GHG are covered; non-CO_2 gases are converted to CO_2e based on 100-year GWP for long-lived gases (>100 years), and based on GWP* for short-lived gases (see appendix). Calculations follow IPCC recommendations from January 1st following their publication.
- Payments to the fund are made at the highest level of aggregation, generally by wholesalers, large retailers, and importers, as well as directly by all emitters of more than 100 kt CO_2e p.a. Sector-specific guidelines are published by the Confederation and revised as needed.
- "Territorial" covers emissions released in Switzerland. For international flights, the entire outbound flight is counted, incoming flights are not.
- Ramp-up of payments: to allow polluters time to prepare, and reduce emissions as far as possible, there will be a transition period of 5 years, during which the price per ton will progressively increase, from the current CO_2 levy (CHF 120 for heating and process fuels, zero for other emissions, as of 2022), to reach the **initial carbon removal price, estimated at CHF 250-290 per t CO_2e**, depending on the speed of decarbonization, to be defined in the law. For example, during the first quarter of the transition, only 5% of the price increase is applied, 10% in the second quarter, and so on, reaching 95% in the 19th and 100% from the 20th quarter, i.e. the initial carbon removal price.
- The price per ton CO_2e is calculated by the fund to be as stable as possible, and revised as needed. Any price changes are published at least 12 months before application.

The fund will develop, run, and continuously refine its own financial model, to manage risks inherent in methods, technologies, and individual projects, as well as portfolio effects and learning curves. The fund will build and manage reserves, sufficient to cover the above risks.

In this paper we propose a basic financial model as a starting point; this model will be refined by the pilot fund, allowing the Swiss Negative Emissions Fund to start with a model validated in practice.

CO_2 flows and governance

The Swiss Negative Emissions Fund aims to rapidly remove the carbon for which it has received payment:

- Only CO_2 will be removed, based on the CO_2e calculation and payment for all GHG, see "GHG and GWP" above
- The quantity removed will progressively increase, starting from the first year of the fund, reaching the maximum after 15 years, and staying stable until all excess emissions have been removed
- All removals will be on Swiss territory
- A suitable mix of methods, technologies and approaches will be covered, based on today's and expected 10 and 20-year benefits in terms of carbon removal, ecosystem resilience, and population engagement.

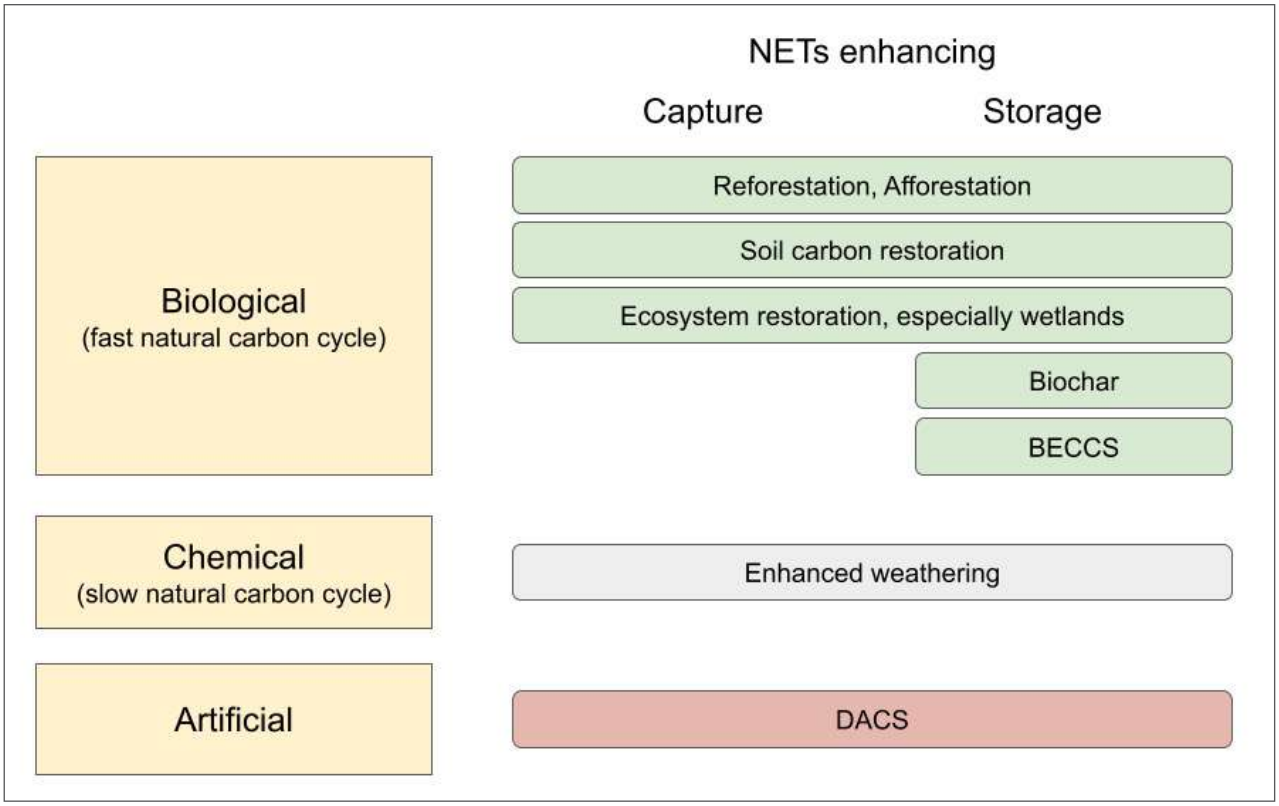


Fig. 2: Classification of NETs

The project mix in the portfolio will cover a range of NETs, biological and chemical, following the classification[1] we reproduce above. The methods are mostly complementary, and the portfolio will be built based on the following criteria:

- **Quality:** carbon removal needs to be proven, measurable, additional, and permanent, meaning that >90% remain after 100 years. Contingency plans for potential loss of permanence are needed.
- **Quantity:** the total carbon for which the fund received payment must be removed. This requires including contingencies, as above for funding, inherent in methods, technologies, and individual projects.
- **Timing:** as quickly as possible. Based on the experience of the pilot fund, specific performance targets will be developed.
- **Infrastructure:** a systemic perspective will be followed, to ensure are required elements are in place, in particular related to geological storage, pipelines, and monitoring.
- **Diversification and price:** a broad mix of methods and technologies will be covered, at various levels of maturity. While most removal will focus on lower-cost methods, a part of the fund will be invested in methods that are high-cost today, but have a reasonable likelihood of removing 1 Mt p.a. at an acceptable price within 10 years of project start. The first assessment will be developed in the pilot fund, and continuously updated thereafter. It is expected that 80-90% of the annual funding will focus on lower-cost and/or biological methods.
- **Benefits for biodiversity:** in addition to carbon removed, this is the main criterion for project selection. Any material adverse effects on ecosystems will eliminate projects from consideration. It is expected that most removal projects will be biological, with significant ecosystem benefits.
- **Benefits for the local population:** the local population will be involved from the planning phase of each project, and the impacts of projects will be systematically assessed.

