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Action Levers towards Sustainable Wellbeing: Re-Thinking Negative Emissions, Sufficiency, Deliberative Democracy

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Abstract

Systems theory defines leverage points as places to intervene in order to change a system. Points with high impact on system behavior are notoriously hard to act upon, and indeed most policy intervention is based at the lowest level (#12 in Donella Meadows' order), via subsidies, taxes, or standards. This thesis explores how some of our most pressing issues, especially climate, biodiversity, or inequality, could be effectively solved using "action levers", coordinated action on multiple leverage points, like mindset (#2), system goal (#3), power to change system structure (#4), or rules (#5). Three action levers are identified, explored and partly tested: Negative Emissions, Sufficiency, Deliberative Democracy.

If suitably governed, **Negative Emissions** could reverse their current effect of extending the fossil era and its power relations and, while limited to perhaps 10% of current emissions, significantly accelerate decarbonization – a beneficial case of the "tail wagging the dog". We modeled two cases, Switzerland and global aviation, and found that an effective 1.5°C-compatible climate policy is affordable and accelerates today's strategies by more than a decade. Through a polluter-financed public fund, investing in nature-based solutions with biodiversity and societal co-benefits, several defining elements of society could be durably changed: democratizing governance, transferring wealth from corporations to communities, avoiding technological lock-in, and building purpose and identity. To test implementation with today's laws, we are preparing a voluntary 1%-scale pilot fund.

Sufficiency is central to any sustainable society. Since May 2022, as part of the SFOE SWICE project, frameworks for wellbeing, human needs, provisioning systems, and resource use were developed, to ensure consistency of the whole consortium, including its living labs. Furthermore, qualitative analysis of attitudes towards sufficiency has been conducted in stakeholder workshops. This will be the basis for quantitative analysis and modeling, building on this thesis – aiming to rethink the Swiss habitat, its satisfiers and provisioning systems, towards wellbeing for all with a much lower resource footprint.

Deliberative Democracy, in countless citizens' assemblies since the 1980s, reached remarkable convergence on complex topics linked to values, impacting human lives. However, it proved difficult to engage the population which has not participated in the assembly. On this foundation of active learning and facilitated deliberation, where knowledge and shared values emerge, we developed the theory, process, and IT tools of a universal "Academic Citizens' Assembly". It has been successfully conducted five times, with 20-200 participants, online and in three cities, on topics like energy, food, health, sufficiency, and climate policy, with final convergence >80% on the main proposals. A commune-scale assembly is in discussion for 2024.

Outreach to citizens and policymakers was developed for all policy-relevant results. Several limitations remain: the role of fossil fuel bans, needed public investments, quantification of a transition towards sufficiency, or how to build acceptance and integrate deliberative assemblies into the political system. Still, the conclusion is clear: the three action levers can be effective, and reinforce each other.

Résumé

La théorie des systèmes définit les points de levier comme des endroits où il faut intervenir pour modifier un système. Les points à fort effet de levier sont notoirement difficiles à actionner, et de fait, la plupart des interventions politiques se font au niveau le plus bas (#12 dans l'ordre de Donella Meadows), en actionnant des paramètres tels que les subventions, les taxes ou les normes. Cette thèse explore comment certains des problèmes les plus urgents de notre époque, notamment le climat, la biodiversité ou les inégalités, pourraient être résolus efficacement en utilisant des points de levier élevés, comme le paradigme (mindset) (#2), l'objectif du système (#3), le pouvoir de changer la structure du système (#4) ou les règles du système (#5). Trois leviers d'action sont identifiés et étudiés en détail : Les émissions négatives, la sobriété, et la démocratie délibérative. Dans la mesure du possible, les trois seront prototypés et testés.

Avec une gouvernance appropriée, les **émissions négatives**, pourraient inverser leur effet actuel de prolongation de l'ère fossile et de ses relations de pouvoir et, bien que limitées à peut-être 10 % des émissions actuelles, accélérer de manière significative la décarbonisation - un cas bénéfique de la "queue qui remue le chien". Nous avons modélisé deux cas, celui de la Suisse et celui de l'aviation mondiale, et avons constaté qu'une politique climatique efficace et compatible 1,5 °C serait abordable et accélère de plus d'une décennie la politique climatique actuelle. Grâce à un fonds public financé par les pollueurs, investissant dans des solutions fondées sur la nature et présentant des co-bénéfices pour la biodiversité et la société, plusieurs éléments déterminants de la société pourraient être modifiés de manière durable : démocratisation de la gouvernance, transfert de la richesse des entreprises vers les communautés, rupture du verrouillage technologique, ainsi que l'émergence d'un objectif commun et d'une identité partagée. Pour tester la mise en œuvre avec la législation actuelle, nous préparons un fonds pilote volontaire à l'échelle de 1 %.

La **sobriété** est essentielle à toute société durable. Depuis mai 2022, dans le cadre du projet SWICE de l'OFEN, des approches-cadres pour le bien-être, les besoins humains, les systèmes d'approvisionnement et l'utilisation des ressources ont été développés, afin d'assurer la cohérence de l'ensemble du consortium, y compris ses laboratoires vivants. En outre, une analyse qualitative des attitudes à l'égard de la sobriété a été menée dans le cadre d'une série d'ateliers réunissant les parties prenantes. Elle servira de base à l'analyse quantitative et à la modélisation, en s'appuyant sur la présente thèse - dans le but de repenser l'habitat suisse, ses principales “satisfiers” et ses systèmes d'approvisionnement, afin d'atteindre le bien-être pour tous avec une empreinte sur les ressources beaucoup plus faible.

La **démocratie délibérative**, dans de nombreuses assemblées citoyennes depuis les années 1980, atteint systématiquement une convergence remarquable sur des sujets complexes liés aux valeurs, ayant un impact sur les vies humaines. Cependant, il s'est avéré difficile d'impliquer la population qui n'a pas participé à l'assemblée. Sur cette base d'apprentissage actif et de délibération facilitée, où les connaissances et les valeurs partagées émergent, nous avons développé la théorie, le processus et les outils informatiques d'une "Assemblée Citoyenne Académique" universelle. Elle a été menée avec succès à cinq reprises, avec 20 à 200

participants, en ligne et dans trois villes, sur des sujets tels que l'énergie, l'alimentation, la santé, la sobriété et la politique climatique, avec une convergence finale >80% sur les principales propositions. Les discussions pour la prochaine assemblée à l'échelle d'une commune sont en cours.

La sensibilisation des citoyens et des décideurs politiques a été développée pour tous les résultats pertinents sur le plan politique. Plusieurs limitations subsistent : le rôle de l'interdiction des combustibles fossiles, les investissements publics nécessaires, la quantification d'une transition vers la sobriété, l'acceptation ou comment intégrer les assemblées délibératives dans le système politique. Néanmoins, la conclusion est claire : les trois leviers d'action peuvent être efficaces et se complètent.

Zusammenfassung

In der Systemtheorie werden Hebelpunkte (leverage points) als Ansatzpunkte definiert, an denen eingegriffen werden muss, um ein System zu verändern. Punkte mit hoher Hebelwirkung sind bekanntermassen schwer zu beeinflussen, und tatsächlich basieren die meisten politischen Interventionen auf der untersten Ebene (Nr. 12 in der Hierarchie von Donella Meadows), durch Parameter wie Subventionen, Steuern oder Standards. In dieser Arbeit wird untersucht, wie einige der wichtigsten Probleme unserer Zeit, insbesondere Klima, biologische Vielfalt oder Ungleichheit, mit Hilfe von Hebeln wie Denkweise (mindset - Nr. 2), Systemziel (Nr. 3), Fàhigkeit, die Systemstruktur zu verändern (Nr. 4) oder Systemregeln (Nr. 5) wirksam gelöst werden könnten. Drei Aktionshebel werden identifiziert und untersucht: Negative Emissionen, Suffizienz, Deliberative Demokratie. Soweit möglich, werden alle drei als Prototypen getestet.

Mit einer geeigneten Governance könnten **Negative Emissionen** ihre derzeitige Auswirkung auf die Verlängerung des fossilen Zeitalters und seiner Machtverhältnisse umkehren und, obwohl sie auf vielleicht 10 % der heutigen Emissionen begrenzt sind, die Dekarbonisierung erheblich beschleunigen. Wir haben zwei Fälle modelliert, die Schweiz und die globale Luftfahrt, und festgestellt, dass eine wirksame 1,5°C-kompatible Klimapolitik durchaus bezahlbar ist und die heutigen Strategien um mehr als ein Jahrzehnt beschleunigt. Durch einen verursachergerecht finanzierten öffentlichen Fonds, der in naturbasierte Lösungen mit Zusatznutzen für Biodiversität und Gesellschaft investiert, könnten mehrere bestimmende Elemente der Gesellschaft nachhaltig verändert werden: Demokratisierung der Regierungsführung, Werttransfer von Unternehmen auf Gemeinden, Vermeidung von technologischem Lock-in und Aufbau von Sinn und Identität. Um die Umsetzung mit den heutigen Gesetzen zu testen, bereiten wir einen freiwilligen Pilotfonds entsprechend etwa 1 % der heutigen Emissionen vor.

Suffizienz ist für jede nachhaltige Gesellschaft von zentraler Bedeutung. Seit Mai 2022 wurden im Rahmen des BFE-SWICE-Projekts Konzepte für Wohlbefinden, menschliche Bedürfnisse, Versorgungssysteme und Ressourcennutzung entwickelt, um die Kohärenz des gesamten Konsortiums, einschliesslich seiner Living Labs, zu gewährleisten. Darüber hinaus wurde in einer Reihe von Stakeholder-Workshops eine qualitative Analyse des Denkens um Suffizienz durchgeführt. Dies wird die Grundlage für eine quantitative Analyse und Modellierung sein, die auf dieser Arbeit aufbaut - mit dem Ziel, den Schweizer Gebäudebestand, seine wichtigsten "satisfiers" und Versorgungssysteme zu überdenken, um Wohlbefinden für alle mit einem viel geringeren Ressourcen-Fussabdruck zu erreichen.

In unzähligen Bürgerversammlungen seit den 1980er Jahren hat die **Deliberative Demokratie** eine bemerkenswerte Konvergenz bei komplexen Themen erreicht, die mit Werten verbunden sind und das Leben der Menschen beeinflussen. Es erwies sich jedoch als schwierig, die breitere Bevölkerung einzubeziehen, die nicht an der Versammlung teilgenommen hat. Auf dieser Grundlage des aktiven Lernens und der moderierten Deliberation, bei der Wissen und gemeinsame Werte entstehen, haben wir die Theorie, den Prozess und die IT-Tools einer universellen "Akademischen Bürgerversammlung" entwickelt. Sie wurde fünfmal erfolgreich mit 20-200 Teilnehmern online und in drei Städten zu Themen wie Energie, Ernährung, Gesundheit,

Suffizienz und Klimapolitik durchgeführt, mit einer Übereinstimmung von mehr als 80 % bei den wichtigsten Vorschlägen. Die Diskussionen über die nächsten Versammlungen sind im Gange.

Für alle politikrelevanten Ergebnisse wurden Massnahmen zur Einbeziehung von Bürgern und politischen Entscheidungsträgern entwickelt. Einige Einschränkungen bleiben: die Rolle von Verboten fossiler Brennstoffe, notwendige öffentliche Investitionen, die Quantifizierung des Übergangs zur Suffizienz, oder die Frage der Akzeptanz, wie deliberative Versammlungen in das politische System integriert werden können. Dennoch ist die Schlussfolgerung klar: Die drei Aktionshebel können wirksam sein und sich gegenseitig ergänzen.

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Acronyms

ACA: Academic Citizens' Assembly

AFOLU: agriculture, forestry and other land use

ATAG: Air Transport Action Group

BAFU (German) - OFEV (French) - FOEN (English): Swiss Federal Office of the Environment

BECCS: bioenergy with CCS

BFE (German) - OFEN (French) - SFOE (English): Swiss Federal Office of Energy

BSL: Business School Lausanne

CCD: UNIL Centre de compétences en durabilité

CCS: carbon capture, and storage

CCUS: carbon capture, utilization, and storage

CDR: carbon dioxide removal

CEN: EPFL Energy Center

CLIMACT: UNIL-EPFL Center for Climate Impact and Action

CORSIA: Carbon Offsetting and Reduction Scheme for International Aviation

DACS: direct air capture and storage (sometimes DACCS)

DLS: decent living standards

E4S: Enterprise for Society Center (UNIL-IMD-EPFL)

ECT: Energy Charter Treaty

EDITS: Energy Demand changes Induced by Technological and Social innovations

EOR: enhanced oil recovery

EPFL: École Polytechnique Fédérale de Lausanne

EW: enhanced weathering

FHN: fundamental human needs

GHG: greenhouse gas

IAMs: Integrated Assessment Models

IATA: International Air Transport Association

ICAO: International Civil Aviation Organization

IIASA: International Institute for Applied Systems Analysis

IPBES: Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services

IPCC: Intergovernmental Panel on Climate Change

LEURE: EPFL Laboratory of Environmental and Urban Economics

NBS: Nature-based solutions

NDCs: country nationally determined contribution (under UNFCCC)

NE: negative emissions

NEFA: Negative Emissions Fund for Airlines

NET: negative emission technologies

ODS: ozone depleting substances

PB: planetary boundaries

SNEF: Swiss Negative Emissions Fund

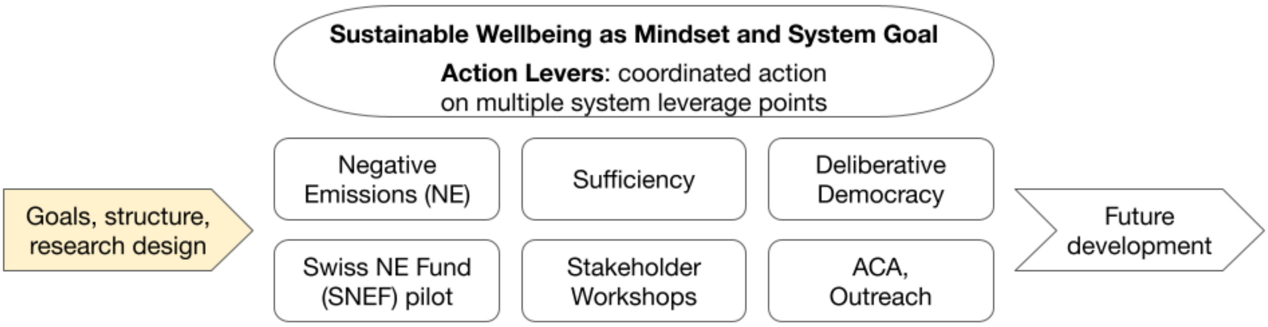
SRM: solar radiation management

STRN: Sustainability Transitions Research Network

SWICE: Sustainable Wellbeing for the Individual and the Collectivity in the Energy transition

WHR: World Happiness Report

Part I: Introduction



1. Introduction: Action levers of societal transitions

1.1. A systems view of the World in 2023

As we enter 2023, there are many good reasons for a sustainability scholar or any concerned citizen to feel bad about the State of the World, as most of the main dimensions related to wellbeing of humans and non-humans are extensively documented as continuously deteriorating. These include climate change (IPCC 2021, 2022), biodiversity loss (IPBES 2019; WWF 2020, 2022), four other planetary boundaries (Steffen et al. 2015, Persson et al. 2022, Wang-Erlandsson et al. 2022), inequality (Piketty 2021), and for the first time in 80 years, in a reversal of the historical trend of reduced great power confrontation (Pinker 2018), increased geopolitical instability.

Could all these developments be linked? The obvious link are fossil fuels, the main driver of climate change, enabler of industrial agriculture, the main driver of biodiversity loss, and especially with oil and gas, the main enabler of the concentration of power (Mitchell 2009), and the funding source of the war in Ukraine.

There is another, less intuitive but equally powerful driver: economic growth. Identified in the late 1960s at MIT with the development of the system dynamics discipline (Forrester 1971), and well documented ever since (Meadows et al. 1972, 2004). In one of the most powerful conceptual tools of systems theory, leverage points, or places to intervene in order to change a system, Donella Meadows (1999, p.1) defines growth as a central leverage point. She writes:

> *The classic example of that backward intuition was my own introduction to systems analysis, the world model. Asked by the Club of Rome to show how major global problems — poverty and hunger, environmental destruction, resource depletion, urban deterioration, unemployment — are related and how they might be solved, Forrester made a computer model and came out with a clear leverage point: Growth. Not only population growth, but economic growth. Growth has costs as well as benefits, and we typically don't count the costs — among which are poverty and hunger, environmental destruction, etc. — the whole list of problems we are trying to solve with growth! What is needed is much slower growth, much different kinds of growth, and in some cases no growth or negative growth.*

Half a century ago, Limits to Growth concluded:

> *If there is cause for deep concern, there is also cause for hope. Deliberately limiting growth would be difficult, but not impossible. The way to proceed is clear, and the necessary steps, although they are new ones for human society, are well within human capabilities. Man possesses, for a small moment in his history, the most powerful combination of knowledge, tools, and resources the world has ever known. He has all that is physically necessary to create a totally new form of human society-one that would be built to last for generations. The two missing ingredients are a realistic, long-term goal that can guide mankind to the equilibrium society and the human will to achieve that goal. Without such a*

goal and a commitment to it, short-term concerns will generate the exponential growth that drives the world system toward the limits of the earth and ultimate collapse. With that goal and that commitment, mankind would be ready now to begin a controlled, orderly transition from growth to global equilibrium. (Meadows et al. 1972, pp.183-4)

Reversing growth alone, however, will not necessarily improve human wellbeing, although it would obviously reduce pressure on planetary boundaries. Contemporary degrowth literature, studying the history of growth, limits to decoupling and "green growth", no-growth employment and money, successful past and today's stationary societies, technological implications, and the politics of degrowth, generally conclude that ending growth would destabilize society, unless its values, institutions, policies, and daily practices are transformed (Kallis et al. 2018).

From a systems perspective, this approach would rethink key elements such as the system goal, mindset, structure, or rules, described in detail in the next section. Furthermore, growth is not only the (often implicit) system goal, it is also an emergent property of the system, resulting from system structure, itself arising from the mindset - supporting the need for expanding the analysis beyond the focus on growth (as system goal) only.

To better understand these links, the thesis includes another tool, the four-level Iceberg Model (Monat and Gannon 2015) – comprising events, patterns, system structure, and mental models – as a complement to system dynamics. In this model, relationships between system elements self-organize over time through their interactions, and together define the **system structure**. For human systems, these interactions are the result of, but also shape culture, values, and paradigms, together defining **mental models**. These two "invisible" areas give rise to the visible dynamic behavior of the system, **events** and **patterns**, as an emergent property.

Today, science has made tremendous progress, and our knowledge has greatly expanded, but with one positive exception of reverting to within the safe zone for the planetary boundary for stratospheric ozone depletion, no global environmental issue has ever improved, although many local ones have.

Yet, contrary to the physical changes to the system, almost always gradual and slow on a human timescale, opinions and mindsets can and are starting to change rapidly. This is our glimmer of hope, and the most promising focus of action.

This thesis identifies three "action levers", shown in Table 1.1, or areas in which coordinated action on multiple leverage points (Meadows 1999) could produce a positive and lasting change to our society. Negative emissions are explored from a country and a global sector perspective. Sufficiency, as a universally applicable organizing principle of society, is primarily explored from a perspective of rich countries. Finally, a way to combine deliberative and participatory democracy is proposed as an improvement of democracy, which presupposes some level of existing democracy in society.

Table 1.1: Linking action levers to leveraging points for societal transitions (Meadows 1999)

Action lever → Leverage point ↓	Negative Emissions	Sufficiency	Deliberative Democracy
2			
3			
4			
5			
6			
7-8			
9-12			

To the extent possible, every key proposal related to the three action levers put forward in this thesis is being prototyped, tested, or at least discussed with multiple stakeholder groups.

1.2. Leverage points in sustainability science

Since Donella Meadows (1999) published her seminal work, it continues to inspire systems change research, and has been linked to a wide range of scientific work, including a large body of literature upon which this thesis was developed.

Leverage points (LP) have been classified (Abson et al. 2017) in four "realms of leverage" or "system characteristics": parameters (#10-12), feedbacks (#7-9), design (#4-6), and intent (#1-3); with growing impact of intervention. The lower six LP (#7-12) are defined as "shallow" LP, and the upper six (#1-6) as "deep" LP. Today, almost all public policy related to sustainability acts on "shallow" LP, making intervention easier but less impactful.

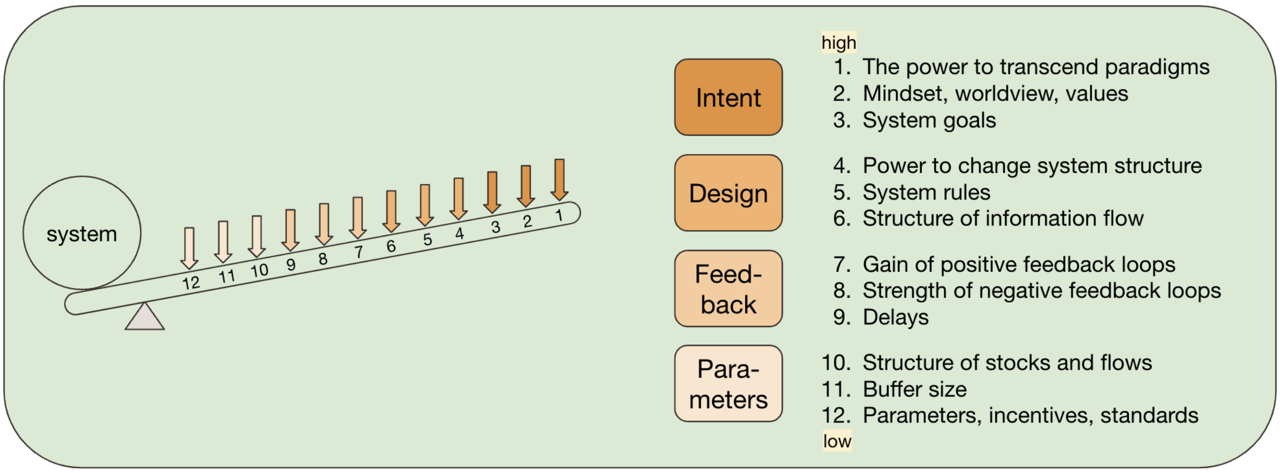


Figure 1.1: Leverage points and "realms of leverage", adapted from Abson et al. 2017 and Meadows 1999

Many good reasons are identified for using leverage points in sustainability science, in particular as a boundary object for multidisciplinary study (Fischer and Riechers 2019). Here a boundary object is understood as a concept used and interpreted in different ways by different (research) communities, yet retaining sufficient common identity (Star 2010). In sustainability science, by nature interdisciplinary, where the "interesting" (for scientific understanding) interactions occur at disciplinary boundaries, such interdisciplinary collaboration is especially important.

Many frameworks at the core of sustainability science have been linked to leverage points (Abson et al. 2017, Fischer and Riechers 2019): Geels' multi-level perspective (2011), Ostrom's Governing the Commons (1990), valuing ecosystem services (Costanza et al. 1997), or resilience (Folke et al. 2006).

Degrowth scholarship regularly relies on system science, but does not frequently focus on leverage points. In a notable exception, Videira et al. (2014) analyze the mapping of cross-impacts of degrowth proposals by experts (conference participants) based on causal loop diagrams, and identify four leverage points for degrowth: creating new negative feedback loops (#8), reducing gains in positive feedback loops (#7), changing system rules (#5), and changing paradigms (#2).

The term "action levers" is not (yet) broadly used in scientific literature. It differs from leverage points as a coordinated set of actions based on multiple leverage points.

The most prominent example of linking policy levers, leverage points, and desired outcomes in terms of drivers of biodiversity loss is included in the IPBES report (2019); the comprehensive Chapter 5 (pathways towards a sustainable future) expert deliberation process is described (Chan et al. 2020), and shown in Figure 1.1.

For example, the highest leverage point, "Visions of a good life" corresponds to changing both mindset and system goal, away from today's hegemonic vision, in the sense of Antonio Gramsci (Bates 1975), of material consumption.

This thesis has a narrower focus than the frameworks cited above, but expands the leverage points beyond #2-5-7-8 linked to main degrowth proposals (Videira et al. 2014), to include at least #3 (system goal: wellbeing for all within ecological constraints), #4 (power to change system structure: sufficiency as organizing principle and universal citizens' assemblies), #6 (information flows: deliberative assemblies), and #12 (incentives: price for carbon removal). Most importantly, it introduces and develops the concept of action levers, areas in which coordinated action on multiple leverage points could produce a positive and lasting change to society.

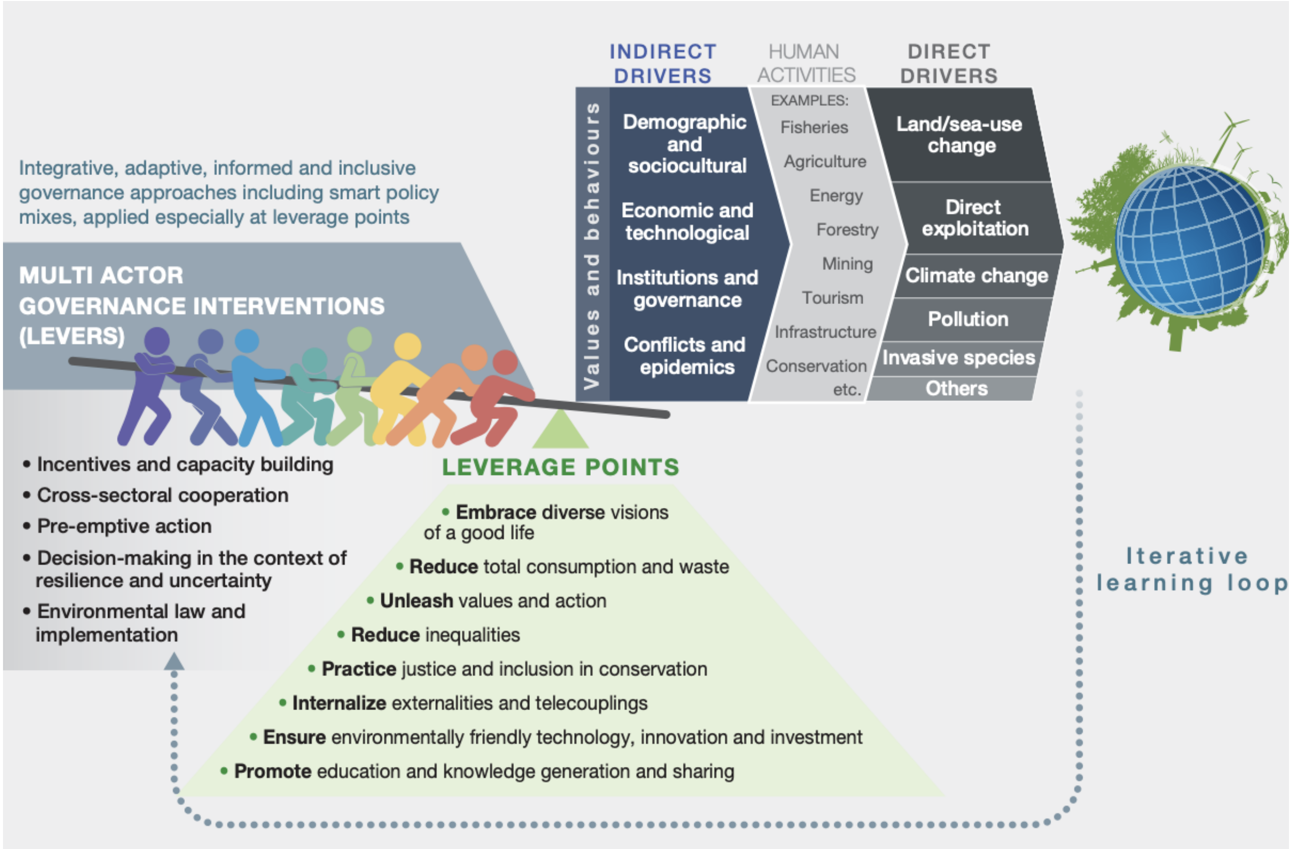


Figure 1.2: Policy levers, leverage points, and desired outcomes in terms of reducing drivers of biodiversity loss (reproduced from the Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, SPM, Fig.9, p.40, IPBES 2019)

2. Goals, gaps, research design, structure

This chapter will highlight gaps in our understanding of society's inability to solve the wicked problems identified in chapter 1, as a basis for structuring the thesis.

The specific choice of topics and gaps is of course subjective, so I will explore the goals I personally followed in writing this thesis, and how these goals influenced the focus and methods. While it is hard for any researcher to explicitly identify his or her biases, I will at least attempt to show the context likely to influence my choices and assumptions.

On this basis, the design and overall structure of the research will be developed. The thesis itself follows the same structure.

2.1. Introduction to negative emissions, sufficiency, and deliberative democracy

Negative emissions (NE) can best be defined as human activities that remove CO_2 already released in the atmosphere (Minx et al. 2018). While in principle applicable to all greenhouse gases, no practical methods have yet been proposed to remove other gases beyond CO_2. The concept itself is as old as climate science itself, and planting trees at a large scale has been proposed since the 1970s. With the limited remaining carbon budget, the 1.5°C target instead of 2.0°C, and their integration in integrated assessment models, large-scale use of negative emissions has integrated in much climate modeling since IPCC AR5 (Minx et al. 2018). The main technological method of sequestering carbon, carbon capture and storage (CCS), was developed in the early 1970s as a way to extract more oil from depleted fields, and has been used ever since to extend the fossil era (Nick and Thalmann 2021). NE are limited by land, water, energy, and most importantly their impact on ecosystems, with a wide range of estimates centered around 10% of current emissions (IPCC 2022). This limitation, together with the large impact on biodiversity and local communities, and the potential for long-term technological lock-in and potentially significant wealth and power transfer, define the context within which a suitable governance of negative emissions must be developed.

Sufficiency is described in many ways, but at a societal organization level, as a major potential contribution towards a sustainable society, it can be defined as "*... a set of measures and daily practices that avoid demand for energy, materials, land and water while delivering human wellbeing for all within planetary boundaries*" (IPCC 2022). Human wellbeing is here understood in the eudaimonic tradition of human flourishing, based on satisfying all fundamental human needs (Max-Neef 1991, Doyal and Gough 1991, Gough 2017). At this level, it combines the system goal of universal wellbeing within an ecological constraint with a number of system characteristics together called an "organizing principle", opposed to the efficiency principle: system structure, rules, information flows (Princen 2005). Society-level sufficiency would significantly reduce material and energy flows (Rao et al. 2019, Millward-Hopkins et al. 2020), redistributing power.

Deliberative democracy is a type of democracy based on deliberation, a public exchange of arguments among equal citizens. According to Habermas, it is the quality of this deliberation that serves as a basis for legitimacy of public decisions, including election and accepted laws and policies (Landemore 2020). In a polarized world, facing multiple wicked problems of sustainability requiring time to understand and strong shared values on which to start building a solution, deliberative democracy is one of the most promising approaches of governance, and perhaps the only one capable of transitioning from the current political system in the market paradigm of competition between interests towards genuine dialogue, which will lead to both opinion- and will formation (Vitale 2006). It has the potential to overcome today's hegemonies of consumption, growth, extraction, preference satisfaction and similar.

Chapters 3, 8, and 11 provide a literature review and specific gap analysis for negative emissions, sufficiency, and deliberative democracy respectively; this chapter takes a system-level view.

2.2. Research gaps and research questions

The Sustainability Transitions Research Network (STRN) identifies nine main research topics: (1) understanding transitions; (2) power, agency and politics; (3) governing transitions; (4) civil society, culture and social movements; (5) businesses and industries; (6) transitions in practice and everyday life; (7) geography of transitions; (8) ethical aspects; and (9) methodologies (Köhler et al. 2019). The whole field has undergone significant development in scale, scope, structure, internal links to other subfields and other disciplines, and overall visibility in less than 20 years.

This is a remarkable achievement, given the key characteristics of sustainability transitions, especially: multidimensionality, including the co-evolution of actors and practices; open-endedness and uncertainty; disagreement on values and goals; and "normative directionality", i.e. given the public good nature of sustainability as an outcome and limited incentives of private actors, the need for public policy to shape transitions based on a normative view of societal goals (Köhler et al. 2019). This comprehensive review paper identifies dozens of nascent and future research directions, corresponding to gaps in our understanding.

For example, under power and politics, understanding starts with answering the key question "who gets what, when, and how" - in this thesis explored as the impact of nature-based vs. technological approaches to negative emissions on appropriation, as well as setting the level of residual emissions as a decarbonization target.

Still, given the broad success in research outlined above, why do we need even more research, given the urgency and the risk of ecological collapse? Don't we already know enough to act? The biggest problems of society, like the climate or biodiversity crisis, or growing inequality are certainly well researched and documented, individually and in connection. We know exactly what is happening, in most cases why and how, and very importantly what to do. For example, recommendations by both IPCC (2022) and IPBES (2019) are perfectly adequate and sufficient to develop a much improved public policy. So, why is very little happening on the ground? This also is well documented: for example climate action is failing for nine reasons, linked to power and politics, governance, vested interests, and dominant mindsets and lifestyles (Stoddard 2021).

In addition to research topics discussed above, two recent papers providing an analysis of research gaps, for a sector and for an academic discipline, can help refine the analysis of gaps. For agro-food, beyond the obvious need to examine power and politics, topics like agency of individual actors such as corporations, or grassroots and community initiatives, or spatial and scalability analysis are identified as the main research gaps (El Bilali 2019).

For ecological economics, an academic discipline essential for understanding any transition towards sustainability, Pirgmaier and Steinberger (2019) identify three gaps (planetary scale poorly integrated in research; biophysical focus overshadowing social understanding, and in particular power, context, and wellbeing; positioning too strongly defined with respect to neoclassical economics), and propose a new research agenda. This new agenda builds on the defining vision of ecological economics of wellbeing for all within limits, but refocuses it away from the current obsession with growth (which is an emergent property of system structure) and towards research on social justice and satisfying needs, complementing the biophysical analysis; confronting dominant thinking of capitalism including mainstream economics, which has led to widespread deprivation, in addition to well-documented environmental destruction; and building a "pluralist heterodox community" of scholars and practitioners.

How do we start changing this inaction on climate, biodiversity, or other key issues? This is the main gap my thesis aims to answer. More specifically, **how could systems thinking help identify areas where coordinated action is likely to start a transition, reconfiguring essential aspects of society for decades?**

The underlying research hypothesis can be formulated as: Negative emissions, sufficiency, and deliberative democracy are suitable "action levers", or areas in which coordinated action on multiple leverage points could produce a positive and lasting change to our society, and the three action levers reinforce each other.

Finally, the following **research questions** and sub-questions crystallize (or in systems theory, "emerge", as a property of linking the elements described above):

1. Do limited negative emissions have the potential to significantly accelerate a country's transition to net zero?
    a. What is needed to make the transition ecologically and socially beneficial and fair?
    b. Can the governance and financial model be adapted to extra-territorial sectors like global aviation?
2. Can sufficiency deliver high wellbeing for all with low resource use in Switzerland? Under which conditions?
3. Can deliberative and participatory democracy provide the needed governance? How?

2.3. Personal goals: based on research, improve teaching, company action, public policy, societal goals

Compared to most EPFL PhD students, my personal context is somewhat unusual, as I decided to pursue a PhD after a reasonably successful career in senior management in technology-based multinational companies, and another career as an inventor and (co-)founder of four start-ups, including one company I still lead. This PhD is a well-reflected choice, absolutely not a necessity, linked to the start of my third career as a teacher, having returned to academia eight years ago, and progressively getting more and more engaged.

This return to teaching complex topics from basics of sustainability to societal transitions made me realize how much I would need to learn to become a confident and broadly knowledgeable teacher, but also practice evidence-based teaching and learning. This was my first goal.

Additionally, as I continue advising companies on sustainability strategy and employee engagement for sustainability, I needed a much more solid basis to better identify areas of high impact. This defined my second goal.

Finally, working on key aspects related to public policy, it became clear early in my work how much is missing in terms of good policy advice, and separately how difficult it is to implement good policy. Contributing to both dimensions became my third goal about a year into my PhD.

Overall, given the context of societal urgency, I'm mainly drawn to topics that can be tested or prototyped rapidly, and if successful, broadly deployed in just a few years.

Also, in terms of possible bias, it is worth noting that my work experience includes several different countries, all of them rich: Switzerland, Austria, France, US, Japan, Germany.

After becoming a Swiss B Leader in 2020, on my B Lab profile page I wrote:

> *There is so much beauty, resilience, and mystery in life that continuing to run after money and material growth is the ultimate tragedy of humanity. Our obsolete system, efficiently transforming the biosphere into waste, needs urgent replacement by a much better, inclusive society, cherishing life in all its forms, enabling human flourishing, starting with science, the arts, and human relationships.*
>
> *Please join me in building this world.*

2.4. Broader context: action research, wicked problems, different practitioner values

Beyond the gaps and my personal views, here I'd like to summarize the relevant broader context.

First, given the urgency, complexity, and multiple perspectives involved, whenever possible, action research seems particularly well suited to the topic of sustainable wellbeing, as a method aiming to understand and solve an issue at the same time. While the benefits in terms of real-life learning and iteratively improving the solution are obvious, challenges are less obvious, especially the need for a common ethical framework between researchers and practitioners (Avison et al. 1999). In this thesis, action research is mainly used in prototyping deliberative democracy approaches, as well as a negative emissions pilot fund.

Second, all three broad issues studied, net zero, sufficiency, and democracy, can be characterized as "wicked problems", a category of uniquely complex problems, without a definitive formulation, where the perspective taken defines possible solutions, and where every problem is a symptom of another one (Rittel and Webber 1973). Most big and interesting issues in sustainability are wicked problems.

Third, practitioners from politics, business, civil society, public administration, or citizens, have very different values, explicit, or more often implicit. This relates directly to wicked problems, where the (value-driven) perspective defines certain solutions, and precludes others.

2.5. Separating advice on evidence from advice on action, integrating personal bias

What level of public engagement by scientists is optimal for a thriving society? What is acceptable, legitimate, desired, or required? In this section, I'll explore two partially opposed views and briefly reflect on my own engagement and bias.