Significant efforts will be made to create employment, minimize nuisances for local residents and generate other co-benefits such as leisure activities.

Engaging society: a significant outreach effort will be included from the start of each project. Projects will be physically accessible to the extent possible, integrated in educational programs at all levels, and documented in the most open way possible. Guided tours, discussions, and hotlines will be offered. To the extent possible, projects suitable for engaging society will be given preference.

Although the fund will focus on NETs, i.e. removing CO_2 from the atmosphere, we make the case[1] for planning and managing CCS+NET together, due to:

- Shared knowledge, monitoring, governance, policy instruments,
- Shared Infrastructure and operations: waste incinerators and partially cement plants burn both fossil fuels and biomass; if equipped with CCS, they will automatically include NET, and
- Complementary timing: CCS must be deployed rapidly, but will become less useful with decarbonization; the installations could then be used for NET.

Direct benefits and co-benefits; acceptance by key stakeholder groups

The direct benefit of the Swiss Negative Emissions Fund is removing at least 5 Mt of CO_2 per year from the atmosphere, and thereby making a Swiss net zero possible, after other types of climate action, such as sufficiency, efficiency, clean energy, and CCS, have reduced emissions by 90%.

Co-benefits (or indirect benefits) include:

- Eliminating the climate externality of fossil energy and enabling sufficiency, efficiency, and clean energy to reduce emissions
- Restoring degraded ecosystems, protecting and improving resilience of fragile ecosystems, enhancing biodiversity
- Restoring soil health and improving Swiss food production resilience
- Creating new jobs paid for by the fund, directly for monitoring projects, and indirectly via project financing at cantons, communes, project developers, including the whole supply chain
- Developing community projects, spaces for the local population
- Improving cultural ecosystem services and wellbeing[21] for the broader society
- A multitude of local opportunities to learn hand-on about climate and biodiversity, at all educational levels

Beyond appropriate communication[22], based on simplicity, fairness, and effectiveness, acceptance requires familiarity and positive subjective perception of benefits[5]. **Engaging broad aspects of society with concrete local projects, and creating and sharing multiple benefits will be a major element of acceptance**. For example, the UK Climate Assembly[23] identified potential leaks of CO_2, distraction from emissions reduction, and "less natural", energy-intensive methods as concerning, while broadly rejecting fossil energy with CCS. While no comparable carbon removal acceptance exists for Switzerland, we expect the pilot fund and its outreach activities to provide an opportunity to create it.

6. Financial and CO_2 flow modeling of the fund

To estimate the financial and CO_2 balance implications of the Swiss Negative Emissions Fund, we developed a simple financial model covering total Swiss territorial GHG emissions, a gradually increasing and then stabilizing volume of carbon removals with decreasing costs, and total removals exactly equaling all emissions from 2030.

We **calculate methane emissions from agriculture differently from the 100-year warming multiplier generally adopted in climate planning and reporting**. The appendix explains why and how, especially during rapid transitions, this change better reflects the warming effect of methane.

Specifically, we define and model the following baseline parameters:

- **Worldwide remaining 1.5°C carbon budget exhausted on 01.01.2030**. The exact timing may shift by a year or so, as IPCC's estimate (300-400 Gt CO_2 in 2021) narrows[2]. We assume the same timing for Switzerland, which will meet its historical responsibility by financially and technically helping disadvantaged countries reach their own net zero. It may have been preferable to reduce the remaining carbon budget of historical polluters, but this appears out of reach now.
    - The fund will pay to remove, as fast as possible, all Swiss GHG emissions from this date.
- **Timing:** the fund launches in **2025**, with a 5-year transition period during which the carbon price increases. Swiss GHG emissions fall linearly from today to a constant level of residual emissions in **2045**.
- **Ramp-up of payments to fund:** to allow polluters time to prepare, and reduce emissions as far as possible, there will be a transition period of 5 years, during which the price per ton will progressively increase, from the current CO_2 levy (CHF 120 for heating and process fuels, zero for other emissions, as of 2022), to reach the initial carbon removal price, calculated by our model, depending on the assumed speed of decarbonization (to be defined in the law). For example, during the first quarter of the transition, only 5% of the price increase is applied, 10% in the second quarter, and so on, reaching 95% in the 19th and 100% from the 20th quarter, i.e. the initial carbon removal price.
    - Note: we examined what would happen if the existing CO_2 levy on heating oil were redirected into the fund, without an obligation to pay for removing all emissions. Result: net zero could not be reached, a taxpayer liability of hundreds of billions CHF would arise, and slow decarbonization would require negative emissions far in excess of what is possible in this time frame.
- **Ramp-up of physical carbon removal:** removal projects start in **2025**, linearly increasing until **2040**, thereafter constant, until all excess emissions are removed.

  Reduction of removal costs: CO_2 portfolio average removal costs **CHF 800** per ton in 2025, progressively falling to **CHF 350**, in **2045**, assuming that costs continue falling while volume is increasing, and for 5 years thereafter, then stabilizing. The cost per ton is intentionally high, as the required negative emissions are at the very high end of what is likely possible - the resulting project portfolio needs to include expensive methods.
    - Comment: regardless of the initial price, in a well-functioning

fund, the need to remove high quantities of CO_2 would expand the portfolio of projects to include less attractive one, i.e. those with a higher average cost, lower project lifetime, higher risks, expanding faster before costs come down etc., all leading to higher removal costs.

- **Interest rate: 2.5%**, earned on the balance of the fund, as it gradually builds up thanks to contributions exceeding disbursements, before reversal.
- **Total GHG emissions:** These assumptions are entirely based on Switzerland's Long-Term Climate Strategy[24], accelerated by 5 years, and adapted using the GWP* methodology, see appendix for details. In 2025, we assume total GHG emissions of **36 Mt CO_2e** (40.5-4.5, assuming GWP* for methane being zero due to reduction effects). Residual emissions after deep decarbonization (sufficiency, efficiency, clean energy), before CCS: **9.7 Mt CO_2e** (11.8-2.1, based on GWP*). Assuming 5 Mt CCS in 2050 (Table 2, p.50[24]), the required NET stabilize at **4.7 Mt CO_2e** p.a. (including 1.3 Mt from biogenic waste and 3.4 Mt from other methods, same source).
- **International aviation:** Switzerland's Long-Term Climate Strategy[24] includes emissions based on fuel sales at Geneva and Zurich airports, projecting a reduction to zero in 2050 based on switching to synthetic fuels. We discuss aviation's impact separately but do not include it in our model - these emissions are essential to reaching net zero, but beyond territorial GHG emissions, and the scope of our model.

Baseline results

Our model indicates that the above assumptions require 10 Mt of annual negative emissions (*Fig. 3*). This level is likely possible, but needs a significant mobilization and would imply high average removal costs. The model does, however, reach **net zero in 2042**, and removes all excess emissions by **2077**, i.e. those above the 1.5°C budget.

This scenario appears financially feasible: payments to the fund grow until a maximum of CHF 8 billion is reached in 2030. This is less than 1% of the Swiss GDP, a reasonable cost to reach net zero. After 2030, the annual payment quickly falls to CHF 1.3 bn. The fund reaches CHF 50 bn before depleting gradually. Over the lifetime of the fund, thanks to interest, the average payment to the fund is **CHF 279 per ton CO_2e**.

Finally, we simulate the effect of interest rate changes: if the interest rate falls, the cost per ton reaches CHF 291 at 2%, and CHF 304 at 1.5%. The sensitivity to interest rate is low: 8.9% cost change for a 1% interest rate change, which is the probably upper end of what we could reasonably expect. This can be explained by the relatively short time difference between cash in and cash out. Specifically, *Fig. 4* shows that the maximum capitalization of the fund is only about 6 times the peak annual contribution to the fund.

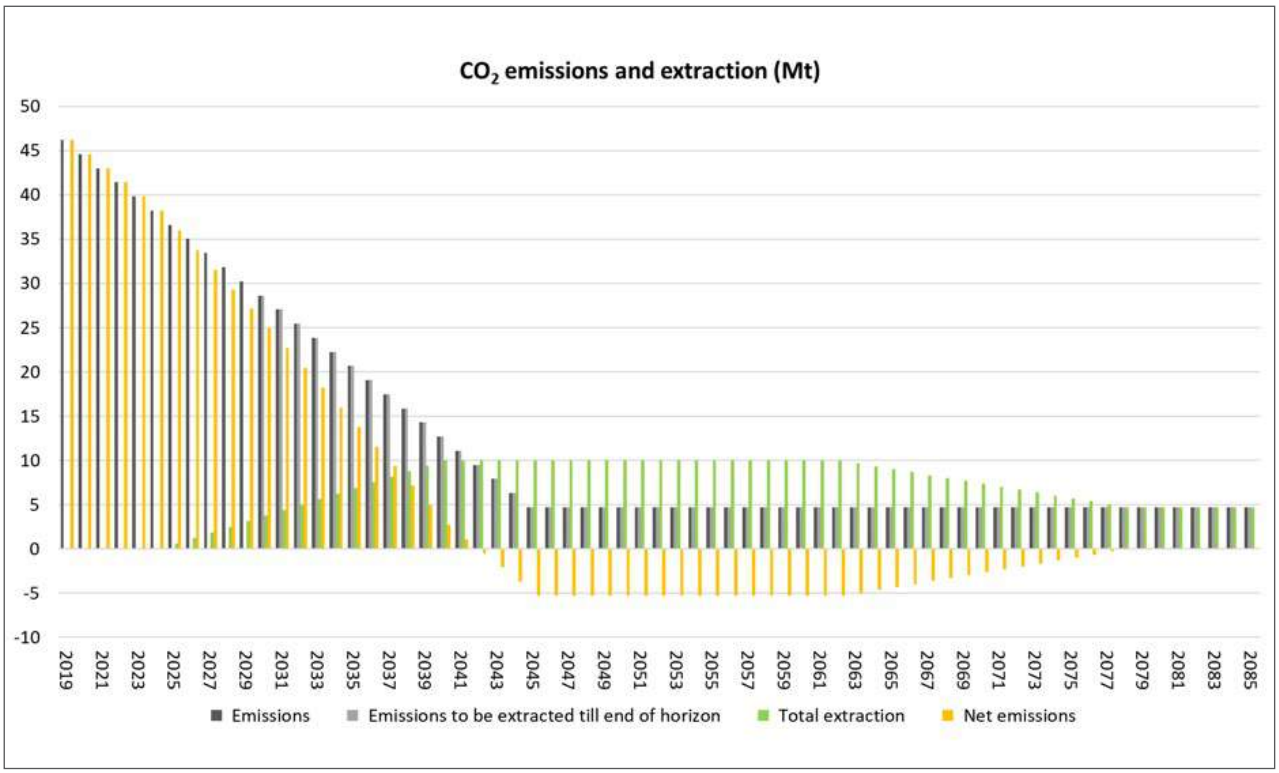


Fig. 3: Simulation of CO_2 flows, baseline

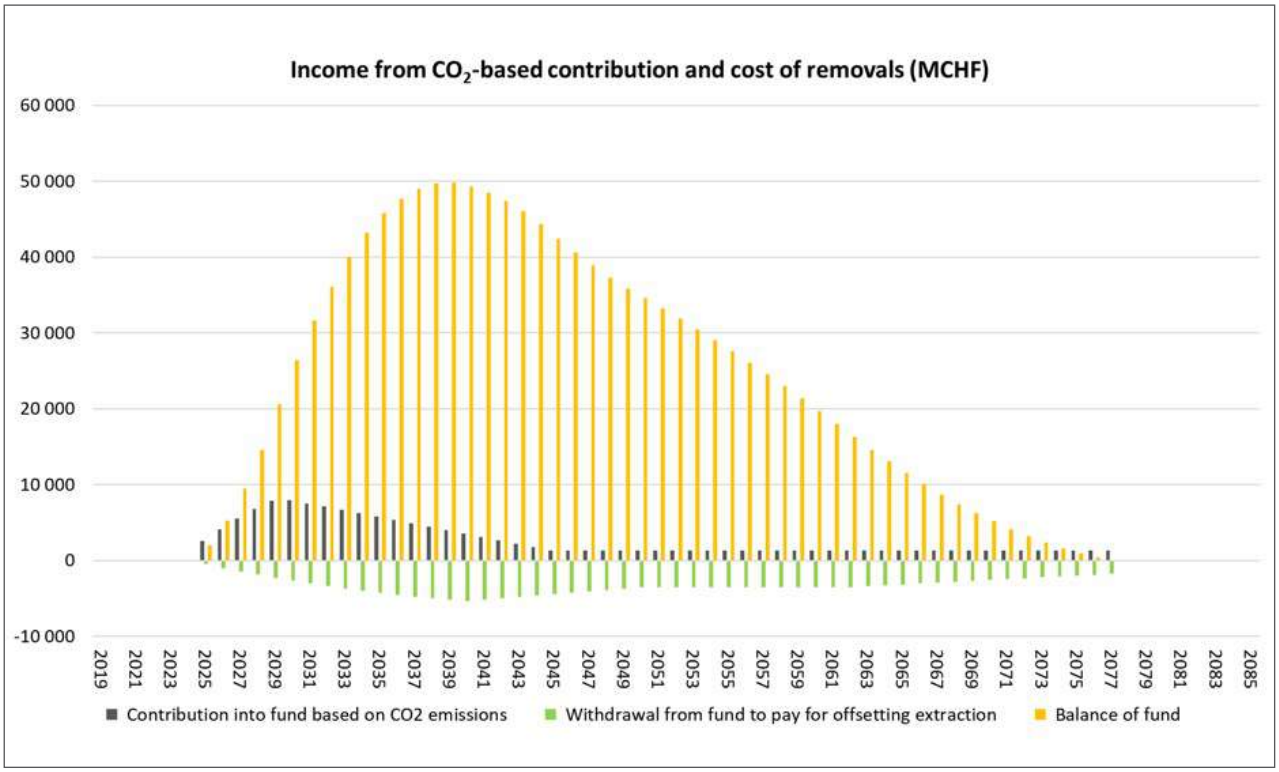


Fig. 4: Simulation of financial flows, baseline

Simulation of a more ambitious climate policy

In the baseline scenario, the required annual negative emissions reach 10 Mt, far above the 5 Mt that can be attained with high confidence[1], which significantly increases the risks and costs of the approach. Additionally, the time to remove all excess emissions before reaching net zero is very long, almost 50 years after reaching net zero.

Reaching net zero in 2042 and removing all

excess emissions already required ambitious assumptions, such as accelerating the decarbonization scenario of Energy Perspectives 2050+ by 5 years, which we consider would be facilitated by the higher carbon price of CHF 279 per ton from 2030 (progressively increased from 2025 to 2030), compared to CHF 86 in 2035 and CHF 140 in 2040 (EP2050+, Fig.6, p.22[25]).

In this section, we **challenge the ambition of Switzerland's Long-Term Climate Strategy:** 11.8 Mt CO_2e or 21.9% of 1990 emissions (54 Mt) are classified as "unavoidable". These emissions are only "unavoidable" in the absence of suitable action to avoid them, for example: questioning the quantity or methods of construction, eliminating single-use plastics, or adopting better diet and food production practices[26]. In contrast to 22% of Swiss "unavoidable" emissions, we consider the case of Germany: less than 3% of its 1990 emissions are defined as unavoidable, while seeking to reduce "at least 97%" of anthropogenic emissions. This is even included in the German Government's official draft climate law[27] (p.16).