Roger Pielke published The Honest Broker in 2007, identifying four archetypal roles scientists can play with respect to policy-making, based on the level of consensus on values, and scientific uncertainty on facts (Pielke 2007, p.19): pure scientist, science arbiter, issue advocate, and honest broker. Pielke separates advice on evidence from advice on options. Values and biases play a much bigger role in selecting options than in presenting evidence. For example, advice on evidence might include the level of climate warming associated with a certain level of CO_2 emissions, and the resulting impact on ecosystems and ecosystem services. It could be value-neutral except for the fact of unbalance of knowledge of policymakers and scientists, and the selection of evidence to present might be influenced by values. On the other hand, promoting an option is almost entirely value-driven: in the above example, choosing to act by drastically reducing the world population, or by eliminating fossil fuels and inequality within a decade, or choosing not to act and hoping for the best, are all perfectly possible. An honest broker will not reduce the scope of choice, but make consequences and underlying values explicit.

Pielke's book brought knowledge brokering to the attention of a large number of scientists. This led to the quest for "effective" science-policy interaction, and recommendations to make it more effective (Gluckman et al. 2021), such as: identify the policymaker "clients", the policy question, think about framing (are we asking the right question), evaluate the level of consensus, and communicate the tradeoffs inherent in policy options.

It is important to recognize that this view limits the engagement of scientists to presenting options in a value-neutral way, but not trying to influence the public debate, and let others decide what to do. Given the imbalance of power, this view limits the challenge to incumbents by the best informed members of society, and on urgent topics where incumbents do not want to change, is likely to slow or delay action. Climate action would be the perfect example.

The "Report of the Working Group on Research and Engagement" of the University of Lausanne (Fragnière 2022), based on a university-wide survey and work of an expert group, presents a much more complete analysis and defines public engagement of scientists as "any interaction with the public whose content has a normative aspect" (p.6), and identifies that the very mission of UNIL and Swiss public universities is to engage in society, included in both law and institutional charters. Such engagement cannot and should not be neutral; instead what is desired is objectivity, scientific rigor, and transparency about values. Beyond individual engagement, it is important that the institution itself support the culture of engagement for its community.

This thesis follows Pielke in separating, to the extent possible, advice on evidence from advice on options. On the other hand, given the moral imperative to act, it takes a much more engaged view on normative questions, closely aligned with the UNIL report.

For example, chapter four structures evidence around negative emissions and their potential, whereas chapter five proposes a specific policy option, the Swiss Negative Emissions Fund, based on specific value principles, such as "polluter pays". Chapter seven combines evidence and policy options, but clearly identified and in separate sections. Yet the very essence of the thesis, action levers to change society, is fundamentally normative.

As any normative policy recommendation is related to specific values, it is important for any researcher to be aware of his or her own values and biases. This personal bias of the researcher is unavoidable and should not be ignored.

Reflecting on my own biases: coming from a rather privileged background, not wealthy but never materially deprived, with a defining focus on education since my childhood, and a growing interest in science since early adulthood, soon followed by the arts. Never a big consumer, I consciously started rejecting consumerism while living in the US, shifted my diet towards plants, reduced travel, and started spending more time in nature. These life changes followed but also shaped my personal values, making them more explicit, and later clearly informed my research interests. At least I try to keep aware of these biases; it would be hard for me to recommend any policy not consistent with such values. However, I will do my best to make them explicit.

Finally, being the father of a son and a daughter, aged 11 and 14, makes me feel the urgency of acting, and disappointment that action is not happening nearly fast enough.

2.6. Structure of the thesis

The thesis is structured in five parts and thirteen chapters, as summarized in Figure 2.1, in order to better highlight the connections between the main concepts, analysis, stakeholder engagement, and prototyping.

The parts are of different length, reflecting the different nature of work in the three parts. Negative emissions work followed the more traditional academic process of literature review, qualitative and quantitative analysis, modeling, writing and publishing three papers, and outreach. Sufficiency was similar, but relied much more on input from stakeholder workshops, as well as exchange within the larger SWICE project, which only started in May 2022. Finally, work on deliberative democracy was largely empirical, and relied on planning, organizing, conducting, and evaluating three citizens' assemblies.

Yet all three parts complement each other, and systems theory frameworks provide the connections, as shown in the examples described in the next section.

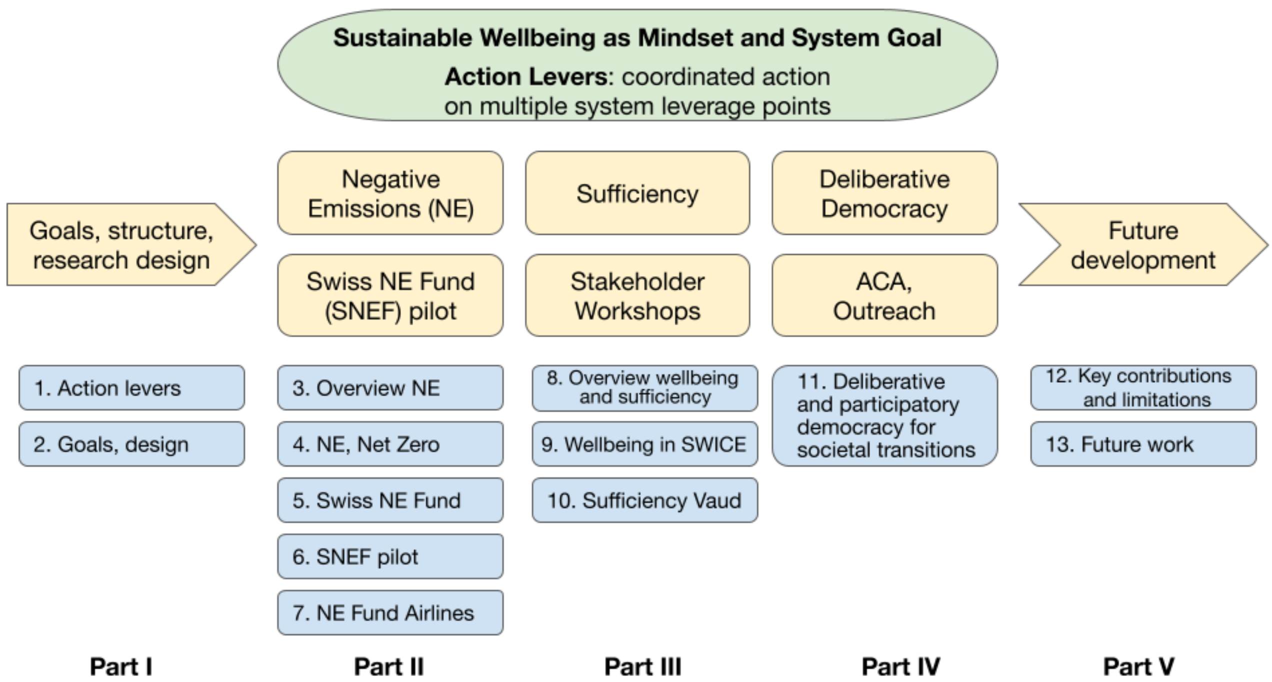


Figure 2.1: Overall research structure, showing analysis (top row, yellow), prototyping and testing (bottom row, yellow), and chapter structure (bottom, blue); NE: negative emissions, ACA: Academic Citizens' Assembly

Table 1.2 summarizes the included articles and manuscripts.

For the three co-authored papers, contributions of the doctoral candidate are detailed in the first page of the relevant chapter (4, 5, and 7), as required by the EPFL Doctoral Commission Decision CDoct 109 (November 2015).

Table 1.2: List of publications and manuscripts by the doctoral candidate included in the thesis

	Title	Type	Ch.
1	**Nick, Sascha**, and Philippe Thalmann. 2021. “Carbon Removal, Net Zero, and Implications for Switzerland.” E4S Enterprise for Society. https://e4s.center/document/carbon-removal-net-zero-and-implications-for-switzerland.	White paper, peer-reviewed	4
2	**Nick, Sascha**, and Philippe Thalmann. 2022. “Swiss Negative Emissions Fund – Paying for Net Zero.” E4S Enterprise for Society. https://e4s.center/document/swiss-negative-emissions-fund-paying-for-net-zero.	White paper, peer-reviewed	5
3	**Nick, Sascha**. 2022. "Swiss Negative Emissions Fund - Implementation Notes for the Pilot Project"	Working papers	6.2, 6.3
4	**Nick, Sascha**, and Philippe Thalmann. 2022b. "Towards True Climate Neutrality for Global Aviation: A Negative Emissions Fund for Airlines" Journal of Risk and Financial Management 15, no. 11: 505. https://doi.org/10.3390/jrfm15110505	Journal paper, peer-reviewed	7
5	**Nick, Sascha**. 2023. "SWICE position paper on wellbeing"	White paper, review by SWICE wellbeing group	9
6	**Nick, Sascha**. 2022. “Towards climate-neutral aviation: fewer flights, benefits for biodiversity and society, and renewed legitimacy for airlines”. I by IMD. Institute for Management Development. 2022.	Magazine article, editor-reviewed	App.D
7	**Nick, Sascha**. 2022. "Report - Action Lab “Sufficiency in the Swiss Habitat” 06-2022"	Report, sent to all workshop participants for validation	App.A
8	**Nick, Sascha**. 2022. "Atelier Associations sur la Sobriété, 01.10.2022"		App.A
9	**Nick, Sascha**. 2022. "Results of the Academic Citizens’ Assembly - K3 Kongress 2022"		App.A
10	**Nick, Sascha**. 2022. "Results and insights of the April 2022 Academic Citizens’ Assembly"		App.B1
11	**Nick, Sascha**. 2022. "Results and insights of the April 2023 Academic Citizens’ Assembly - MYBLUEPLANET 2023"		App.B1

2.7. Principles and research design

Overall the thesis follows three principles: a systems view of societal transitions, an interdisciplinary approach covering the range from biophysical limits to human wellbeing, and to the extent possible, include prototyping, testing, and engaging stakeholders.

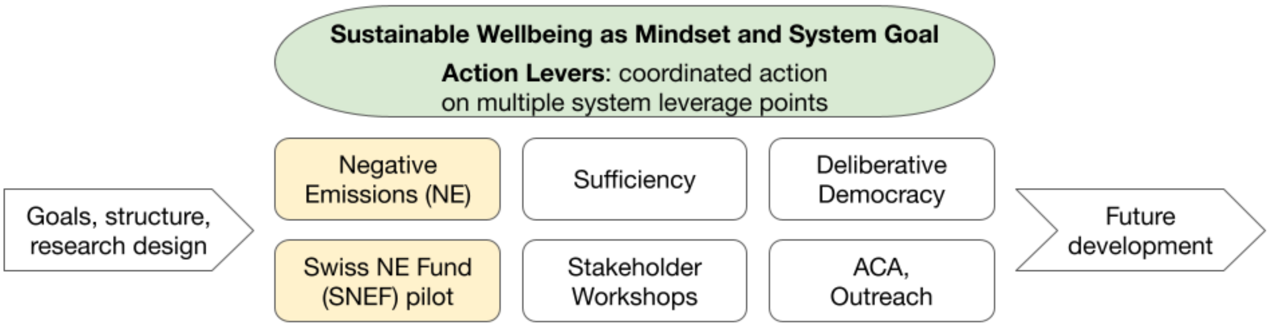
Here are examples describing how these principles have been integrated in the thesis:

The **systems view** of transitions has led to the development of action levers, where coordinated action on several leverage points is possible. The three analyzed action levers – negative emissions (NE), sufficiency, and deliberative democracy – interact and reinforce each other in multiple ways. For example, NE are recognized as essential to reaching net zero and stabilizing the climate (IPCC 2022); in addition, in many countries, there is a growing consensus towards supporting NE, including in Switzerland. This support (Swiss Federal Council 2021) makes NE attractive for an action lever. Yet NE, if limited to a realistic scale for Switzerland corresponding to 10% of current territorial GHG emissions, will only work if emissions fall by 90% (Nick and Thalmann 2021). Given the short timeframe, at least half of this reduction will have to come from sufficiency. To be effective, sufficiency would need to be collective and even become an organizing principle of society (Princen 2005). This requires changing the system goal and the way people think of a good life. Lacking a magic wand, the best way to support such changes is deliberative and participatory democracy, which is also needed to integrate nature-based solutions for negative emissions into local governance. This closes the loop linking NE, sufficiency, and deliberative democracy, reinforcing the same high leverage points, as summarized in Table 1.1.

Several elements described above have been **tested or prototyped** complementing the analysis described above. While the proposed Swiss Negative Emissions Fund (SNEF) requires a change of law to oblige polluters to pay, a long process in Switzerland, it can be tested today at approximately a 1%-scale on a voluntary basis. To do this, we propose a pilot negative emissions fund, described in chapter 6, and in 2022 started discussions with several organizations potentially interested in joining. The discussions are slow but promising, and it is likely that the fund will be tested, in the proposed or modified form. The discussions themselves contribute to our understanding, and insights gained have been included in our SNEF and pilot proposals (chapters 5 and 6). Understanding of sufficiency and barriers to implementation have been tested in three stakeholder workshops, all described in Appendix A; several further stakeholder dialogues on sufficiency are planned for Q2, 2023, in collaboration with Romande Energie, Oiken, and MyBluePlanet. A better approach to deliberative democracy has also been prototyped, organizing and evaluating three citizens' assemblies (06-2021, 04-2022, 09-2022), details in chapter 11.

This design aims to provide coherence between identified research gaps (§2.2), personal goals (§2.3), the broader context (§2.4), and integrating values and normative perspectives of the proposed society after a successful transition (§2.5).

Part II: Negative emissions as a lever to structure climate action



3. Can negative emissions accelerate climate action?

This chapter provides a historical and current political context to negative emissions and their role in climate action, and briefly summarizes the methodology, results, limitations, and outlook for the whole Part II, which consists of published or working papers in chapters 4-7, where the specific literature, methods, results and next steps are discussed in more detail.

3.1. Introduction to climate action and negative emissions

Climate action can broadly be classified in seven categories, shown in Figure 4.1 (in the next chapter, as part of the published paper): sufficiency, efficiency, clean energy, carbon capture and storage (CCS), negative emissions (technologies - NE or NET), solar radiation management (SRM), and adaptation. Reaching net zero is the sum of the first five, consisting of reducing emissions which covers the first four, and negative emissions to remove whatever is left after the reduction. As CCS and NET often use the same infrastructure and technologies, even at the same time, we argue for analyzing them together (Nick and Thalmann 2021). Also, in practice CCS is limited to relatively large point sources.

This classification is somewhat conceptual, focusing on outcomes, rather than policy, especially for the first three (sufficiency, efficiency, clean energy). Related public policy would cover a combination of regulation, economic instruments (taxes, subsidies, tradable allowances), public investment, or voluntary measures (IPCC 2022, Ch.13). This is the reason why fossil fuel bans, arguably the most important decarbonization action, are not directly analyzed in this thesis, but are mentioned as an option in section 5.4.7. Future Swiss climate policy. Bans would drive efficiency and clean energy, and if enacted at a climate-useful scale and timeframe, would have an even bigger impact on sufficiency. This is analyzed in chapter 10 for the case of Vaud.

Fossil fuel bans, unusually defined a regulatory restriction of at least one part of the value chain (exploration, extraction, processing, supply, or consumption) of at least one fossil fuel (oil, gas, coal), beyond reducing fossil fuel related activity, has the major benefit of contributing to establish a new social norm, increasingly likely to proliferate internationally. Contrary to carbon pricing which has no moral dimension and is concerned with efficient allocation of resources, a ban establishes what is morally wrong, and is much more powerful in the long run (Green 2018).

From the beginning, it is important to understand where negative emissions come from, and how they are used today to delay climate action. Injecting CO_2 underground was originally developed in the 1970s to extract more oil from depleted oil fields and named enhanced oil recovery (EOR); the oldest large-scale installations were built in 1972, using CO_2 from underground reservoirs. EOR is explored in detail in section 4.3.3. Later, as subsidies to remove CO_2 from flue gas of power plants became available, carbon capture and storage (CCS) installations were built, in part replacing extracting additional underground CO_2. While CCS only reduces emissions from point sources, with biogenic feedstock, negative emissions are in theory possible, called bioenergy with CCS (BECCS). As of 09-2022, only 1 Mt CO_2 per year BECCS is in operation (IEA 2022).

Climate action is generally modeled and assessed using integrated assessment models (IAMs), which take a cost-based view of what is possible, leading to reliance on BECCS in proportions that are hard to justify based on past deployment, which was already evident in the IPCC AR5 (Anderson and Peters 2016). Anderson and Peters conclude that “Negative-emission technologies are not an insurance policy, but rather an unjust and high-stakes gamble” (p.183).

On this basis, Lenzi (2018) looks at the ethics of negative emissions, and explains how their integration in IAMs obstructs climate mitigation, as it is nominally less expensive to emit more now and remove more CO_2 later towards the end of the century. Additionally, Markusson et al. 2018) show that a broader perspective of cultural political economy is necessary to overcome mitigation deterrence based on a hegemonic political regime and dominant thinking, leading new imaginaries. This cannot easily happen with “individualist, managerialist and economist analyses” commonly used.

Additionally, there are many good reasons to decarbonize rapidly and deeply, both global, related to the probability of staying within 1.5°C with limited overshoot (IPCC 2018), and local, related to better public health and ecosystem resilience, as well as lower costs and adequately preparing the society and its economy for a post-fossil world.

The negative emissions pathway defines both the speed and depth of required decarbonization.

3.2. Literature contributions and gaps

As chapters 4-5-7 have their own more specific overview of literature, this is a summary of main sources cited and a new highly relevant paper on residual emissions, published after the main papers of this thesis.

IPCC (2018, 2021, 2022) defines the importance of limiting global warming to 1.5°C from pre-industrial times, and outlines pathways to do so, with varying need for negative emissions, ranging from very low (IPCC 2018, SPM.3b, P1), based on the LED scenario (Grubler et al. 2021), to unrealistically high, as shown by Keyßer and Lenzen (2021). Minx et al. (2018) provide a comprehensive overview of negative emissions technologies, their potentials and limitations. Stoddard et al. (2021) explore the political economy of climate action and identify nine main reasons why it has been ineffective to date; this context also applies to negative emissions.

For the Swiss perspective, climate objectives and the energy context are summarized in Energy Perspectives 2050+ (BFE 2020) and Switzerland’s Long-Term Climate Strategy (Swiss Federal Council 2021). Steubing et al. (2010) estimate the Swiss sustainable biomass potential, as a basis for estimating biogenic negative emissions.

For aviation, Lee et al. (2021) and Klöwer et al. (2021) estimate the non-CO_2 climate impact of aviation, and Gössling and Humpe (2020) provide an overview of the uses of aviation. Jenkins et al. (2020) propose a Carbon Takeback Obligation as a policy framework for reaching net zero.

A just published perspective on unexplored politics of residual emissions (Lund et al. 2023) calls for a more central role of researchers in exposing the politics and interests behind emissions that are “incompressible”, “unavoidable”, “challenging to eliminate”, or similar. The most commonly cited examples are **aviation** (growing demand, no technological solution expected in decades, but no mention who benefits today - we explore this in detail in chapter 7), **meat production** (need to feed the growing population, no mention of harm and losses of animal farming, nor food waste - today’s food production could theoretically feed 35 bn people - Berners-Lee et al. 2018), **fossil energy** (growing population, reducing energy poverty - no mention of inequality and today’s non-essential uses), **IT** (enabler of decarbonization, no mention of innovation to boost data use, not reduce energy needs), **steel** (hydrogen-based “green” steel is expensive), or in the Swiss context, **cement** (no substitute at today’s scale of use) and **waste incineration** (growing quantity of waste projected for 2050). Unless we properly understand human needs (chapters 8-9), it is impossible to disentangle needs, satisfiers, desires, and “preferences”, and residual emissions will be defined by the politically powerful.