There are many similarities between the two countries, such as climate, diet, density, structure of the economy, population dynamics. There are also major differences, such as the German reunification, fast decarbonization after 1990, and crucially a larger, more integrated economy, where consumption emissions are much closer to production emissions than in Switzerland. In other words, decarbonizing by 97% in Germany covers a much bigger fraction of consumption due to lower per capita embodied emissions of imports[28].

In 1990, Germany's population of 79.43 million emitted[29] 1242 Mt CO_2e, or 15.64 t per capita. When reduced by at least 97%, emissions should be less than 37 Mt. For a population of 80 million (2050 middle estimate[30]), the upper annual limit of emissions is 465 kg CO_2e per capita. The comparable per capita goal of Switzerland's Long-Term Climate Strategy is 11.8 Mt / 10.257 million = 1150 kg CO_2e. The German economy being more integrated, i.e. importing less relative to production, these numbers understate the difference in ambition.

Our more ambitious climate policy allows for 11% residual emissions (half of 22%), or 575 kg CO_2e per capita.

On this basis of a deeper and faster decarbonization, we modeled the following scenario:

- Timing: the fund launches in **2025**, as above. Total GHG emissions are reduced from today's to a constant level of residual emissions in **2040**.
- GHG emissions in the first year of the fund (2025): **36 Mt CO_2e**, as above. Assuming residual emissions reduced by half compared to the baseline (11.8 Mt/2 or 11% of 1990 emissions), then applying the GWP* calculation, assuming the same contribution of all sectors to this reduction, we subtract 1.1 Mt. We get 5.9-1.1=4.8 Mt CO_2 to be removed, before CCS. Assuming 3 Mt CCS, the required NET stabilize at **1.8 Mt CO_2e** p.a. (including biogenic waste and other methods).
- Costs same as baseline: CO_2 portfolio average removal costs **CHF 800** per ton in 2025, progressively falling to **CHF 350**, as in the baseline. Due to a smaller project portfolio, the average cost might be even lower, as only the best projects need to be included. The deeper and faster decarbonization is reached through additional non-monetary public policy instruments, such as regulation.

These modifications significantly improve the outcome (*Fig. 5*, *Fig. 6*). The annual level of negative emissions can now be **capped at 6 Mt**, which makes implementation much less risky, allowing the choice of better projects, and reducing the average price to **CHF 245 per ton CO_2e** (compared to CHF 279 before, but of course this scenario involves more mitigation). All excess emissions are removed by **2068**, and **net zero is reached in 2038** (as opposed to 2042). Additionally, the required level of CCS is significantly reduced, further saving costs.

In conclusion, even a modestly more ambitious climate policy can significantly reduce risks and costs, shorten the overshoot by a whole decade, and reduce by 40% the scale of the entire required effort.