To facilitate researchers’ work in exploring these murky politics, Lund and his colleagues (2023, p.5) helpfully provide seven questions to ask, reproduced below:

1. Who claims the residual emissions?
2. Why are the residual emissions seen as both necessary and impossible to abate?
3. What evidence and assumptions about the future (e.g. economic growth, technological innovation) are the claims of necessity and possibility based on?
4. Could these assumptions be different?
5. Who is likely to benefit and lose from the residual emissions and corresponding carbon dioxide removals?
6. Do those who claim the residual emissions acknowledge the likely distribution of the benefits and costs?
7. Are there alternative claims about the necessity and possibility of these emissions? If so, repeat 1–6 above on the alternative claims.

As an illustration, Figure 3.1 shows the example of the aviation sector claiming an excessive share of residual negative emissions, with its projected growth leading to approximately 3 Gt CO_2e annually for decades, already including expected technology improvements. This corresponds to well over half the likely global annual potential of proven negative emissions (IPCC 2022, C3.5, p.25, AFOLU potential mid-point).

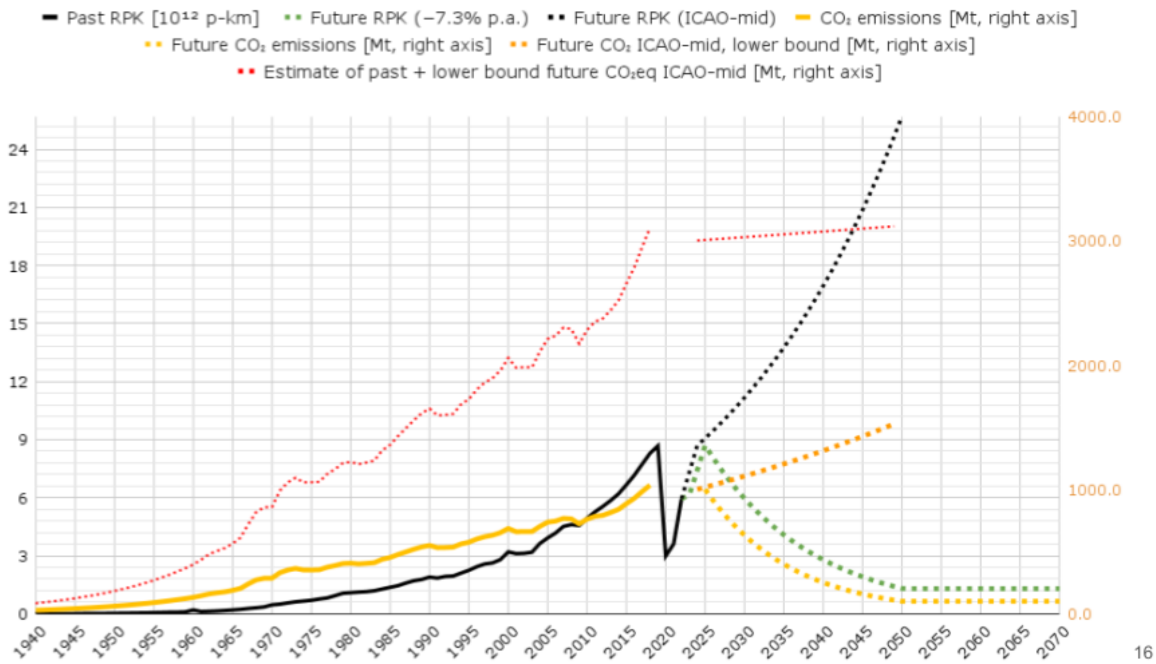


Figure 3.1: Example of exposing excessive residual emissions claims, E4S-Climact event presentation 01.03.2023 at EPFL, based on Nick and Thalmann 2022b

Other than overlapping sectoral claims on the same limited negative emissions (NE), the main gaps in literature, explored in chapters 4-5-7 fall in four categories: (1) defining the “needed” but unrealistic NE based on unambitious country or sectoral decarbonization pathways, instead of identifying and using possible NE with co-benefits as a basis for the decarbonization pathways; (2) little or no analysis of co-benefits of NE for biodiversity or society and especially local communities; (3) very limited perspective of the political economy impacts of NE approaches to power relations; and (4) very few workable governance proposals likely to work in the real world, with different legal frameworks pre country, multinational companies shifting resources to minimize tax payments to countries, which is likely to apply to any future funding of NE, and the need to shift payment and NE investments in time.

In this thesis, (1) “needed” but unrealistic NE claims are analyzed for a country net zero pathway on the example of Swiss and German residual emissions (Nick and Thalmann 2022a and chapter 5, in particular 5.6.2.), and for global aviation in Nick and Thalmann 2022b and chapter 7; (2) co-benefits for society and biodiversity are analyzed in chapters 4 and 7; (3) power relations in chapters 4-5-7; and (4) governance proposals in chapters 5 and 7, and chapter 6 for a pilot.

3.3. Methodology

Given the urgency of climate action and the need to overcome the reasons of past failure (Stoddard et al. 2021), this thesis aimed at producing actionable and to the extent possible testable policy proposals.

As the Paris Agreement is operationalized at a country level through Nationally Determined Contributions (NDCs), this became the focus of analysis, with the exception of the aviation sector, which was analyzed separately. In principle, covering countries and international sectors covers the world's climate action; in practice country pathways might be very different and this work will need significant adaptation to work everywhere. For international sectors, the only other case, maritime shipping, could probably easily be adapted from the proposed aviation framework.

This thesis covers negative emissions from the perspective of Switzerland (chapters 4-5-6) and global aviation (chapter 7).

Both perspectives follow a similar methodology, including (1) Analysis, (2) Modeling of CO_2 and monetary flows of the proposed approach, and (3) A governance proposal.

For Switzerland, the analysis covers several aspects, summarized in Fig. 3.2. below.

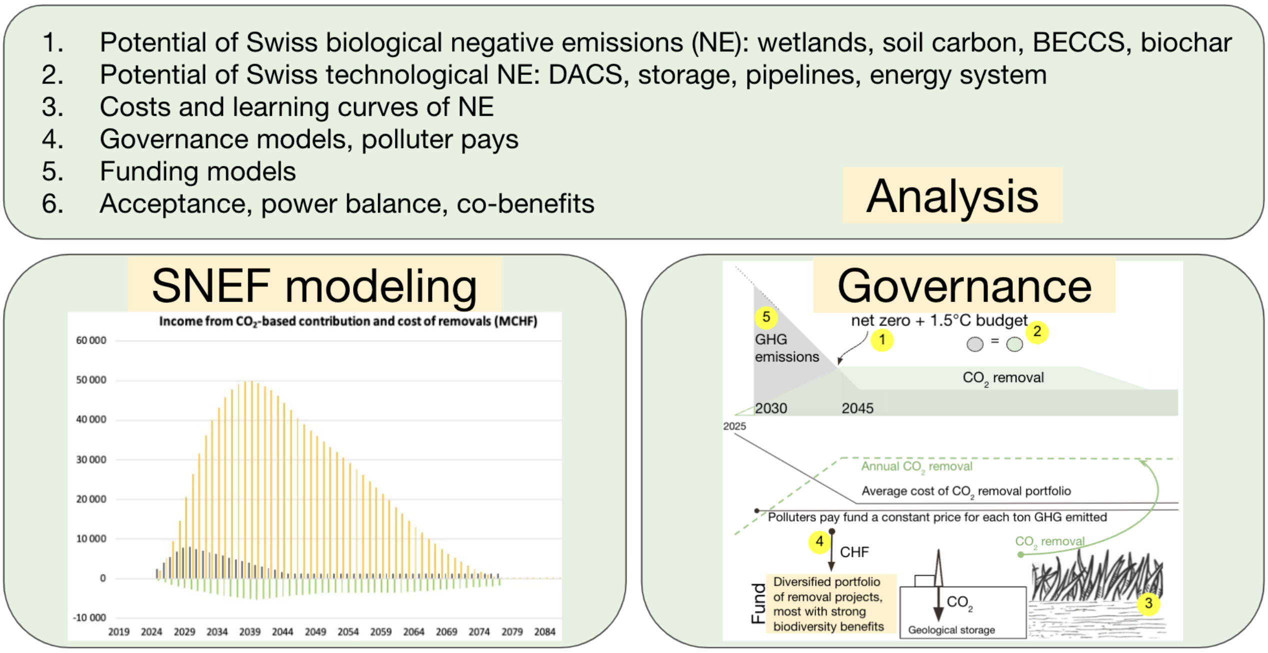


Figure 3.2: Methodology overview for Swiss negative emissions, based on Nick and Thalmann 2021, 2022a

First the potential of biological and technological NE is calculated based on the main constraints from literature (land, water, biomass, energy, chemicals, construction materials), to which additional constraints were added, principally the implications for biodiversity and local communities. Data from Swiss federal offices, and WSL from the ETH Domain, were principally used. The assumptions and calculations are explained in chapters 5-6. Especially for technology-based NET, cost curves were assessed and compared to cost-curve literature, to identify what determines the shape and slope of a cost curve, and how this applies to each NET. The principle of polluter pays is discussed from an ethical and practical governance perspective, a number of existing and proposed polluter pays schemes are analyzed, in Switzerland and elsewhere, and the main requirements for a successful policy are defined. Finally, acceptance and the political economy perspective of the proposed policy is analyzed and discussed, including possible lock-in effects of large-scale technological solutions.

In the second and third part, on this basis a governance approach is developed around a public polluter-pays fund with a constant CO_2 price, and the physical feasibility (relative to identified constraints) and financial viability are modeled. The robustness and sensitivity of the main outputs (CO_2 price, tons CO_2 removed, year by which "excess" emissions beyond the 1.5°C-budget are removed) is analyzed and summarized.

For global aviation, the analysis covers several aspects, summarized in Fig. 3.3. below.

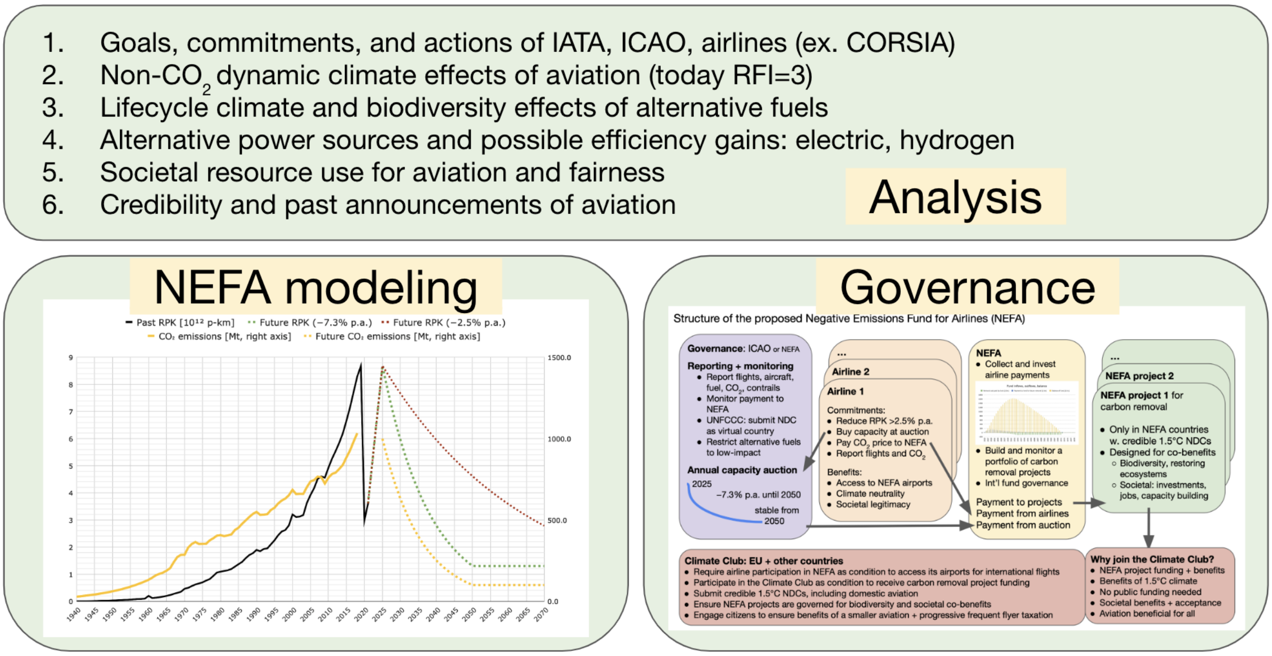


Figure 3.3: Methodology overview for global aviation, based on Nick and Thalmann 2022b

While at a conceptual level, the same methodology sequence analysis-modeling-governance was followed, the specifics were very different. There is no UNFCCC goal for international aviation, only the domestic portion of each member state, so voluntary goals of the main actors were analyzed and compared to 1.5°C pathways. The non-CO_2 component of climate forcing is dynamic and not a fixed multiple of CO_2 emissions, depending on sectoral decarbonization pathways. Alternative "sustainable" aviation fuels were analyzed, with focus on future availability, impacts on biodiversity and society, using similar calculations to the case of Switzerland, as was the lifecycle impact of such fuels. Incremental technology improvements were estimated based on past improvements and literature, and the likelihood for radical changes such as hydrogen airplanes estimated.

In both the country and aviation perspective on climate action and negative emissions, a systems perspective allows us to better understand the dynamics of negative emissions, power structures, and in fine a society's ability to reach net zero, or not. Beyond the obvious fossil-fuel-related infrastructure lock-in, for example coal or gas electricity generation plants, or zoning and territorial planning creating the need for excessive mobility and leading to a car lock-in (Mattioli et al. 2020), here I explore the impact on power arrangements.

The system structure will "emerge" or self-organize based on the expected future available negative emissions, expected and realized funding, which at large scale could change the structure of power in society, or inversely, if captured by incumbents, block any societal transition for decades. This is precisely the strategy of major oil and gas players, from historical uses of CCUS, current subsidy programs, or future focus on large-scale BECCS - all having a questionable to negative impact on climate, a disastrous impact on biodiversity, and transferring public money to private interests. For aviation, the structuring element is the expected future availability of alternative fuels. All are analyzed based on data from literature and described in their respective chapters. The resulting monetary transfers from and to major stakeholders are included in both the Swiss anc aviation models.

Finally, a 1%-scale pilot to test the Swiss Negative Emissions Fund was designed, not needing any change of law. The concept went through several iterations and was refined in discussions with potential partners, which are still ongoing in view of a pilot launch.

3.4. Results and main contributions

The main result, and also the main contribution of my work on negative emissions is the development of a two workable approaches to reach the (a) Swiss net zero, and (b) global aviation net zero in a realistic way, a decade faster than current objectives, with a much higher likelihood of success, taking into account both net zero in 2050 goal and also the remaining cumulative carbon budget, without using any public money for decarbonization and negative emissions.

The second contribution is the analysis of how negative emissions evolved, and are still being used to extend the fossil era and slow down the much needed deep decarbonization.

The third contribution is the ongoing effort to pilot this approach in the existing legal context.

All contributions are detailed in chapters 4-7.

3.5. Discussion and limitations

Given the diversity of results in Part II on negative emissions, here I provide only a condensed summary, and refer to the next four chapters for specifics. Beyond individual results, the important overall conclusion is that any decarbonization scheme relying on negative emissions needs to take into account their limited availability, the need to repurpose them to serve society and not vested interests, and that building acceptance requires broad engagement and the ability to see benefits for climate, biodiversity, society based on real-life implementation, even if small scale. In other words, the results reinforce each other and support the hypothesis that action levers, or coordinated action on multiple leverage points, could be effective.

The main limitations are related to the scope of the work, acceptance, and limited evidence to date that NE funds work. While the scope of this work is broad for a thesis, it is far from a comprehensive action plan that could replace existing climate strategy; rather it is a basis upon which such strategy could be developed. Acceptance is partially explored in the deliberative democracy part of the thesis. As for evidence or the polluter-pays funds, while successful, no funds cover such a deeply transformational aspect of human activity as getting to net zero.

Negative emissions were analyzed as a goal-setting mechanism for decarbonization, but no detailed analysis of additional policy instruments to achieve the needed decarbonization, such as fossil fuel bans, domestic sectoral policies for agriculture, buildings, energy or mobility. Additionally, a comprehensive analysis would also consider the impact of Switzerland in the world, for example through investments, trade, hosting extractive industries, or ECT arbitration, etc.

These policy instruments, not analyzed in the thesis, must consider that deep decarbonization will not only transform or improve many human activities, it will necessarily have to stop or significantly reduce others. This will lead to stranded assets, also called the “carbon bubble”, where asset prices do not reflect pathways compatible with 1.5°C or even 2.0°C climate action. It is the responsibility of governments to deflate the illusion that such assets can be used to the end of their useful life, so owners can timely assess and mitigate risks. Also, reducing or stopping activities will create hardship for some people, who will need support in their transition to 1.5°C lifestyles, including suitable living and meaningful work arrangements, requiring public investment, but also support structures embedded in all parts of society.

4. Carbon removal, net zero, and implications for Switzerland

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Abstract: Carbon removal, including carbon capture, utilization and storage (CCUS) and negative emission technologies (NET), is an important but small part of climate action, unlikely to scale beyond 5-10% percent of current emissions, in the 2-3 critical decades we have to stabilize our climate and stop biodiversity loss.

Keywords: climate action, net zero, negative emissions, polluter pays, nature based solutions

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4.1. Executive summary

This E4S white paper provides an overview of carbon removal in the context of climate action towards net zero, covering the main points policymakers and organizational leaders should keep in mind.

We will make the case for **carbon removal, which in this paper includes 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.

This insight is key for properly designing and governing carbon removal, as a complement to deep emission reductions based on sufficiency, efficiency, and clean energy. We will argue that CCUS and NET are important contributions to broader climate action, with potential limited to several percent of current emissions. This is not a contradiction: no single approach will solve the climate crisis.

After decades of **climate inaction** and ever-increasing emissions, despite increasingly urgent and precise warnings by the IPCC, several successful international agreements (Kyoto, Paris), unprecedented mobilization of the civil society around the world, and more frequent extreme weather events (flooding, drought, fires, temperature extremes) - the time to act is running out, if we want to keep warming within 1.5°C above pre-industrial times. We have less than a decade to globally halve emissions (IPCC 2018), and less than 30 years to reach -90%. We may need costly, difficult to implement measures like carbon removal, which we could have easily avoided with timely reductions.

To stay within 1.5°C warming, IPCC's AR6 (IPCC 2021), published in August 2021, defines the remaining **carbon budget** we can safely emit at 300-400 Gt CO_2. 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, and the time to deploy existing ones - suggesting an emphasis on policy, behavior, and economic measures.

In this context, **carbon removal**, both **CCUS** (carbon capture before it reaches the atmosphere) and **NET** (negative emissions, removing carbon from the air and storing it at climate-relevant time scales) will have an important role to play. Today, carbon removal beyond the fast natural carbon cycle (i.e. photosynthesis and storage in living biomass and soils) is experimental and small-scale. Worldwide, it is **highly unlikely to scale beyond 5-10% percent of current emissions** (i.e. 3-6 Gt CO_2e) (Hepburn et al. 2019), at least in the 2-3 critical decades to come, during which we must stabilize the climate (IPCC AR6 WG3 will include a new estimate). Yet it can still provide **significant climate benefits** such as reaching net zero if combined with deep decarbonization.

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 (WWF 2020). **Protecting ecosystem services** is one of the main reasons for climate action. Many biological carbon removal measures, if properly implemented, can offer significant biodiversity co-benefits, even at relatively small scales.

What carbon removal cannot provide is a stable climate with business as usual, without deep cuts in emissions.

Since 1972, CCS has been used commercially, mostly to enhance oil recovery from depleted oil fields (details in the section "CCS+EOR"); today it removes 0.1% of current emissions. The so far committed expansion plans will not significantly change this ratio. Given the investment and deployment cycle, carbon removal is unlikely to play more than a marginal role before the 2030s.

It is essential to keep in mind the **purpose of carbon removal**: help reach net zero by removing the residual emissions, after sufficiently deep decarbonization. Additionally, it should provide real biodiversity co-benefits, and avoid any negative ecosystem impacts. This is not how CCUS has developed historically (to extract more oil from depleted fields) or is viewed by big players today: to extend the fossil era, prolong the lifetime of stranded assets like coal power plants, open new markets for oil companies (solvents), or simply benefit from available "green" subsidies. Stabilizing the climate is missing from the goals of almost all main players.

Unless this purpose (and the actions it leads to) changes, carbon removal will not meaningfully contribute to climate action, even distracting from real action, while transferring wealth from taxpayers to corporations.

Carbon removal is costly and requires funding to be deployed at a meaningful scale. Funding can be based on a carbon tax plus removal subsidy of several hundred dollars per ton CO_2 or through some form of a carbon removal mandate, directly or via a cleanup fund. One such proposal for Switzerland, the Swiss Climate Cleanup Fund, is developed in the E4S working paper "***Climate Cleanup Fund - getting to Swiss Net Zero***".

In practice, carbon removal will only work within a framework of international cooperation, except perhaps for small-scale projects with significant local ecosystem benefits. If positioned as a complementary measure to reach net zero based on deep decarbonization across all sectors, the moral hazard can be limited - carbon removal will not be seen as a possible substitute for significant emission cuts. With such international cooperation and proper positioning, carbon removal can play a limited but very important role in our task of stabilizing the climate.

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 BECCS. The realistic potential in Switzerland is around 5 Mt per year, corresponding to the last 10% of territorial emissions, reaching net zero together with deep decarbonization. Carefully designed and monitored, carbon removal measures could also strengthen the resilience of fragile ecosystems.

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, and setting an "objective" carbon price**. The realistically achievable carbon removal potential determines how deep and how fast we must reduce emissions to stay within the remaining 1.5°C 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. Nature-based carbon removal also offers rapid and significant biodiversity benefits, if designed and monitored for this goal. Metaphorically, the "tail" of carbon removal could be wagging into action the "dog" of deep decarbonization.

4.2. Overview of climate action

4.2.1. State of the Climate in 2021, based on IPCC AR6 and SR15

Since 1896, when Svante Arrhenius (Arrhenius 1896) quantified the climate sensitivity of the already well-known greenhouse effect of atmospheric CO_2, we have been able to estimate with remarkable precision to what extent human activities cause climate warming. IPCC's six assessment reports since 1990 have summarized one of the most critically studied areas of human knowledge. To date, 26 annual UN climate conferences (COPs) have pressured the biggest emitters to act, with increasing urgency. Major agreements have been reached, such as Kyoto 1997 and Paris 2015.

Yet emissions continue to rise and are now about 50% higher than in the Kyoto year, 1997. After several decades of inaction, time is running out, and difficult-to-implement measures such as removing CO_2 from the atmosphere may be required, which we could have easily avoided with timely reductions.

Relative to the pre-industrial baseline (average temperature 1850-1900), the world is already 1.2°C warmer on average, with significant regional variations: for example in Switzerland the average temperature is around 2°C higher (BAFU 2020). The effects of global warming are highly non-linear (IPCC 2018), and 2.0°C warming is *much* worse than 1.5°C, making the Earth much less habitable for humans and ecosystems on which we depend for survival. 2.5°C warming would be much worse still. Yet, despite recent progress (COP21-COP26, 2015-2021), current policies (Climate Action Tracker 2021a) still lead us towards 2.7°C, as of November 2021.

4.2.2. Remaining carbon budget, getting to Net Zero

To limit global warming to 1.5°C, the 2021 IPCC AR6 (IPCC 2021) estimates the remaining carbon budget at 300 Gt CO_2 (relatively safe) to 500 Gt CO_2 (highly uncertain). Without massive emissions reduction, the safe limit will be reached in 2027-2028. Any additional CO_2 emitted will have potentially dangerous consequences unless rapidly removed from the atmosphere. If we waste another decade, 1.5°C will be out of reach (IPCC 2018, 2021).

Net zero, for a country or organization, signifies that no carbon is added to the atmosphere on a net balance. In practice it means first that emissions are significantly reduced, and that any residual carbon emitted in the atmosphere will be removed. It does not include any compensation. To be useful and lead towards a 1.5°C world, it also means that cumulative emissions should be compatible with the remaining carbon budget, so it includes a pathway to net zero, according to IPCC on average -50% by 2030 and at least -90% by 2050 relative to 2020, with faster reductions for big emitters.

4.2.3. Is CO_2 compensation part of climate action?

Compensating CO_2, i.e. paying someone else to reduce their emissions somewhere in the world and applying the reduction to your own emissions, is often seen as an easy and cost-efficient way to get to net zero. Unfortunately, this appears highly problematic for several reasons: (a) it is hard to ensure the reductions are real, additional, and permanent, (b) projects are often double-counted, (c) the projects may be crowding out the host country's own much needed net-zero efforts, and (d) the framework for such cooperation under the Paris Agreement (Art.6) just adopted at COP26, is still unclear. Specifically, to avoid double counting, Art.6.4 requires host countries to apply "corresponding adjustments", i.e. exclude the transferred credits from their own commitments (NDCs). It is too early to evaluate how well this will work in practice. There is no shortcut for effective climate action.

4.2.4. Overview of climate action by type and effect

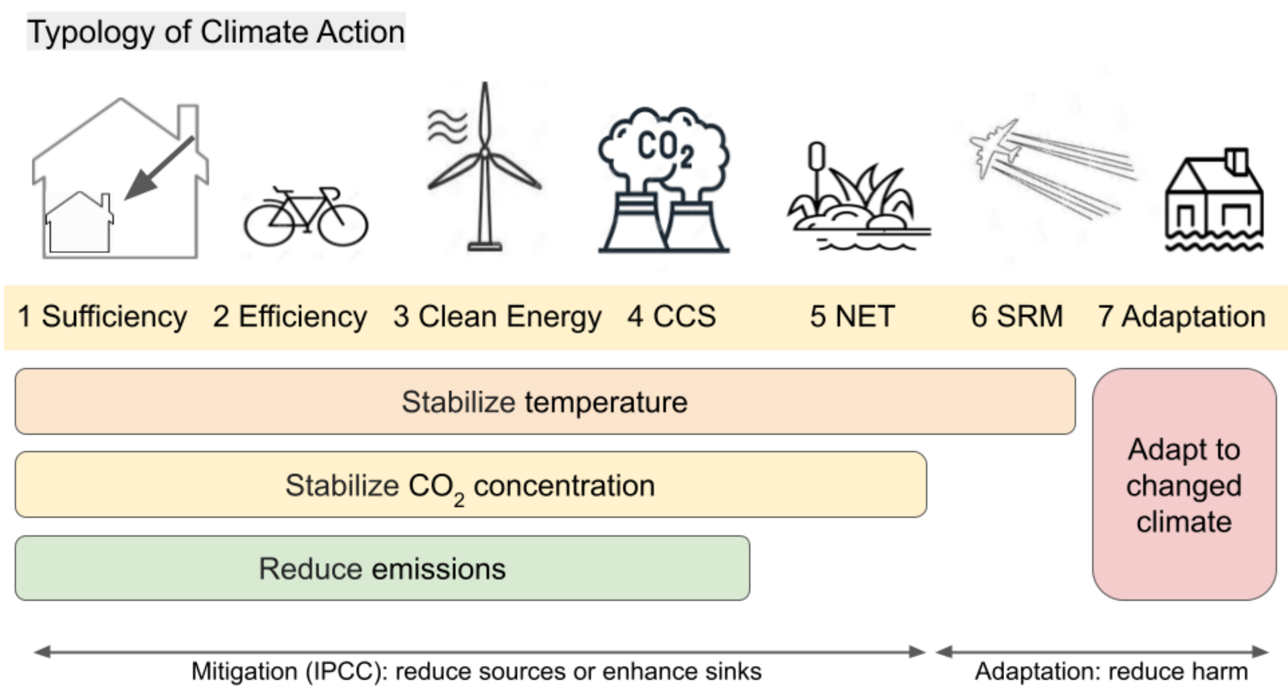

Figure 4.1: Types of climate action (see text below for acronyms and explanation)

Climate action can be classified in seven distinct types (adapted from Minx et al. 2018) ranging from avoiding emitting activities to adapting to live with a warmer climate:

1. **Sufficiency**: avoid or reduce activities emitting CO_2. This includes for example not flying, reducing consumption, using less floor space per person.
2. **Efficiency**: for a given activity, use less energy and emit less CO_2. Deploy more efficient processes or technology such as LED lights or train travel; build with wood instead of concrete (Note: this is effective only if the rebound effect can be limited, see below for details).
3. **Clean energy**: replace fossil energy by renewable sources, minimize embodied CO_2.
4. **Carbon capture**: capture the CO_2 before it reaches the atmosphere. Captured CO_2 can be stored underground (Carbon Capture and Storage, CCS) or transformed for example to chemicals or plastics (Carbon Capture and Utilization, CCU). In some cases both U and S can be achieved together, such as in the utilization of carbon in building materials (Carbon Capture, Utilization and Storage, CCUS).
5. **Negative emissions** (**NET**, also referred to carbon dioxide removal or CDR): remove CO_2 from the atmosphere, using biological or chemical processes, such as planting trees, restoring ecosystems, or using chemical sorbents, and store it at climate-relevant time scales (see NET section for details).
6. **Solar radiation management (SRM)**: methods to deliberately reduce anthropic global warming by increasing Earth's average albedo (reflectivity). This could for example be achieved by mimicking volcano eruptions and injecting millions of tons of sulfur aerosols in the stratosphere.
7. **Adapt to climate change**: this can range from building floodwalls, planting heat-resistant crops, painting roofs in white, to abandoning cities or even countries as they become uninhabitable.

Actions 1-4 reduce emissions; action 5 reduces CO_2 atmospheric concentration (which, among other effects, reduces temperature), action 6 reduces temperature only, without having much impact on other consequences of increased CO_2 concentration, such as ocean acidification, and action 7 adapts to the changed climate.

4.2.5. All approaches have limitations, and some can be dangerous

There are no technical barriers to sufficiency, only cultural ones and the need to adjust societal norms, structures and incentives. The benefits of efficiency are mainly limited by the rebound effect, where efficiency improvements reduce the cost of production or use, leading to higher demand, in turn reducing energy saving, and sometimes *increasing* aggregate energy use. Clean energy is limited by the speed of deployment - it would take decades to replace the 500 EJ fossil energy used today. Fortunately, with sufficiency and efficiency, this much energy will not be needed (Grubler et al. 2018; Millward-Hopkins et al. 2020).

CCS is limited by the high energy and financial cost (see section “Cost overview”), and its existing infrastructure. It removes 80-95% of CO_2, less on a lifecycle basis (including resources to make the CCS equipment), and none of the other pollutants, such as $PM_{2.5}$, sulfur dioxide, benzene, ozone, nitrogen oxides, carbon monoxide (Markandya and Wilkinson 2007). Due to efficiency loss (more fuel used), such non-CO_2 pollutants may actually increase.

CCU is limited by the use of CO_2 as such, with most uses requiring the breaking of the strong C-O bonds at a great energy cost. Additionally, carbon used in CCU quickly returns to the atmosphere, for most applications.

Biological negative emissions need a lot of land and water, and must be carefully designed for biodiversity co-benefits, ensuring no ecosystem damage, further limiting their potential. Ensuring permanence is challenging. Chemical NETs are extremely expensive, financially and in terms of energy, and are highly unlikely to scale quickly (see analysis in section “Technical analysis of limits to NET”).

SRM has never been tested (although aerosols from volcanic eruptions do cool the climate), and poses many ethical and governance issues, as well as numerous side effects. The climate effects will be highly uneven, with winners and losers, whose whole countries could become uninhabitable. Who gets to decide about deployment? Could this potentially lead to conflict and war?

This paper covers CCUS and NETs (#4-5), as a complement to deep reductions based on #1-2-3. We will argue that CCUS and NETs are important components of broader climate action, with potential limited to several percent of current emissions.

4.3. Carbon capture, utilization and storage (CCUS)

4.3.1. Carbon capture: sources, technologies, current deployment

Carbon capture (CC) is a process to capture CO_2 *before* it enters the atmosphere, storing it safely for hundreds or thousands of years, typically in geological formations, such as saline aquifers, depleted oil fields, or basalt formations (CCS) or using the CO_2 (CCU). CC always includes CO_2 separation, compression, transport, and storage or utilization.

It can be applied to large point sources such as cement, steel or chemical plants, coal or gas power plants, or waste incinerators, typically emitting >100 kt CO_2 per year.

CCS has been used since 1972. As of mid-2021, 26 commercial facilities (>100 kt CO_2/yr) are in operation (Davy Guidicelli 2021), of which 12 in the US, 4 in Canada, 3 in China, for a total of

40.12 Mt CO_2/yr, or approximately 0.1% of world's total emissions. There are no CCU facilities at this scale.

Per sector, 24 of the 26 facilities are in the petro-chemical industry (gas, oil, ethanol, methanol, hydrogen, fertilizer, bulk chemicals), plus one coal power plant and one steel plant. There are small-scale pilot plants in cement and waste incineration, but no commercial facilities yet.

There are three main processes to separate CO_2 from the flue gas (concentration 3-15%, typically 10%):

1. **Post-combustion**, by far the most common, used in 25 of 26 commercial plants, as it can be retrofitted to existing facilities. Technically, it is based on a liquid solvent which absorbs CO_2 from the flue gas, which is then heated to release high-purity CO_2. Membranes are a promising alternative to solvent-based separation, used in a number of pilot projects; no commercial facility (>100 kt CO_2/yr) is yet deployed.

2. **Pre-combustion**, which chemically separates the fuel (oil, gas, coal) into CO_2 and H_2 before using the hydrogen as fuel. This is a complex process that cannot be retrofitted to existing power plants, and is not yet deployed in commercial facilities.

3. **Oxyfuel combustion** uses unchanged fuel, which is burned in pure oxygen, producing pure CO_2 mixed with water vapor. Vapor is easy to remove by cooling the flue gas, and the whole process is very simple. Oxyfuel is used today in several coal power plants without CCS, but only in one commercial CCS facility. The main barrier is the cost of pure oxygen.

Separating CO_2 from the flue gas is energetically expensive, increasing the fuel consumption of a power plant (Cuéllar-Franca and Azapagic 2015) by 11%-40%, typically 20-25%. In CCS, 2/3 of the energy is used for separation, 1/3 for compression and transport (Kearns, Lui, and Consoli 2021).

4.3.2. CCS: transport and storage of CO_2

Once separated, CO_2 can easily be transported (Onyebuchi et al. 2018) by pipeline, ship, or for small quantities and distances, by rail or truck. Existing oil and gas pipelines can be adapted. Currently there are very few CO_2 operational pipelines, mostly in the US, linked to EOR. The Sleipner gas field in Norway, Europe's biggest geological storage facility, under the name of "Northern Lights", will rely exclusively on ship transport when it opens mid-2024.

"CCS Hubs" built around storage facilities like "Northern Lights", linking several capture facilities by pipelines, could generate economies of scale, facilitate learning, and lower costs.

The main transport-related challenges are the cost of building or retrofitting pipelines, the energy requirements to compress and transport CO_2 at scale, and public acceptance. Landlocked countries like Switzerland are dependent on transport via other countries to reach the sea. One option for Switzerland would be repurposing the old Genoa to Collombey oil pipeline (E50), unused since 2015. This is far from easy: there is little experience in retrofitting pipelines.

Additionally, there is no CO_2-terminal in Genoa, and only the portion to Ferrera is unused, requiring a new pipeline for the last 25% to Genoa. Within Switzerland, Collombey is far from the main emitters (cement plants and waste incinerators), requiring additional pipelines.

Permanent geological storage is abundant almost all around the globe, in saline aquifers, depleted oil fields, or basalt formations. On land, saline aquifers and depleted oil fields are more common, much of the sea bed and oceanic islands are made of basalt, offering massive potential storage, many orders of magnitude beyond what is needed (Snæbjörnsdóttir and Gislason 2016). In Switzerland, there is a wide range of estimates (SCCER 2020; Chevalier, Diamond, and Leu 2010), from 50 Mt to 2680 Mt CO_2, the uncertainty reflecting the lack of experimental validation. Most estimates suggest Swiss capacity to store at least decades of captured emissions.

4.3.3. CCS+EOR (Enhanced Oil Recovery)

After separation, CO_2 must be permanently stored in suitable geological formations. Since the first operational commercial facility opened in 1972, the main purpose of CCS has been **Enhanced Oil Recovery (EOR)**, corresponding to 90% of historical capacity. Even today, 75% of today's storage capacity is in EOR, with the remaining 25% in permanent geological storage.

EOR is a process where the CO_2 is injected in a depleted oil field, where oil extraction otherwise ceases to be profitable. Injected high pressure CO_2 will dissolve in oil, liquefying it and allowing extraction of most of the remaining oil. From a climate perspective, this is problematic, as the extracted oil will be burned, emitting more CO_2 than was used to extract it, *increasing* total emissions instead of reducing them. The exact ratio is complex to calculate (Davy Guidicelli 2021) and depends on two parameters, the crude oil recovery ratio, typically 2-3 barrels of oil per ton CO_2, and the additionality of the extracted oil (short-term displacement effect vs. long-term oil market increase). Longer-term, the emissions of burning EOR oil correspond to 1.5-2 times the CO_2 stored, with significant variation (Davy Guidicelli 2021), *increasing* net emissions.

4.3.4. CCU: tiny today, unlikely to grow much anytime soon

In common with CCS, carbon capture and utilization (CCU) is a process to capture CO_2 before it enters the atmosphere. Then, instead of storing the CO_2 underground, it is used in industrial products, before it re-enters the atmosphere. Therefore, CCU does not directly contribute to removing CO_2. Its contribution depends on how CO_2 was produced before: (1) as a by-product of ammonia production, in which case CCU will have no effect, or (2) by burning natural gas, in which case CCU replaces fossil with atmospheric carbon, avoiding more fossil-based CO_2 entering the atmosphere. It may be viewed as "carbon recycling".

Over 90% of today's total use of CO_2, around 250 Mt p.a., is used in fossil fuel-based urea production and EOR (IEA 2019). Food and beverage use represents 6%, with the rest in metals, chemicals, water treatment, and health care.

Today's CCU market based on captured CO_2 is tiny, less than 0.1% of Swiss territorial emissions, mainly used in greenhouses to accelerate plant growth, and for carbonated drinks, if food-purity CO_2 can be obtained. In all cases, the CO_2 is released within days.