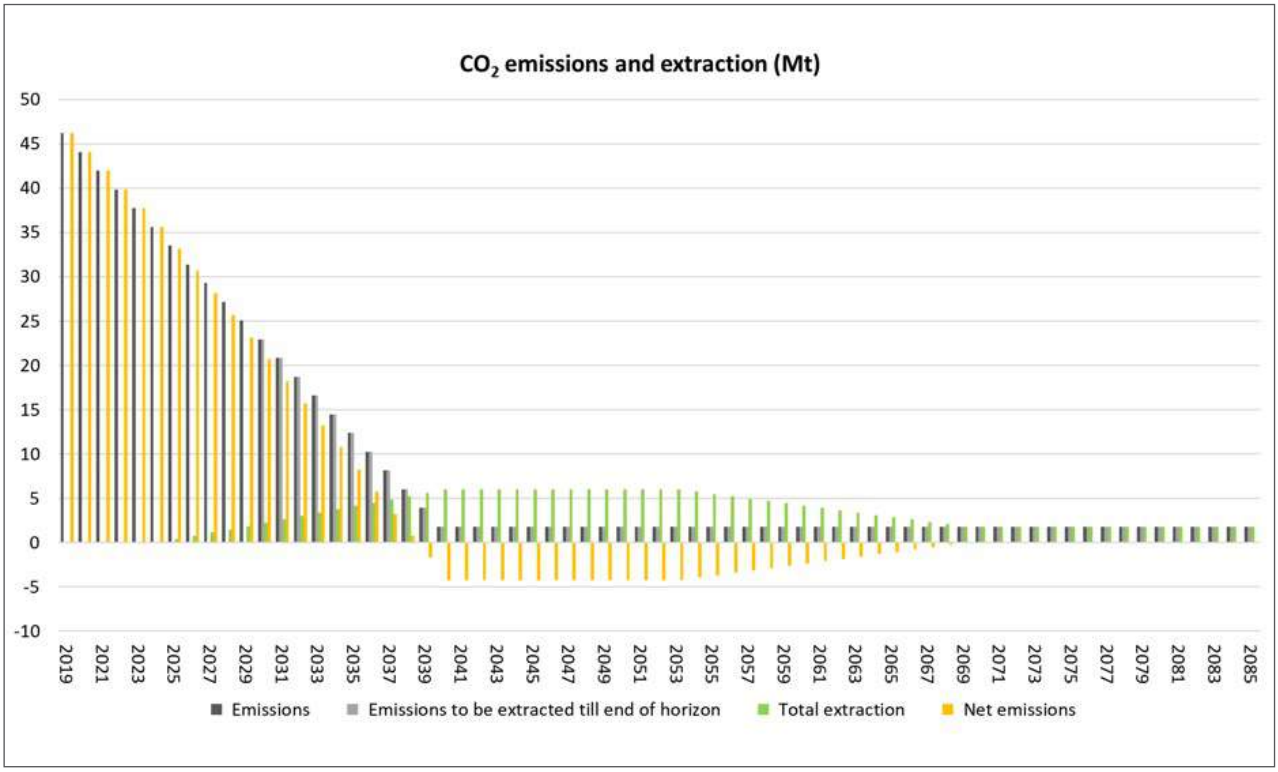


Fig. 5: Simulation of CO_2 flows, more ambitious climate policy

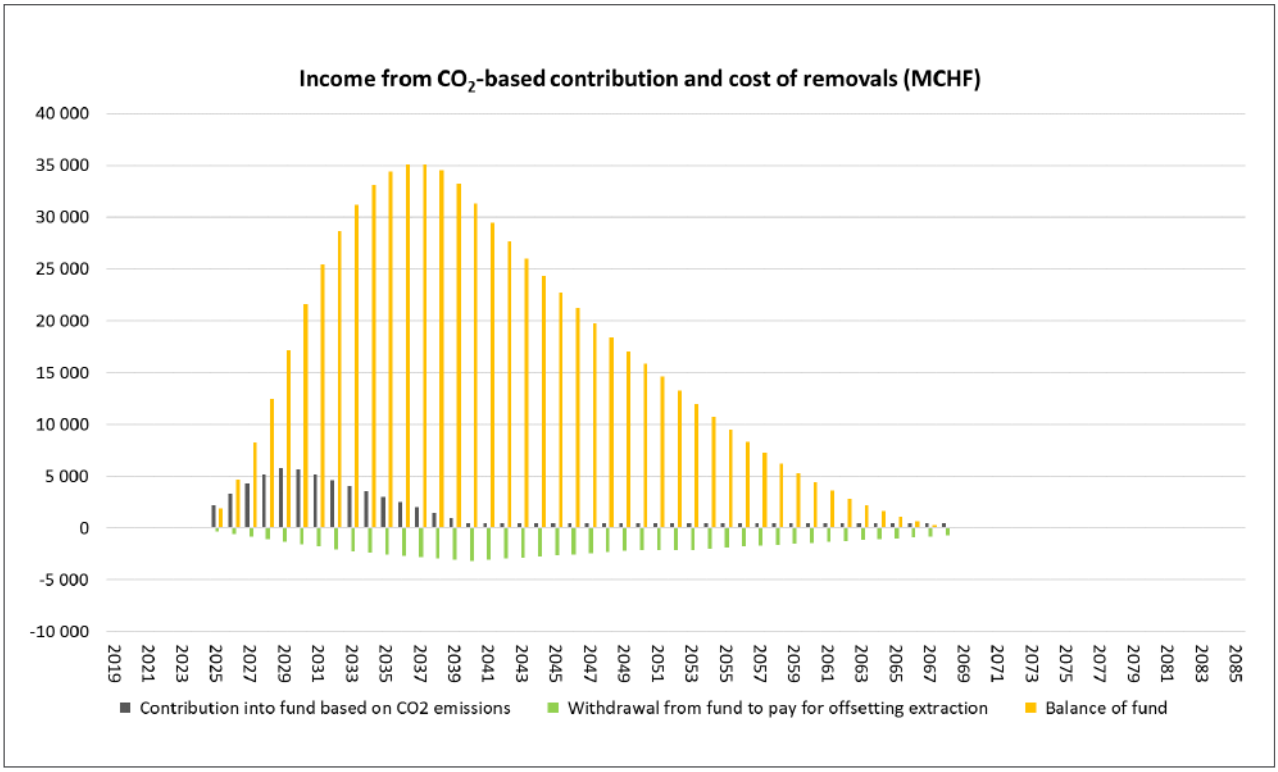


Fig. 6: Simulation of financial flows, more ambitious climate policy

Conceptually, this validates the model. However, as a basis for a national climate strategy, all the assumptions need to be empirically tested and refined. This is precisely why we propose a pilot fund, which could be launched rapidly, almost certainly before the end of this year, 2022.

Impact of aviation

The 2019 CO_2 emissions of Swiss international and domestic aviation[31], mainly based on jet fuel sales at the Geneva and Zurich airports, were 5.8 Mt. The total climate impact of aviation, however, is best measured by the Radiative Forcing Index (RFI), and a recent comprehensive analysis[32] suggests using RFI = 3. Recalculating Swiss emissions with this RFI shows that aviation contributes 17.4 of 63.6 Mt (46.2+17.4), or 27%, placing it ahead of ground transport (if embodied emissions of airplanes, airports, cars, trucks and roads are not counted).

The E4S White Paper[33] "Introducing an Air Ticket Tax in Switzerland: Estimated Effects on Demand" analyzes growth projections and impacts of different air ticket taxes on future demand. Even highly optimistic scenarios with rapid and sustained improvements in aircraft fuel efficiency still result in significant worsening of climate impacts by 2050, in the best case by 36%, and in some scenarios more than tripling the warming impact. The airline ticket taxes proposed in the rejected 2021 CO_2 law would have reduced emissions by 16% relative to the (bad) baseline. An annually increasing tax (+4.71% p.a.) would be more effective, reducing emissions by 26-38% from the same baseline, which would still correspond to an absolute increase.