Beyond capture limitations, the uses for CO_2 as such are very limited, with most uses requiring the breaking of the strong C-O bonds at a great energy cost. This is the fundamental limit to any future development.

Potential future large-scale use includes chemical feedstock for plastics production, intermediate high-value materials like methanol, synthetic liquid fuels, or synthetic methane. All replace fossil fuel feedstock by captured atmospheric CO_2, which re-enters the atmosphere within days or weeks, when the fuel is burned, or plastic incinerated at the end of its life. The benefit is obviously to eliminate the use of additional fossil fuels, making the whole cycle potentially almost carbon-neutral, if 100% clean energy is used. None of this exists today at scale.

This process is very energy-intensive, requiring 2-3 times more energy to produce the synthetic fuel, compared to the chemical energy contained in the produced fuel, typically 100 MJ to produce a kg of liquid fuel containing 45 MJ of energy when burned. This means that the required scale of the energy system to achieve any meaningful substitution of today's plastic or fuel consumption will be very likely unreachable for decades: it would not only require replacing today's annual 500 EJ of fossil energy by renewables, but much of it multiplied by 2-3 (see section "Technical analysis of limits to NET").

4.3.5. Limitations of CCUS

In summary, carbon capture is limited by its high energy and financial cost. Additionally, if the stored CO_2 is used for EOR, it ends up *increasing* emissions and contributing to the climate crisis. CCS removes 80-95% of CO_2, and none of the other pollutants, which for coal power plants include $PM_{2.5}$, sulfur dioxide, benzene, ozone, nitrogen oxides, carbon monoxide (burning gas is cleaner, not producing SOx or benzene, and little NOx and CO). The other pollutants actually *increase*, due to the additional fossil fuel used to power CCS itself. On a lifecycle basis, including the energy and CO_2 cost of building the needed equipment, only 63–82% of CO_2 is removed, with the high end of this range requiring expensive oxyfuel capture (Cuéllar-Franca and Azapagic 2015).

CCU is limited by the small market of using CO_2 without further transformation. CO_2 is a very stable molecule, requiring a lot of energy to transform into feedstock or fuel, generally 2-3 times the energy contained in the fuel. Long term, a less energy-constrained future may be imaginable, reducing the importance of this constraint, but almost certainly not for many decades.

There are no insurmountable issues in transport or storage, but many engineering challenges such as cost, energy requirements, risks, public perception and acceptance, and the time to build the infrastructure.

Finally, the potential of CCUS will decrease with the move away from fossil energy, only partially compensated by bioenergy with carbon capture and storage (BECCS), described in the section on NETs. Once we completely eliminate fossil fuels, as we must do for reasons of climate and also health and biodiversity, CCUS could retain a limited role in industrial processes like cement.

4.4. Negative emissions technologies (NET)

4.4.1. Methods and technologies: many complementary methods at small scales

Negative emissions technologies (NET) differ from CCUS as they remove CO_2 *after* it has been released to the atmosphere. This has an obvious benefit that it can be done anywhere in the world, for example where land, water, energy, or geological storage is available. It also has a major drawback: CO_2 constitutes only 0.04% (420 ppm) of the atmosphere, compared to around 10% of the flue gas. As a result, the task is much harder (lower partial pressure, much more air flow per ton CO_2), and the process about 3-4 times more energy intensive.

This is also the reason why restoring or accelerating natural carbon cycles is generally more attractive than creating an entirely artificial process:

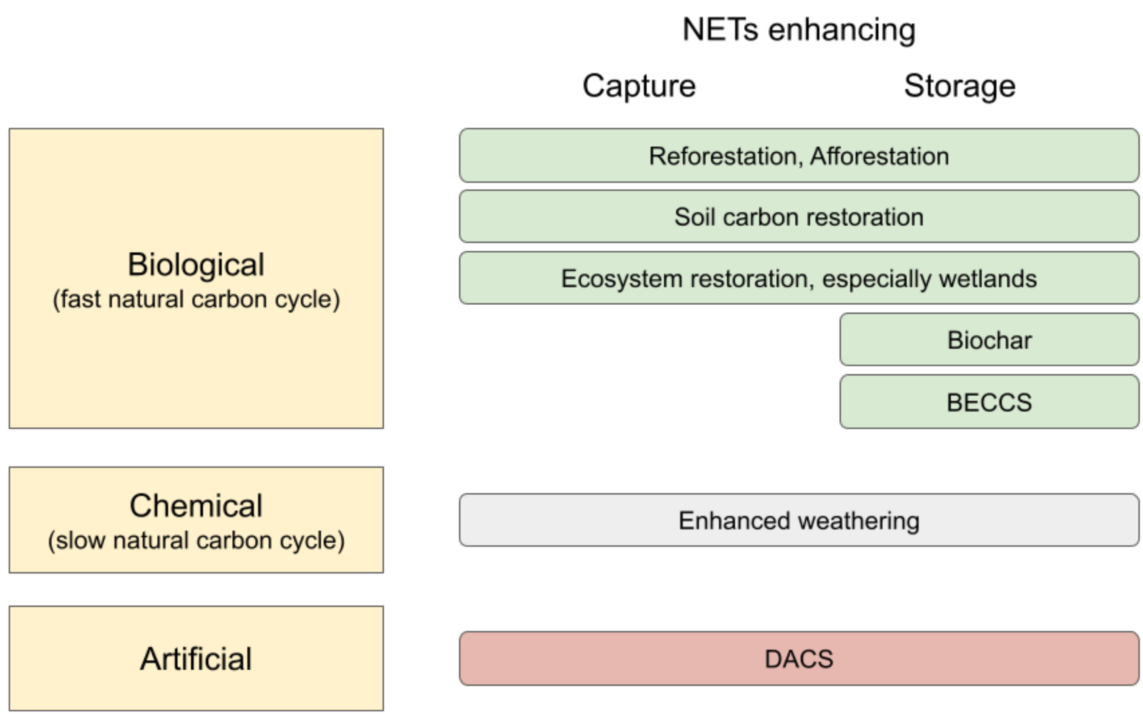

Figure 4.2: Classification of NETs

Alternatively and more commonly (adapted from Minx et al. 2018 and Fuss et al. 2018), the wide range of NETs can be classified by type of capture and type of storage. Biological capture and storage is often referred to as Nature Based Solutions. Ocean fertilization is not included due to its very limited potential and numerous side-effects, altering physical, chemical and biological properties of marine ecosystems.

1. **Biological capture and storage**: photosynthesis captures CO_2, converts it to biomass, which can be directly stored, in several ways:

   - **Reforestation or afforestation**, storing carbon in trees: this is relatively easy and mostly inexpensive, but requires a large land area. For example, capturing all current Swiss territorial emissions of 47 Mt CO_2e, using average young forests (Bernal, Murray, and Pearson 2018) at 6 tons/ha/year would need twice the total area of Switzerland, replanted every 20 years. Significant biodiversity benefits require "primary forests of native species, where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed" (FAO 2015), which takes decades. This suggests a tradeoff between capturing CO_2, as young trees grow faster, and biodiversity, requiring old-growth forest. An additional difficulty is ensuring permanence, as forests could be cut down. They could also burn, quickly releasing the captured CO_2, which becomes likelier with a warmer climate and changed precipitation patterns.

   - **Restoring ecosystems, especially wetlands**: this is one of the most promising climate actions. It is relatively easy and quick to reflood and stop further emissions from decaying peat biomass (flooding cuts oxygen flows). Within months, this generates significant biodiversity co-benefits, as wetlands tend to be "hotspots" of biodiversity. Reflooded wetlands immediately stop emitting and slowly start re-capturing the lost carbon, as plant matter accumulates over decades to centuries in wet, acidic and anoxic conditions. The main challenge is overcoming resistance, as most drained wetlands are productive agricultural land, due to rich organic soils. Worldwide, wetlands represent 3% of land area and store 30% of soil carbon (550 GtC). For Switzerland, of the 2500 km^2 wetlands in the early 1800s (BAFU 2007), well over 90% have been drained, with much of the rest degraded. The total potential of either avoided further emissions or recaptured carbon is not yet quantified, but decomposition of organic matter continues to emit thousands of tons of CO_2 per km^2 annually (typically 3500 t for organic soils used as cropland and 2000 t for the mineralization of drained raised bogs). These emissions alone probably reach millions of tons of CO_2 each year, and could be stopped rapidly and relatively easily.

   - **Soil restoration / soil carbon sequestration**: soils naturally contain around 5% organic matter, about half of which is carbon, with significant local variations. Industrial agriculture degrades all components of soils, including the carbon content. Restoring soils naturally takes decades to centuries. Agroecology can help accelerate soil restoration, providing significant biodiversity co-benefits, but this is a complex undertaking, not yet fully quantified.

- **Biochar**: heating biomass without oxygen (pyrolysis) produces biochar, which is stable and can be stored for a long time, or applied to soils to help restore them, which improves both biodiversity and food production. The potential is limited by the quantity of available biomass. For Switzerland, see the biomass analysis in the BECCS section below.

2. **Biological capture, geological storage**: this method is also called bioenergy with carbon capture and storage (BECCS), and combines gasification or direct combustion of biomass for energy, with CCS, storing the resulting CO_2 underground. This works very well at small scale:

    - If limited to excess biomass and agricultural waste, and combined with biological storage described above, it remains limited in size but offers biodiversity co-benefits. In Switzerland the additional unused sustainable biomass potential is 2.6 Mt dry mass (Steubing et al. 2010). Reaching 80% of this potential, with 50% carbon in dry mass, we obtain BECCS potential of 2.6 Mt x 80% x 50% x 44/12 = 3.8 Mt CO_2 or 8% of 2020 Swiss territorial emissions. On a lifecycle basis, 5-6% is more realistic.

    - Trying to scale BECCS quickly becomes very problematic, as it requires much land and water to plant fast-growing biomass, competing with biodiversity (biodiversity needs old-growth forest, the opposite of fast-growing monocultures of young trees) and food (although this is more linked to our inefficient food system than to BECCS itself), very likely using fossil energy for the vast logistics required, and generating significant air pollution not captured by CCS.

3. **Natural chemical capture and storage**: this is the natural slow carbon cycle, which will remove all excess CO_2 from the air even if we do nothing, in thousands of years, through rock weathering, at a rate of 10-100 Mt C/yr. As we do not have so much time, we can accelerate this process:

    - Enhanced weathering is the name for all accelerated processes of grinding silicate and carbonate rock, or even recycled concrete. While the process effectively absorbs carbon, it could be hard to scale beyond just reducing emissions of recycled concrete, for lack of space to place the crushed rock, and the required energy. One ton of CO_2 may need around two tons of rock.

4. **Artificial chemical capture, geological storage**: also called **direct air capture and storage** (DAC or DACS). This process is similar to CCS, with several significant differences:

    - Geographical flexibility: DAC can be placed anywhere, for example in proximity to energy sources or geological storage formations.

    - Limited need for land and water.

- Type of material used: typically solid sorbents using adsorption, i.e. capturing CO_2 on their surface (liquid solvents are also used, generally requiring high temperatures, and in hot and dry climates, a lot of water (Fasihi, Efimova, and Breyer 2019)). The process is relatively new, and the scale of facilities is much smaller than CCS, by a factor of 100-1000 per facility, as of 10-2021. Latest research however determines that sorbent or solvent consumption and manufacturing is not a limiting factor (Madhu et al. 2021). Hybrid approaches, like adsorbent+membrane, might be used in the future.
- Energy use: this is by far the biggest issue, and most likely the fundamental limit of DAC. Due to the low concentration of CO_2 in the air at least 7 GJ is needed per ton; today the energy needed is closer to 10 GJ per ton CO_2.

In summary, many good and complementary methods for carbon removal exist, many of them with significant biodiversity co-benefits. A significant effort is needed to properly develop the knowledge, and then to widely build this capacity in society. The main issue is the possible scale, before the downsides predominate. From today's perspective, it looks difficult to remove more than a few percent of current emissions of 40 Gt/yr. This underlines even more the urgency of rapidly reducing emissions.

For Switzerland, all biological methods (Fig. 4.2) should be explored and implemented within the limits of available land and biomass, with focus on biodiversity co-benefits. Due to energy and land limitations, enhanced weathering will likely be limited to cement and concrete production; DACS is unlikely to scale (see next chapter).

4.4.2. Technical analysis of limits to NET

All NETs have fundamental limits, which are very different in nature:

1. Biological capture and storage: Overall land use, prevalent diets, agricultural practices, and food self-sufficiency; and more specifically:
    - Land area for forests and wetlands
    - Biomass for biochar
    - Agricultural practice for soil carbon
2. Biological capture, geological storage (BECCS): availability of excess biomass and agricultural waste
    - Additional bottlenecks in the short term: geological storage, CO_2 transport, and methanisation
    - Note: the above limits apply to small-scale BECCS. Large-scale BECCS is much more problematic, see comment in previous section.

3. Natural chemical storage: land to place crushed rock, energy
    - Additional bottlenecks in the short term: integration with cement and concrete production
4. DACS: see analysis below

In summary, for the above methods 1-2-3, the fundamental constraint is land use, at a country and worldwide level, and interaction with / competition with food production, biodiversity preservation, and water use.

Direct air capture and storage (DACS): this is the most misunderstood NET method, as there are few absolute fundamental limits, and in theory tens of Gt CO_2 per year could be captured and stored. In practice, DACS is likely to play a much smaller role in the decades critical for stabilizing the climate.

Our technical analysis is based on "*Techno-economic assessment of CO_2 direct air capture plants*" (Fasihi, Efimova, and Breyer 2019), one of the best-researched (optimistic) assessments of DACS, evaluating the feasibility of massive deployment, reaching 7-15 Gt CO_2 removed in 2050. The proposed analysis is based on technology learning curves, claiming that Gt-scale DAC is cost-feasible with early scale-up: "*CO_2 capture costs of LT DAC systems powered by hybrid PV-Wind-battery systems for Moroccan conditions and based on a conservative scenario, without/with utilization of free waste heat are calculated at 222/133, 105/60, 69/40 and 54/32 €/tCO2 in 2020, 2030, 2040 and 2050, respectively*". While the analysis is sound, we question the underlying fundamental assumptions:

1. **Technology readiness**: the paper (Fasihi, Efimova, and Breyer 2019), written in 2018, assumes total installed capacity of 1.5-3 Mt CO_2 p.a. in 2020. As of 11-2021, the global DAC capacity is well below 10 kt, or a factor of 2^8=256 lower than assumed, i.e. 8 doublings. Today there are no concrete plans to build 1 Mt DAC facilities, the standard size for large-scale deployment, which is again the same factor of 250x relative to the largest plant in operation. Clearly, we are not learning at the rate required for this scenario. The base case scenario implies the opening of one new functional 1 Mt DAC facility every week from 2020 to 2030, one every day from 2030 to 2040, and finally 3 per day from 2040 to 2050. As we still don't know how to build a single 1 Mt facility, this is highly ambitious. Even the conservative scenario, the basis for the final cost figures, assumes half this deployment rate (one Mt-scale facility every two weeks, two days, 16h in the 2020s, 2030s, 2040s, respectively).
2. **Reliability of cost data**: much initial cost data comes from a handful of DAC companies, generally secretive about their costs (their B2B contracts include a secrecy clause), with a strong incentive to account for their costs in the most favorable way, and no public audit. It is impossible to independently evaluate its reliability.
3. **Shape of the learning curve**: learning curves cover economies of scale, cost of inputs, experience of workers and managers, standardization, and discontinuities such as new

product, process or technology. Every learning curve ultimately flattens out and may not be "well-behaved". Essential components of a DAC system such as PV, wind turbines, storage, fans, solvents, heat pumps will likely exhibit much lower capex reduction rates due to their large initial installed base, limiting DAC-induced doublings (see Ferioli et al. 2009 for a discussion of the component-learning hypothesis (Ferioli, Schoots, and van der Zwaan 2009)). Large uncertainties must be expected due to the very limited past scaling to date of DAC on which all cost data is based (Yeh and Rubin 2012).

4. **Scale of required energy system**

    a. Total DAC energy need: using the model developed in the paper (250 kWh-el + 1750 kWh-th per ton CO_2), for 15 Gt CO_2 we need 30 PWh energy, or when using a heat pump with COP of 3.5, a total of 11.25 PWh, or 40.5 EJ. This is almost half of today's global electricity generation (26 PWh) and 150% of the 2020 global renewable electricity generation (8 PWh). This does not count compression, transport, storage of CO_2, or conversion to synthetic fuels or feedstock.

    b. Liquid fuel and feedstock estimate: liquid fuels contain around 45 MJ/kg; producing them from CO_2 and hydrogen needs at least twice this energy, typically 100 MJ/kg (Meunier 2016). To convert 7 Gt CO_2 to liquid fuels, which are around 87% carbon, we obtain 7 Gt * 12/44 / 0.87 = 2.2 Gt fuels. This requires around 220 EJ energy, which is much more than the DAC alone (but includes DAC for the portion converted to fuels).

    c. Battery storage: to ensure 8000 h/year operation needed due to high capex, battery electricity storage covers 56% of total energy, i.e. 40.5 EJ / 365 * 56% = 62 PJ or 17.26 TWh. This represents around 86 Mt of batteries (200 Wh/kg) or 4.3 Mt of lithium (250 g li/kWh), around 50 times the 2020 world lithium production.

    d. Waste heat: given the total thermal energy needed of almost 100 EJ, this probably exceeds the expected world waste heat in 2050, assuming improved energy efficiency and therefore less waste heat. This would make the second set of cost figures unlikely (222/133, 105/60, 69/40 and 54/32 €/tCO_2 in 2020, 2030, 2040 and 2050, respectively).

Building on the results of this detailed model (Fasihi, Efimova, and Breyer 2019), we have shown several fundamental reasons why optimism about DACS seems misplaced, in particular the learning curve potential and energy constraints. Without trying to predict the future, it calls for caution about the prospects of Gt-scale DACS in the next 3-4 climate-critical decades.

4.5. Costs and financing

4.5.1. Cost overview

Almost every aspect of removing CO_2 discussed above is difficult, for different principal reasons:

- Energy use, loss of efficiency, cost
    - Post-combustion CCS requires separating CO_2 from other flue gases, starting from a low partial pressure, and requires compression and filtering.
    - Oxyfuel and pre-combustion CCS simplify separation by adding costly and complex processes to transform the combustion medium or fuel.
- Land use, need to reform agriculture, cost
    - Restoring wetlands is relatively easy as it generally just needs re-flooding. If polluted, de-pollution is a slow, expensive process. However, many ex-wetlands are today productive agricultural land, requiring significant change in agricultural practices.
    - Billions of years of evolution have made photosynthesis very resilient. Yet it is inefficient, converting only 1-2% of solar to chemical energy. This leads to very high requirements for land, water, nutrients, and competes with other land use, especially agriculture as practiced today, limiting the potential of all biological capture and storage methods. This in no way diminishes the importance of biological methods, just means they will not remove more than a few percent of today's emissions.
- Engineering challenges, time to deploy, cost
    - Almost no industrial sites are equipped today with CCS. Many could be retrofitted, at significant cost.
    - Compressing and transporting CO_2 requires infrastructure, energy, and has to overcome corrosiveness and risk of potentially dangerous leakage.
    - Storing CO_2 in geological formations requires the development of suitable sites, which takes years to well over a decade and needs careful and constant monitoring. Often the sites are far from emission sources, making transport more expensive and complex.
    - BECCS is based on expensive methanisation, or highly polluting biomass burning, requiring filtering.
    - Collecting and transporting biomass at scale must be done without fossil fuels. Almost no such infrastructure exists today.

    - Very little pyrolysis capacity for making biochar exists today.

Unsurprisingly, carbon removal is expensive (Minx et al. 2018), with the exception of some biological methods:

- Reforestation or afforestation is the only inexpensive method, usually well below $100 per ton CO_2
- Soil carbon, depending on method <$100/t
- Biochar, $8-300/t
- BECCS, $45-250/t
- DACS, around $1000/t in 2021, expected to fall slowly (European Commission 2021) estimates €894 in 2030, and €595 ultimate); see also "Technical analysis of limits to NET"
- Enhanced weathering, $40-1000/t

As carbon removal grows in scale, it will simultaneously experience two opposite cost effects:

- **Costs will *fall*** with scale, this is the learning curve: technical methods become less expensive over time, methods improve, standards emerge, people are trained, etc.
- **Costs will *increase*** with scale, as the project portfolio changes. Lowest-cost projects get funded first, for example: most accessible biomass, easiest to develop geological storage, most suitable / unpolluted ecosystems to restore. With growing scale, higher-cost projects must be added.

The first effect, learning curve related cost reduction, can be quantified based on experience. The Global CCS Institute estimates scaling costs (Kearns, Lui, and Consoli 2021) of CCS, relative to the size of the plant:

$$capture\_cost\_index = scaling\_factor^{n-1}$$

At constant CO_2 partial pressure, n is typically 0.6 (single plant) to 0.8 (multiple plants)

For Switzerland, this means for example:

- Scaling from 100 to 500 kt CO_2 reduces capture cost by 47%: $1 - 5^{0.6-1}$ (from incineration to cement plant)
- Scaling from 1 to 20 point sources reduces capture cost by 45%: $1 - 20^{0.8-1}$ (from 1 to 20 incinerators)

This is consistent with the only detailed Swiss CCS cost estimate, for the KVA Linth incinerator, by ETHZ Sus.Lab (Sus.Lab 2021), estimating initial single-plant operation at CHF 156-190/t CO_2, and scaling potential to reduce this cost to CHF 68-108/t.

This may be optimistic, as it assumes sufficient scaling of Norwegian geological storage. Once we reach Mt-scale CCS in Switzerland, the storage may need to be domestic, to avoid international transport and storage bottlenecks, adding uncertainty to future costs.

4.5.2. Financial incentives

CO_2 capture is costly, whether it is through capture at the smokestack or a NET, a cost that cannot be covered by selling the CO_2. The fundamental reason is that CO_2 is a stable molecule, with very limited use as such (carbonated drinks, greenhouses). For any other use, as material or fuel, the strong bonds between carbon and oxygen need to be broken, at great energy cost, in complex processes, using expensive equipment. Furthermore, using the CO_2 would result in its ultimate release into the atmosphere. This would be at best neutral, if it replaces fossil CO_2.

Compressing, transporting, and permanently storing the CO_2 captured at the smokestack or through a NET further increases the costs. The options for covering the capture and storage costs differ between CCS and NETs.

CCS is implemented by a CO_2 emitter as a means to reduce his CO_2 emissions. Therefore, the incentives for emission reductions could contribute to covering the costs of CCS. The implications for global net emissions depend on the type of mitigation incentive chosen:

1. **Tax or subsidy on CO_2 emissions**. The emitter gets the costs of CCS covered if the tax avoided or the subsidy earned exceed these costs. He selects the CCS option only if he does not have cheaper means to reduce his emissions. In that case, CCS is a net reduction of global emissions.

2. **Emission rights (cap-and-trade)**. If the emitter is endowed with an allocation of emission rights, CCS saves him a quantity of these rights that he can sell. If he gets no endowment or a too small one, CCS dispenses him from buying emissions rights. The emitter gets the costs of CCS covered if the market price of the emission rights exceeds the costs of CCS. As the emission rights not bought thanks to CCS or sold will be used by another emitter, CCS does not lead to a net reduction of global emissions under a cap-and-trade regime.

3. **Specific subsidy**. A subsidy for setting up and operating CCS could, of course, encourage the CO_2 emitter to adopt this solution if it covers the full cost. In case of partial cost coverage, the subsidy must be complemented with other mitigation incentives.

Thus, CCS leads to a net reduction of CO_2 emissions if the emitter is granted a subsidy or exposed to a CO_2 tax that induces him to adopt this technology and to reduce thereby his emissions beyond the level he would have chosen to abate through other mitigation options.

A NET is usually operated by an operator who does not emit much CO_2. His costs can be covered through these instruments:

1. **Voluntary compensation**. A CO_2 emitter pays for the NET because he wishes to be carbon neutral from an accounting point of view. In this case, the NET offsets emissions which otherwise would not have been abated.

2. **Legal compensation**. A CO_2 emitter pays for the NET, the quantity of CO_2 captured being subtracted from his own emissions with a view to meeting a mitigation target or avoiding the purchase of emission rights. As the NET offsets emissions which otherwise would have been abated, it does not contribute to a net reduction of the CO_2 emissions.

3. **Emission rights**. The NET operator is granted emission rights per tons of CO_2 removed from the atmosphere. He can then sell the permits to cover his costs. In this case, the NET does not contribute to reducing total emissions under the "bubble" created by the cap-and-trade system, as it simply allows another emitter to emit more CO_2, the emitter who buys the permits from the NET operator.

4. **Subsidy**. The NET operator is paid a subsidy for setting up and operating the system or per ton of CO_2 removed from the atmosphere. In this case, the NET leads to an actual reduction of the CO_2 concentration in the atmosphere.

Thus, NETs only lead to an actual reduction of the CO_2 concentration in the atmosphere when they are paid for through subsidies, or are voluntary.

Under the polluter pays principle, the financial resources for the subsidy should be provided by CO_2 emitters, past or present. Raising these contributions pro rata of their CO_2 emissions would provide them with an additional incentive to reduce these emissions. Furthermore, the quantity of CO_2 extracted from the atmosphere thanks to the subsidy they make possible could be interpreted as an offset for their emissions.

4.5.3. Disconnecting polluter payment from clean-up costs

Given the high cost of NETs, the proportion of CO_2 emissions offset through them and the timing of these offsets is critical. Consider this thought experiment. Suppose that NETs could be deployed on a large scale as soon as 2023 at an average cost of CHF 500 per ton of CO_2 permanently removed from the atmosphere. If 100% offset were the goal, a contribution of CHF 500 would have to be levied on every ton of CO_2 emitted in 2023. This would be a huge burden. Furthermore, as time passes the cost of NETs decreases but so do the emissions of CO_2. Some time between 2040 and 2050, CO_2 emissions would be down to zero, so there would be no base any more for financing the subsidy for NETs, precisely when they could extract CO_2 at much reduced costs.

It is, therefore, preferable to disconnect the collection of the contribution and the payment of removal costs. This can be achieved through a fund, such as the Swiss Climate Cleanup Fund proposed in the E4S working paper “*Climate Cleanup Fund - getting to Swiss Net Zero*”. How this could work is illustrated in Fig. 4.3. In this illustrative example, the emitter pays a constant fee of CHF 200 per ton CO_2 emitted into the fund. These payments decrease together with the volume of emissions, to reach zero in 2050. In 2022, when removal costs CHF 500 per ton, only 1% of that year’s emissions are removed. The expense is withdrawn from the fund. As removal costs decrease, the volume of CO_2 removed increases, up to its maximum in 2060, when it is over 50 times the volume removed in 2022. Between 2022 and 2060, all emissions accumulated between 2022 and 2050 have been removed at a cumulated cost that is equal to the total amount of contributions into the fund (with interest added).

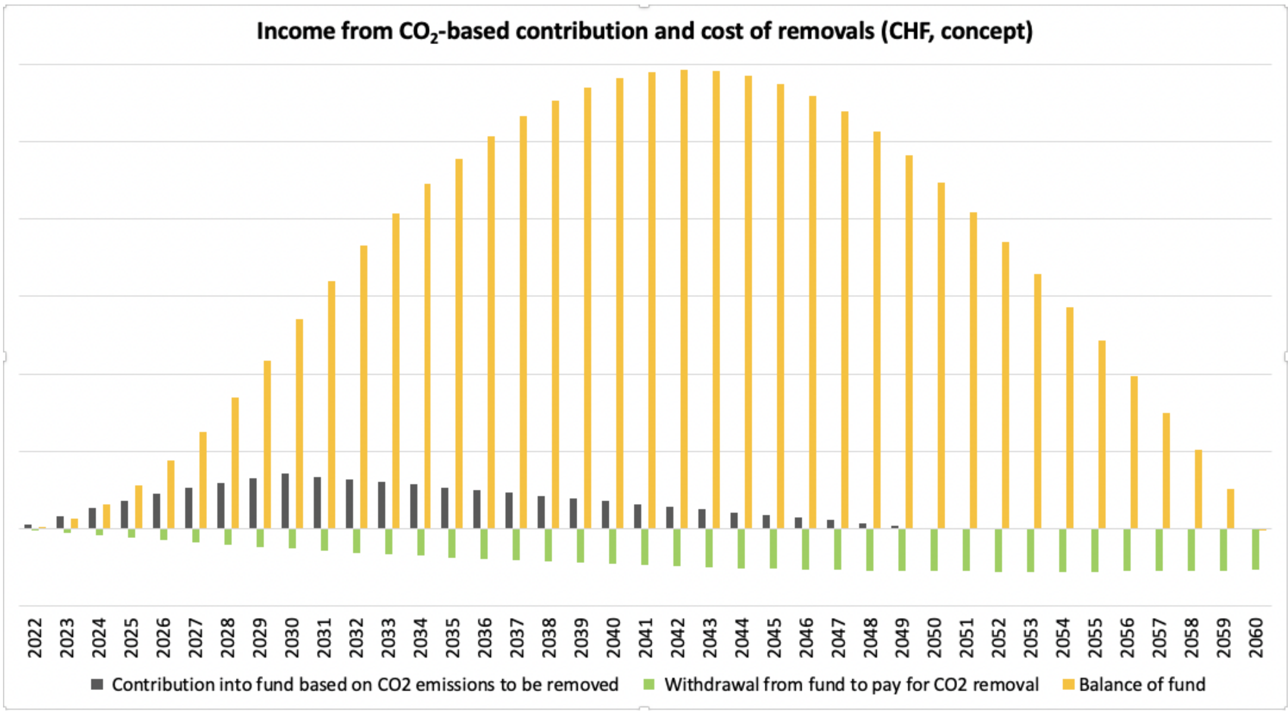

Figure 4.3: Example of separating revenues from removal projects via a climate cleanup fund

Finally and crucially, the fund mechanism is self-correcting, as the carbon price will be highly dependent on the speed of decarbonization. In any given year, there is a portfolio of available carbon removal projects, with very different costs per ton. The lowest-cost projects get funded first, and the average price will be strongly dependent on the volume: fast decarbonization will leave little residual emissions, and a low average removal prices. If decarbonization is slow, carbon removal volume will be high, with a very high average price. This will create a strong incentive to decarbonize faster.

4.6. Strategy and implications

4.6.1. The case for planning CCS+NET together

Conceptually, CCS and NET are very different, as the first reduces emissions, and the second removes CO_2 from the atmosphere. However, there is a strong case to analyze CCS and NET together, for the following reasons:

- Many technologies or non-tech systems are shared: carbon capture (fossil CCS and BECCS), CO_2 pipelines, geological storage, as well as monitoring, financing, reporting, and governance.
- CCS is needed short-term, while we still burn fossil fuels, but has little long-term potential beyond cement. Building the infrastructure becomes more feasible if later used for BECCS. In case of constrained availability of shared infrastructure, a common perspective is essential.
- CCS and NET might work best if they share the same policy instruments, for example a price for emitting or credit for removing CO_2, or a mandate to remove all emissions.

4.6.2. Geopolitical conditions for deployment

There is a big difference between:

1. Biological capture and storage (reforestation, ecosystem restoration, soil carbon, biochar), where the carbon storage is either a living part of biodiversity (trees, wetlands) or a major contributing factor (carbon-rich soils),
2. BECCS, if limited to excess biomass and agricultural waste, with no adverse biodiversity effects, and
3. Other methods, such as CCS or DACS

if properly designed and managed, and limited in scale (see §4 NET), the first helps biodiversity (and resilience, ecosystem services, climate adaptation), the second generates electricity and heat, and the third has no co-benefits beyond removing carbon, especially no local co-benefits.

Therefore the first two may work if supported in the local context. Due to the absence of co-benefits of CCS or DACS, other than removing CO_2 from the atmosphere, they require an almost perfect global coordination. Even a 20-25% leakage, i.e. a quarter of the world continuing to emit CO_2 unabated, would completely negate the whole effort: assuming the “climate action world”, accounting for 80% of 2020 emissions, decarbonized according to IPCC SR15 (IPCC 2018) and reduced emissions by 90%, the “no climate action world” would account for over ⅔ of global emissions - in this case carbon removal in the first group would be just as costly but would have little impact. At a minimum, this coordination would cover restricting emissions, regulating CO_2 transport and sequestration, and financing CCS and NETs. This is much harder than accelerating existing approaches such as the Paris Agreement NDCs, CBAM, carbon taxes and regulation, and financing CO_2 removal with local biodiversity or societal co-benefits, which can all be effective at the regional scale or in partial coalitions (“climate clubs”).

The Carnegie Climate Governance Initiative (C2G 2021) provides a good overview of carbon removal governance, and the numerous remaining gaps.

In particular proponents of massive DACS (Fasihi, Efimova, and Breyer 2019) sometimes mention the theoretical scenario where we wait so long that nothing other than multi-Gt-scale DACS works. This is particularly unlikely - if ecosystem services start to collapse, leading to widespread hunger, migration, conflicts, and possibly war, coordinated global action towards long-term goals becomes even more difficult. Unilateral, uncoordinated SRM could be a more likely outcome.

4.6.3. Purpose of carbon removal

Let us restate the main purpose of carbon removal: help reach net zero by removing the residual emissions, after sufficiently deep decarbonization. Longer term, beyond reaching net zero, carbon removal could progressively reduce the CO_2 concentration. However, the urgency remains to reach net zero by 2050 latest (IPCC 2018).

As this includes CCS and NET, there could be a scenario where rapid deployment of CCS alone reaches 10-15% of 2020 emissions, before declining due to the required phase-out of fossil fuels for health and ecosystem reasons. However, the high costs, difficulty of reaching the almost perfect geopolitical coordination needed (see above), and the fact this huge transformation of society would be useful for perhaps only 2-3 decades, makes this rather unlikely.

Additionally, the goal is to provide real biodiversity co-benefits, and generate electricity and heat (BECCS).

This is not at all how CCS developed historically: to extract more oil from depleted fields. It is also not why major players today show their enthusiasm for CCS, and confidence in future NETs: to extend the fossil era, prolong the lifetime of stranded assets like coal power plants, open new markets for oil companies (CCS solvents), or simply benefit from many available “green” subsidies. Stabilizing the climate is conspicuously missing from the goals of almost all main players.

As carbon removal is essential, it is urgent to set the right priorities and policies. Otherwise, it will remain a transfer of wealth from taxpayers to corporations, and not help stabilize the climate.

As the Economist (2021) wrote just before COP26 opened: “*One problem is that fossil-fuel industries and governments that value them have an interest in saying they are pursuing CCS, because it seems to provide a future for some fossil fuels, but no pressing reason to make it an implemented reality. The technology makes plants more expensive and less efficient, and in the absence of a high carbon price that is a penalty nobody wants to pay*”.

4.6.4. Global moral hazard?

Moral hazard in economics is a situation when an organization has an incentive to take too much risk because it is not fully liable for the consequences.

Moral hazard related to carbon removal could occur if it limited or delayed emission reductions (Florin et al. 2020).

As argued in this paper, the moral hazard can be significantly reduced if carbon removal is seen as a method to remove residual emissions only, assuming the deep decarbonization pathway is reasonably well defined. It is especially important to define the timeline and sequence of activities scheduled for fossil fuel exit, and the “acceptable” residual emissions for other sectors like cement or agriculture. Lacking clear pathways, many sectors could consider their own emissions “unavoidable”, and part of the last 10%.

Successful initial deployment of CCS or NET with rapidly falling costs could also create a moral hazard, reducing the pressure to decarbonize rapidly, creating an incentive to invest even more in carbon removal, making it the single point of failure of climate policy. Such failure could materialize due to an unforeseen barrier or simply flattening of the learning curve (see “Technical analysis of limits to NET” above), leaving the world dangerously unprepared for the climate emergency.

4.6.5. Social acceptance

In this new field, public perception is constantly evolving, and much depends on how questions are framed. The UK Climate Assembly, comprising 108 randomly selected citizens using stratified sortition and thus representative of society, deliberated between January and May 2020, to determine how the UK could reach net zero. The final report (Climate Assembly UK 2020) specifically includes carbon removal, with 4 measures broadly accepted (reforestation and better forest management, restoring wetlands, using wood in construction, and enhancing soil carbon), and two very divisive measures (BECCS and DACS). The concern for the last two methods were related to:

- Potential leaks from geological storage
- Failing to address the problem, distracting from emission reductions
- Less natural, costly and unproven, for DACS also “needs a lot of energy”

Very interestingly, UK Climate Assembly members also said that BECCS and DACS “*should only be used in moderation as a way of capturing that last bit of carbon that can’t be captured by a combination of natural methods of carbon storage and moves towards generating carbon neutral energy*”. Additionally, fossil energy with CCS was strongly rejected as a pathway to low-carbon electricity, much more than BECCS and DACS.

4.6.6. Energy limits and alternative uses

Fossil fuels still account for well over 80% of the almost 600 EJ annual world primary energy consumption (BP 2021). Rapidly exiting fossil energy is a climate, biodiversity, health and ethical imperative. Retrofitting CCS to coal and gas power plants benefits the climate but increases non-CO_2 pollutants, due to higher fuel consumption, hurting the most vulnerable ecosystems and people. It also extends the fossil age. Replacing these 500 EJ with clean energy will be a colossal task, making energy constrained for decades to come, very likely at levels below today's 600 EJ total.

In this context, which uses of this precious available clean energy will lead to the highest level of human wellbeing? This question is of course worth asking for many activities. Given the energy intensity and scale needed for carbon removal, it is particularly important for DACS and synthetic fuels.

On average, each human uses 63 GJ of fossil energy per year, emitting 4.8 t CO_2. Removing this CO_2 using DACS requires around 48 GJ not counting compression, transport and storage, which is around ¾ of the primary energy and 100% of final energy generated by burning this fossil fuel. Replacing this fossil by DACS and synthetic fuels (a form of CCU, where the carbon is re-emitted within weeks) would require at least 150 GJ clean energy per person per year (see Scale of energy system in Technical analysis of limits to NET). This is a quantity of energy unlikely to be available for a very long time, and around 10 times the energy needed to satisfy all human needs (Millward-Hopkins et al. 2020).

In perspective, 15 GJ of clean energy can power energy services to satisfy the annual needs of one person. Or it could sequester 1.5 tons of CO2 using DACS, a third of their emissions. Alternatively, it can produce around 6 GJ synthetic fuel or 130 kg, corresponding to 1/10 of their current use.