Switzerland's Long-Term Climate Strategy includes air travel emissions and solves this problem, projecting a reduction to zero in 2050, by switching to imported synthetic fuels, a hypothesis qualified in the same report[24] as "optimistic from a current perspective" (p.49).

If this optimistic development fails to materialize, air travel emissions (including RFI=3) need to be included in the proposed Negative Emissions Fund. Even if synthetic fuels fully replace fossil fuels, they will still produce contrails and contrail cirrus clouds, and depending on combustion, also NO_x compounds (with a tradeoff between NO_x formation and fuel use, i.e. CO_2 emissions) - the two highest-impact non-CO_2 components[34].

This suggests that **synthetic fuels will continue warming the climate at a rate of ⅔ of kerosene**.

Without additional ambitious measures, including complete substitution of European flights by trains, and severe restrictions on remaining long-distance flights, the fund cannot remove the additional emissions of aviation to reach Swiss net zero.

7. Getting started: proposed pilot fund

Purpose of the pilot fund

The Swiss Negative Emissions Fund proposal represents a major change in climate policy, with many **aspects that need to be developed in detail: reporting GHG emissions, financial modeling, project selection and monitoring, governance, knowledge transfer, as well as outreach, awareness, and acceptance building**. It will also be necessary to revamp the existing climate and energy policy entirely, and modify other policy domains (transportation, agriculture), when the contribution to the Swiss Negative Emissions Fund becomes a major levy on greenhouse gas emissions. Social cushioning and other supporting measures need to be adapted.

There are no insurmountable difficulties or even major uncertainties to overcome, but success will still depend 100% on good implementation. The purpose of the **pilot fund** is to develop, test, refine, validate, and document such aspects, ensuring the smooth start and much better acceptance for the full-scale national fund. As there is no legal basis yet for compulsory participation, the pilot fund must be attractive for voluntary participation.

Pilot fund structure and governance

First, the proposed pilot fund is a private initiative, based on voluntary participation of organizations who choose to be climate pioneers and wish to learn and engage in carbon removal initiatives, gain time for their own transitions, and signal their commitment. They still need to fulfill their legal climate obligations, such as paying the CO_2 levy on heating fuel or participating in the EU ETS. As a private initiative, it does not need any additional legal basis, and could start very quickly.

It is not meaningful to define a 1.5°C budget for the pilot fund: to provide useful insights for the national fund, the pilot must start well before 2030; nor is calculating the historical responsibility of an organization possible.

In addition to developing the aspects listed above to the benefit of the future national fund, the voluntary pilot fund needs to provide immediate and tangible benefits to its participating organizations ("members"), so they will be motivated to participate:

1. Facilitate internal deep decarbonization through an objective carbon price and organizational learning
2. By decarbonizing own operations faster, save more money than the direct contribution to the pilot fund
3. Identify and develop opportunities around decarbonization and negative emissions:
    - for universities: research, teaching and learning
    - for companies: new products and services
4. Improve governance and quality of life, become a more attractive employer or university, establish or consolidate reputation as a climate leader
5. Gain time to prepare for society-wide deep decarbonization

The pilot fund will be a foundation with independent financial and carbon removal project supervision. It would share most principles with the Swiss Negative Emissions Fund:

- GHG and GWP (Global Warming Potential): All GHG are covered; non-CO_2 gases are converted to CO_2e based on 100-year GWP for long-lived gases, and GWP* for short-lived gases (see appendix).
- Emissions are declared by each member at the end of each quarter and paid within 30 days after declaration. Declarations are independently audited for consistency of methodology.

- All territorial GHG emissions in Switzerland are covered, plus international flights.
- Ramp-up: to allow members time to prepare, and reduce emissions as far as possible, there will be a transition period of 5 years, during which the percentage of emissions subject to payment to the fund will linearly increase every quarter, from 0 to 100%. For example, during the first quarter of the transition, only 5% of effective emissions will require payment, 10% in the second quarter, and so on, reaching 95% in the 19th and 100% from the 20th quarter.
- Synchronized or individual ramp-up timing, to be decided:
    - Option 1: On a given date, the same percentage of emissions subject to payment applies to all members; late joiners will align with other members. Benefits: motivation to join early, clearer communication, faster results of the pilot fund which can be used for the national fund.
    - Option 2: The ramp-up percentage is calculated by quarter from date of joining the pilot fund, for each member separately. Benefit: late joiners are not discouraged.
- The stabilized price per ton CO_2e will start at CHF 250, and be revised as needed.

The voluntary pilot fund is slightly different from the national fund. Given the small scale of the pilot fund, carbon removal projects can be developed quickly, limited only by money and efforts invested. Therefore, the implementation delay will be short, typically several months. Participating organizations will pay the full price on a growing percentage of their emissions, which will then be removed rapidly. This setup will lead to faster results, which is key for preparing the full-scale Swiss Negative Emissions Fund.

A key focus from the beginning will be how to account for and monitor project emissions and biodiversity impact over time. Additionally, given the learning character of the pilot fund and its small scale, a balance needs to be found between the following dimensions:

- **Diversification:** balance the need to gain in-depth experience with the need to cover multiple carbon removal methods (define min and max number of project types and projects)
- **Time horizon:** balance the low cost and short-term removal potential with the high(er) cost and longer-term potential (define min-max % fund allocation per time horizon)
- **Carbon removal vs. co-benefits:** for biological projects they are usually aligned; geological projects may include tradeoffs (define weight of co-benefits, elimination criteria for projects with negative effects)
- **Predictability vs. learning potential:** balance projects with low uncertainty with projects with learning potential for teaching and research (define min level of sequestration and cost predictability for acceptance of projects)
- **Geological storage:** if possible, use the pilot fund to open and validate 1-2 geological storage sites in Switzerland, as a much-needed basis for ca. 5 Mt CO_2 CCS p.a. from 2035-40.

CO_2 removal projects - selection and example

Given the initially small size of the pilot fund, a careful selection of the first carbon removal projects is essential.

This is a first estimate of the size of the pilot fund, assuming that it starts with 4 member organizations, emitting 10 kt, 15 kt, 25 kt, 50 kt CO_2e p.a. in Switzerland, with a ramp–up of 5% per quarter. The emissions subject to payment for the first year will correspond to

(5%+10%+15%+20%)/4 = 12.5% or 12.5 kt CO_2e. At the estimated starting price of CHF 250 per ton, the total funding for the first year would be CHF 3125k.

To ensure diversification, a mix of biological and geological projects, as well as short-term carbon removal and longer-term learning, this funding could be distributed as follows:

- Capture: 80% biological, 20% chemical
- Storage: 80% biological, 20% geological
- 80% short-term removal, <CHF 250/t, 20% long-term learning, >CHF 250/t
- Max 10% of annual investment (CHF 300k) on any single project
- Max 30% of annual investment on any single type of project

Each project must be attractive in its own right, but there is a strong benefit in ensuring a balanced portfolio.

As a **hypothetical example**, a balanced portfolio after one year could include:

- Three wetland restoration projects, total CHF 800k, CHF 200/t, 4000 t
- One forest restoration project, total CHF 100k, CHF 100/t, 1000 t
- One riverbed restoration project, total CHF 200k, CHF 200/t, 1000 t
- Five biochar and soil restoration projects, CHF 400k, CHF 500/t, 800 t
- One low-cost biochar project, temporary subsurface storage, CHF 200k, CHF 200/t, 1000 t
- One agroecology and soil restoration project, total CHF 100k, CHF 100/t, 1000 t
- One geological storage project, first year CHF 300k, CHF 1000/t, 300 t
- One enhanced weathering project, first year CHF 100k, CHF 500/t, 200t

Analyzing this hypothetical portfolio, we identify:

- Total 14 projects, total investment CHF 2200k, total CO_2 removed 9300 t, average cost CHF 236/t
- Reserve CHF 925k (29.6% of 3125k), CO_2 removed 74.4%
- Capture: 82% biological, 18% chemical
- Storage: 75% biological, 25% geological
- 64% short-term removal, <CHF 250/t, 36% long-term learning, >CHF 250/t
- Costs of monitoring each project are included in the project

Stakeholder acceptance

For the small size of the pilot fund, two main groups of stakeholders are key to acceptance: (1) students, employees and managers of the member organization, who need to pay into the fund and take action to reduce their emissions, and (2) local populations who need to support the removal projects to make them successful, and who will be the first to benefit from successful projects.

Learning how to win this acceptance is one of the most important outcomes of the pilot fund. An excellent starting point could be the community engagement resources of the United Nations Office for Disaster Risk Reduction, UNDRR and the Sendai Framework for Disaster Risk Reduction, as well as the UNEP Eco-DRR (Ecosystem-based Disaster Risk Reduction) Source Book[35], especially the chapters on community engagement and operationalizing resilience.

Alternatively, and closer to the Swiss tradition of direct democracy, deliberative approaches could be explored.

8. Appendix

Short-lived and long-lived GHG, and the case of methane

This technical chapter explains why and how, especially during rapid transitions, **methane emissions from agriculture must be considered differently from the 100-year warming multiplier generally adopted in climate planning and reporting**. It forms the basis for our modeling.

International climate policy has universally adopted the use of the metric GWP_{100}, which converts the climate effect of non-CO_2 GHG, such as methane (CH_4), nitrous oxide (N_2O), and fluorinated gases (F-gases, especially HFCs and SF_6). GWP_{100} calculates the equivalent Global Warming Potential of a gas relative to CO_2 over a period of 100 years. This works fine in practice for long-lived gases like nitrous oxide and most fluorinated gases, which remain in the air for well over 100 years, in some cases well over 10'000 years.

However, methane behaves very differently, and the convenient metric GWP_{100} poorly captures its impact on the climate. Initially, methane contributes to global warming well over 100 times as much as CO_2, but after a decade most of it has broken down[36] into CO_2 and water through natural oxidation in the atmosphere, mainly within the troposphere by reacting with the hydroxyl radical (OH). Therefore, GWP_{100} of methane, which is 28, only shows the "average" warming contribution, understating the effect of short-term changes and overstating the long-term effect.

Specifically, GWP_{100} suggests a long-term and constant warming due to methane, where in reality there is a short-lived powerful spike in warming effect. When methane emissions are constant, its concentration does not increase, as natural oxidation corresponds to emissions. However, an **increase in methane emissions has a significant warming effect; conversely reducing annual emissions has a one-time cooling effect**.

For this reason, the Swiss Academy of Sciences (SCNAT) recommends[37] using an adapted metric GWP*, which measures the effect of change in the rate of methane emissions, both for national and international GHG reporting. Pending international agreement, national accounting should include both metrics, GWP* and GWP_{100}. IPCC does not (yet) make a recommendation, but discusses this in detail in the AR6 Technical Summary[2] (TS.3.3.3 "Relating Different Forcing Agents").

Additionally, SCNAT recommends using GWP* to calculate required negative emissions, which in the case of **Switzerland, with slowly falling methane emissions, significantly cuts the needed NET related to methane**.

We follow the methodology recommended by SCNAT: $CO_2e^* = (105 \cdot \Delta E_m) + (7 \cdot E_m)$, where E_m are current methane emissions and ΔE_m is the absolute change in methane emissions over 20 years.

For methane from Swiss agriculture, based on the 1999-2019 period[31], when emissions slightly decreased from 160 to 155 kt CH_4, ΔE_m is -5 kt CH_4, the equivalent CO_2 emissions using GWP* are 105*(-5)+7*155 = 560 kt CO_2e, significantly less than the 155*28 = 4340 kt CO_2e obtained when using GWP_{100}

For the purpose of reaching net zero in 2050, we assume that most of the one-time step reduction in methane emissions happens well before this year, so we keep only the long-term component of GWP*: $CO_2e^* \approx 7 \cdot E_m$. Based on Switzerland's Long-Term Climate Strategy[24], E_m for agriculture corresponds to a 40% reduction from the 1990 level of 173 kt, or 104 kt CH_4. This means that total emissions of Swiss agriculture in 2050, using GWP*, reach **2.5 Mt CO_2e**, instead of 4.6 Mt, i.e. reducing the annual need for NET by 2.1 Mt, from 6.8 to 4.7 Mt. This is the number we will use in our model for calculating required negative emissions.

Modeled scenarios, assumptions, and parameters

	Baseline adapted from Switzerland's Long-Term Climate Strategy	**More ambitious climate policy**
ASSUMPTIONS		
Fund launch	2025	2025
Emissions decrease until	2045	2040
CO_2 price ramp-up to	2030	2030
2025 NET cost	CHF 800	CHF 800
2040 NET cost	CHF 350	CHF 350
Interest rate	2.5%	2.5%
2025 GHG emissions	36 Mt CO_2e	36 Mt CO_2e
2045 GHG emissions	9.7 Mt CO_2e	4.8 Mt CO_2e (from 2040)
2045 GHG after CCS	4.7 Mt CO_2e	1.8 Mt CO_2e (from 2040)
RESULTS		
Net zero reached in	2042	2039
Excess CO_2 removed by	2077	2068
CO_2 price per ton	CHF 279	CHF 245
Peak NET p.a.	10 Mt CO_2	6 Mt CO_2
Peak annual payment to fund	CHF 7.99 bn	CHF 5.75 bn

9. References

1. Nick, S. & Thalmann, P. *Carbon removal, net zero, and implications for Switzerland. E4S Enterprise for Society.* (2021).
2. IPCC AR6 SPM Climate Change 2021: The Physical Science Basis. in *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (eds. Masson-Delmotte, V. et al.) (Cambridge University Press, 2021).
3. *WWF (2020) Living Planet Report 2020 - Bending the curve of biodiversity loss. Almond, R.E.A., Grooten M. and Petersen, T. (Eds). WWF, Gland, Switzerland.*
4. *IPCC, 2018: Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. In Press.*
5. Stadelmann, I. Das Nein zum CO_2-Gesetz war kein Nein zu Lenkungsabgaben. *ProClim Flash 75* (2021).
6. Agreements for the implementation of Article 6 of the Paris Agreement, Federal Office for the Environment FOEN. https://www.bafu.admin.ch/bafu/en/home/themen/thema-klima/klimawandel-stoppen-und-folgen-meistern/klima--internationales/staatsvertraege-umsetzung-klimauebereinkommen-von-paris-artikel6.html.
7. *Climate Action Tracker | Warming Projections Global Update - November 2021*.
8. Climate Action Tracker: Switzerland. https://climateactiontracker.org/countries/switzerland.
9. *IIASA Policy Brief #30, October 2021*.
10. Luppi, B., Parisi, F. & Rajagopalan, S. The rise and fall of the polluter-pays principle in developing countries. *International Review of Law and Economics* **32**, 135–144 (2012).
11. Fressoz, J.-B. Le décret de 1810 : la libéralisation des « choses environnantes ». *Annales des Mines - Responsabilité et environnement* **62**, 16–22 (2011).
12. Liability - Legislation - Environment - European Commission. https://ec.europa.eu/environment/legal/liability/.
13. About *Carbon Takeback* - Stopping fossil fuels from causing global warming. *Carbon Takeback* https://carbontakeback.org/about/ (2020).
14. Allen, M. R., Frame, D. J. & Mason, C. F. The case for mandatory sequestration. *Nature Geosci* **2**, 813–814 (2009).
15. Jenkins, S., Mitchell-Larson, E., Ives, M. C., Haszeldine, S. & Allen, M. Upstream decarbonization through a carbon takeback obligation: An affordable backstop climate policy. *Joule* **5**, 2777–2796 (2021).
16. Landis, F., Marcucci, A., Rausch, S., Kannan, R. & Bretschger, L. Multi-model comparison of Swiss decarbonization scenarios. *Swiss Journal of Economics and Statistics* **155**, 12 (2019).

17. Thalmann, P. & Vielle, M. Lowering CO_2 emissions in the Swiss transport sector. *Swiss Journal of Economics and Statistics* **155**, 10 (2019).

18. Carbon Pricing Dashboard, The World Bank. https://carbonpricingdashboard.worldbank.org/.

19. *Setting the context for an EU policy framework for negative emissions, CEPS Scoping Paper*. https://www.ceps.eu/ceps-publications/setting-the-context-for-an-eu-policy-framework-for-negative-emissions/ (2021).

20. *Faktenblatt Oktober 2019 Nuklearforum Schweiz / swissnuclear: Finanzierung von Stilllegung und Entsorgung gesichert*.

21. Pedersen, E., Weisner, S. E. B. & Johansson, M. Wetland areas' direct contributions to residents' well-being entitle them to high cultural ecosystem values. *Science of The Total Environment* **646**, 1315–1326 (2019).

22. *Partnership for Market Readiness (PMR), Carbon Pricing Leadership Coalition (CPLC), 2018. Guide to Communicating Carbon Pricing.*

23. *Report - The Path to Net Zero - Climate Assembly UK*. https://www.climateassembly.uk/report/ (2020).

24. *Switzerland's Long-Term Climate Strategy Long-term low greenhouse gas emission development strategies (LT-LEDS) The Federal Council*. (2021).

25. *Energieperspektiven 2050+, Kurzbericht, Prognos AG / TEP Energy GmbH / INFRAS AG, im Auftrag des Bundesamts für Energie (BFE)*. (2020).

26. Willett, W. *et al.* Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. *The Lancet* **393**, 447–492 (2019).

27. *Gesetzentwurf der Bundesregierung Entwurf eines Ersten Gesetzes zur Änderung des Bundes-Klimaschutzgesetzes, 2021*.

28. Ritchie, H. & Roser, M. CO and Greenhouse Gas Emissions. *Our World in Data* (2020).

29. *Umweltbundesamt* Deutschland, Data › Environmental Indicators › Indicator: Greenhouse gas emissions › Emission of greenhouse gases covered by the UN Framework Convention on Climate. Umweltbundesamt https://www.umweltbundesamt.de/en/data/environmental-indicators/indicator-greenhouse-gas-emissions (2022).

30. Statistisches Bundesamt Deutschland - GENESIS-Online - Vorausberechneter Bevölkerungsstand: Deutschland, Stichtag, Varianten der Bevölkerungsvorausberechnung. https://www-genesis.destatis.de/genesis/

31. *Greenhouse gas inventory of Switzerland, Inventory data and documentation submitted under the UNFCCC in 2021 (covering the years 1990-2019). Submission of April 2021*.

32. *Neu U (2021) The impact of emissions from aviation on the climate. Swiss Academies Communications 16 (3).* https://scnat.ch/en/id/cSx4y.

33. *Thalmann, P., Cocker, F., Abraham, P.C., Brülhart, M., Orgland, N., Rohner, D. and Yaziji, M., 2021. Introducing an Air Ticket Tax in Switzerland: Estimated Effects on Demand. E4S Center.*

34.

35. Lee, D. S. *et al.* The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018. *Atmospheric Environment* **244**, 117834 (2021).

36. *Sudmeier-Rieux, K., Nehren, U., Sandholz, S. and Doswald, N. (2019) Disasters and Ecosystems, Resilience in a Changing Climate - Source Book. Geneva: UNEP and Cologne: TH Köln - University of Applied Sciences*.

37. *Jardine, C.N., Boardman, B., Osman, A., Vowles, J. and Palmer, J., 2004. Methane UK. The environmental change institute.*

38. *Swiss Academy of Sciences (SCNAT): Klimawirkung und CO_2-Äquivalent-Emissionen von kurzlebigen Substanzen, forthcoming.*