There are many good reasons to develop clean energy as quickly as possible. Still, in an energy-constrained world, at any given point, surely the highest priority must be universal access to basic energy services. Rapidly exiting fossil fuels, building renewables, and ensuring inclusivity are already highly ambitious. Simultaneously doubling or tripling the energy system to provide for DACS and synthetic fuels at scale is highly unlikely.

4.6.7. Potential limits to carbon removal

Are there hard, physical limits to carbon removal? Yes, but too far to be of practical importance in the coming decades or even centuries. Incoming solar radiation on Earth is limited; this energy has many other essential uses. Regardless of the energy source, any energy conversion generates waste heat, which will, at sufficient scale, heat the planet. On the other hand, geological storage is probably sufficient to store all the world's carbon.

In the coming decades, essential for stabilizing the climate (IPCC 2018), the main constraint are ecosystem services. Do we optimize BECCS for yield by planting high-growth monoculture, or for biodiversity and resilience, giving the primary forest the long time it needs to grow, slowly capturing carbon? How do we transform our food system for health, sustainability and resilience, so it complements carbon removal, not competing with it? For optimal soil health, how much crop biomass can we remove, while reducing chemical fertilizers?

The size of CCS is limited by suitable point sources, which will all sooner or later move away from fossil fuels. This limits the time window during which CCS operates, and unless potentially converted to BECCS, makes it harder to finance. Constrained energy supply might change our priorities, as argued in the previous section.

The IIASA ENGAGE project (IIASA 2021) analyzes “net-negative” scenarios with slow decarbonization and massive carbon removal later this century, showing “hazardous levels of overshoot”. Limiting this warming overshoot requires faster decarbonization, and ultimately less need for carbon removal, as in IPCC 1.5°C pathways P1 and P2 (IPCC 2018).

Finally, it will take time to learn: refine methods, train people, develop monitoring and governance, share best practices, standardize key components and their production, create the needed geopolitical conditions for deployment, structure financing and raise money. CCS has decades of experience in EOR; now we have a completely different challenge and little experience.

Given the extraordinary complexity and all these moving parts, we are not aware of any suitable complete model, beyond the estimates of afforestation and BECCS used in IAMs. So it would be hard to model, much less prove, our estimate that carbon removal is unlikely to exceed 5-10% of current emissions. We do, however, show the estimates for Switzerland, which are consistent with this level. At a worldwide level, this remains an ongoing effort; IPCC AR6 WG3 will provide a new estimate.

The remaining open questions should not delay urgent climate action, and carbon removal is clearly one of several good 10% solutions. It must not be seen as *the* solution to the climate crisis.

4.6.8. Implications for Switzerland

What does this mean for Switzerland? Switzerland has a few specificities, each with their own implication (->):

- Rich but fragile ecosystems, partly high altitude, stressed by industrial agriculture, already exposed to 2°C warming
    - -> Importance of measures with biodiversity co-benefits, especially ecosystem restoration and biochar / soil carbon projects.
- Small size, high density: biomass very limited, multiple competing uses
    - -> Strong limitation of the total potential of carbon removal for reforestation, ecosystem restoration, biochar, or BECCS, highlighting the importance of rapid and deep decarbonization.
- Geological structure conducive to permanent storage in saline aquifers unexplored, only theoretical assessments available. Landlocked country with no significant storage in neighboring countries
    - -> Urgency to explore domestic geological storage, even more so given the long lead times.

- Significant short-term CCS potential from cement, chemical plants and waste incineration
    - -> This potential can be exploited at scale only if domestic geological storage is developed rapidly. It is likely that deep decarbonization will significantly reduce the potential of CCS, perhaps after 20-30 years.
- Growing acceptance of the idea of equipping waste incinerators with CCS
    - -> As about half of incinerated waste is wood and other biomass, this part would count as NET (BECCS). BECCS provides a way to extend the lifetime of shared CCS infrastructure: storage, transport, and capture, at least in waste incineration.
- No suitable energy sources for DACS at any meaningful scale
    - -> DACS unlikely to scale in Switzerland.
- Significant imports of embodied emissions, ⅔ of the total (Nathani and Soceco 2019)
    - -> In a logic where carbon removal follows emissions, probably only territorial emissions could be removed domestically. Deep decarbonization will very probably completely reconfigure the value chain, so these proportions may change.

The Swiss potential carbon removal, costs and a financing mechanism are developed in the E4S working paper “*Climate Cleanup Fund - getting to Swiss Net Zero*”.

5. Swiss Negative Emissions Fund - paying for Net Zero

Authors: Sascha Nick, Philippe Thalmann

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Abstract: 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 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” CO2. The compulsory payment into the fund replaces the existing CO2 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 CO2 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: 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.

Keywords: climate action, net zero, negative emissions, polluter pays, nature based solutions

5.1. 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 5.5, 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 5.6): 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.

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.

5.2. Carbon removal, negative emissions, and net zero

Our December 2021 E4S White Paper "***Carbon removal, net zero, and implications for Switzerland***" (Nick and Thalmann 2021) 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 (IPCC 2021, 6) 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 (WWF 2020; IPCC, 2018). 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.

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

5.3.1. 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 (Stadelmann 2021), 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.

5.3.2. 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 (Nick and Thalmann 2021), 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 (BAFU 2022) 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 (Climate Action Tracker 2021a; 2021b).

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

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

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.

5.3.3. 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 (IPCC 2021) 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. 5.1).

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 overshoot (IIASA 2021), with warming beyond 1.5°C. This limits acceptable emissions to low- or no-overshoot pathways, such P1 and P2 in IPCC SR15 (IPCC 2018). **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 (IPCC 2018).

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

5.4. The case for a Swiss Negative Emissions Fund

5.4.1. 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

5.4.2. 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

5.4.3. Externalities and lack of climate action

Why focus on carbon removal, if we know this is at best one of the good 10% solutions (Nick and Thalmann 2021), 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.

5.4.4. 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.

5.4.5. 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 (Luppi, Parisi, and Rajagopalan 2012), and first introduced in law (Fressoz 2011) in 1810 in a very limited form. It has since become a major principle of environmental liability in the EU (European Commission n.d.), 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 section, 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.

5.4.6. Carbon takeback obligation

The carbon takeback obligation (Carbon Takeback 2020), first conceptually proposed in 2009 (Allen, Frame, and Mason 2009), 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 (Jenkins et al. 2021) 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 (Jenkins et al. 2021) “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 (Nick and Thalmann 2021) 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.

5.4.7. 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 (Thalmann and Vielle 2019) of around CHF 1000 per ton CO_2. Excluding individual sectors would lead to even higher prices in the remaining sectors (Thalmann and Vielle 2019).

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.

5.4.8. Swiss climate action and geopolitical implications

We examined geopolitical conditions for deployment (Nick and Thalmann 2021), 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 (World Bank n.d.) 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.

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 (CEPS 2021), which simply allows emitters to emit as much CO_2 as was removed.

5.5. 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 (Swissnuclear 2019).

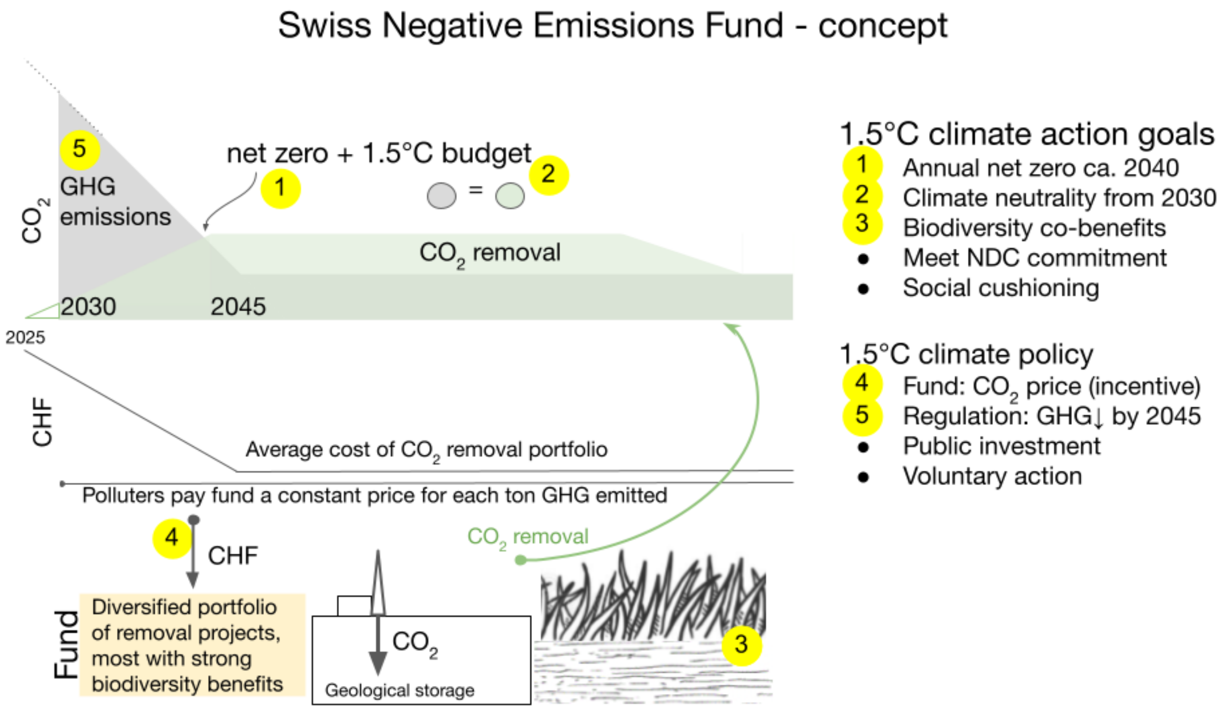

Figure 5.1: Visual description of the Swiss Negative Emissions Fund, facilitating climate goals, integral to climate policy

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 CO_2 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.

5.5.1. 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.

5.5.2. 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.

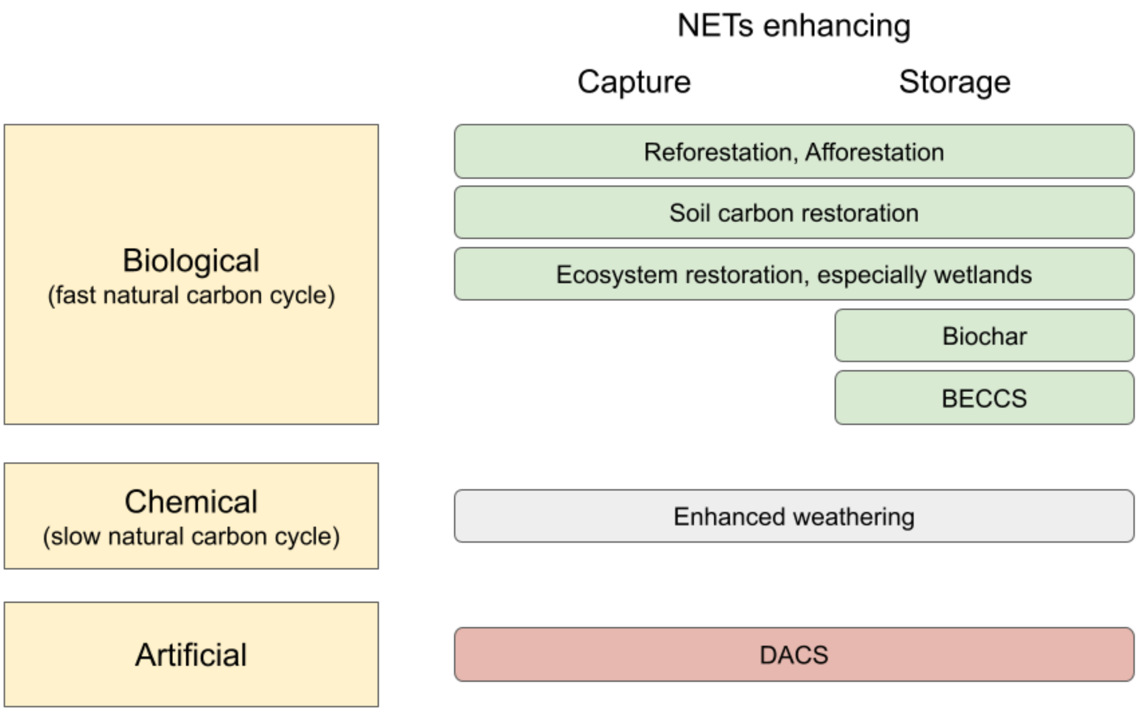

Figure 5.2: Classification of NETs considered for the SNEF

The project mix in the portfolio will cover a range of NETs, biological and chemical, following the classification (Nick and Thalmann 2021) 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 (Nick and Thalmann 2021) 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.

5.5.3. 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 (Pedersen, Weisner, and Johansson 2019) for the broader society
- A multitude of local opportunities to learn hand-on about climate and biodiversity, at all educational levels

Beyond appropriate communication (CPLC 2018), based on simplicity, fairness, and effectiveness, acceptance requires familiarity and positive subjective perception of benefits (Stadelmann 2021). **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 (2020) 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.

5.6. 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 (IPCC 2021). 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 (Swiss Federal Council 2021), 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, Swiss Federal Council 2021), 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 (Swiss Federal Council 2021) 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.

5.6.1. Baseline results

Our model indicates that the above assumptions require 10 Mt of annual negative emissions (Fig. 5.3). 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. 5.4 shows that the maximum capitalization of the fund is only about 6 times the peak annual contribution to the fund.

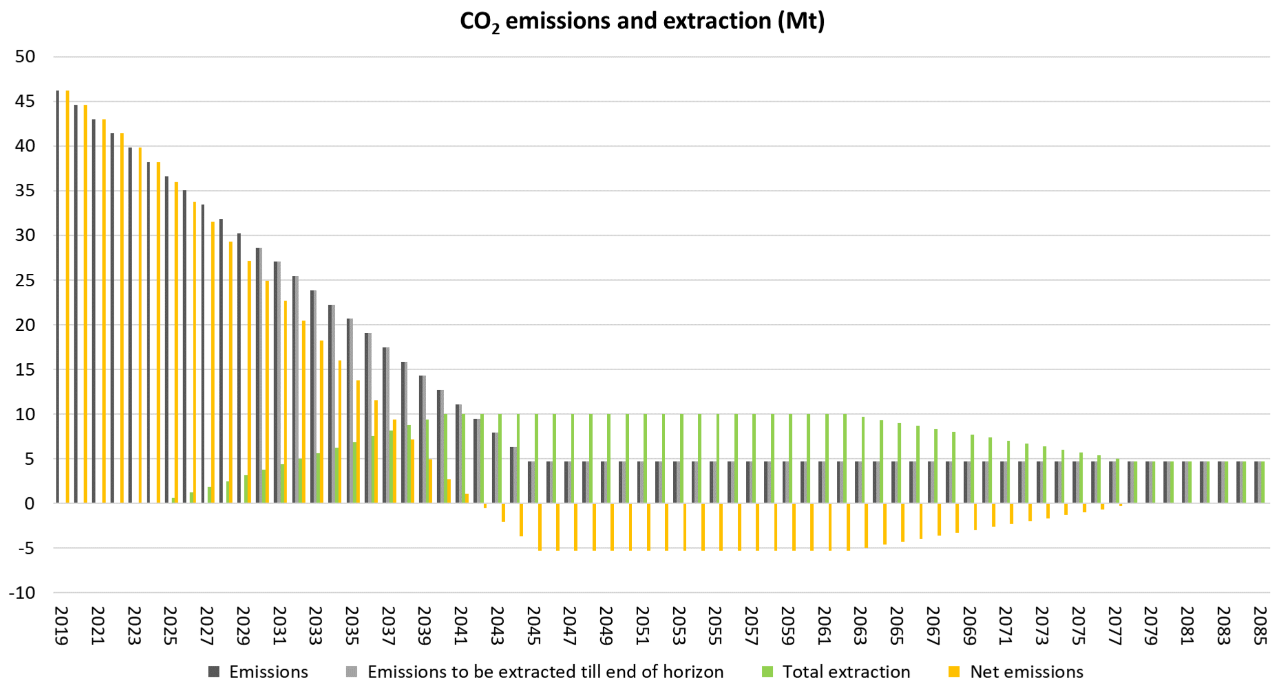

Figure 5.3: Simulation of CO_2 flows, baseline

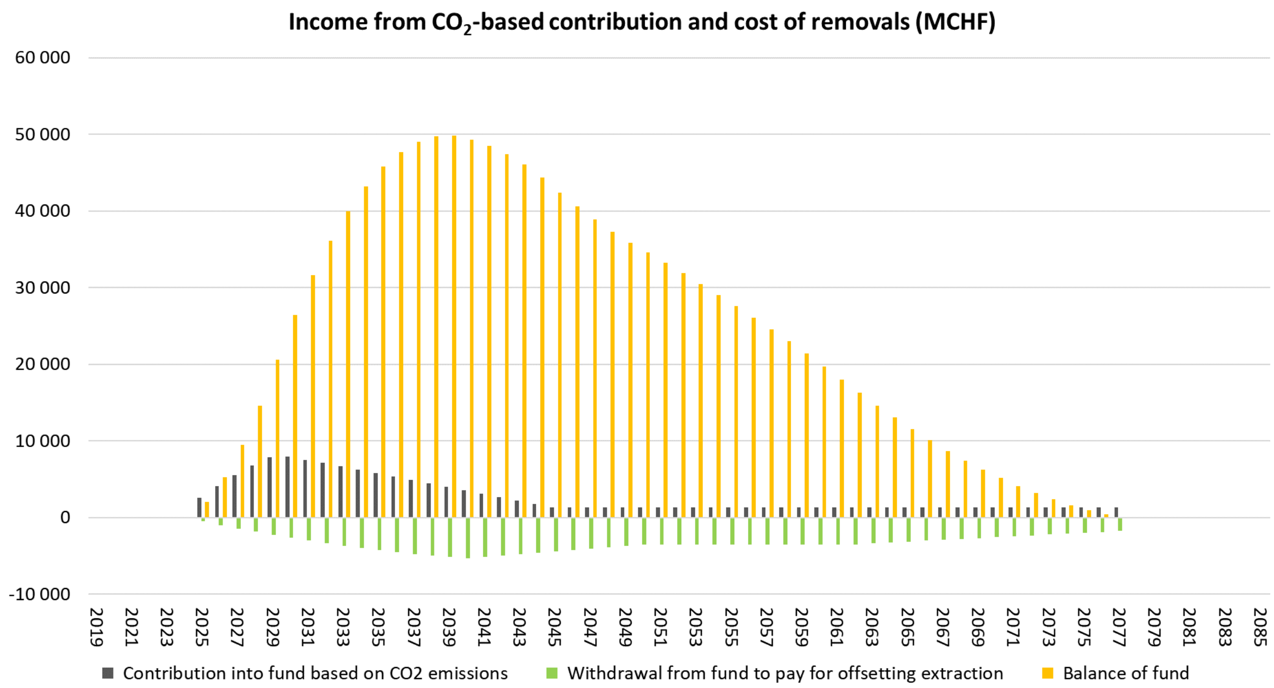

Figure 5.4: Simulation of financial flows, baseline

5.6.2. 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 (Nick and Thalmann 2021), 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 (Fig.5.6, p.22, BFE 2020).

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 (Willett et al. 2019). 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 (BMUV 2021, 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 (Ritchie and Roser 2020).

In 1990, Germany's population of 79.43 million emitted (Umweltbundesamt 2022) 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, Statistisches Bundesamt Deutschland 2022), 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. 5.5, Fig. 5.6). 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.

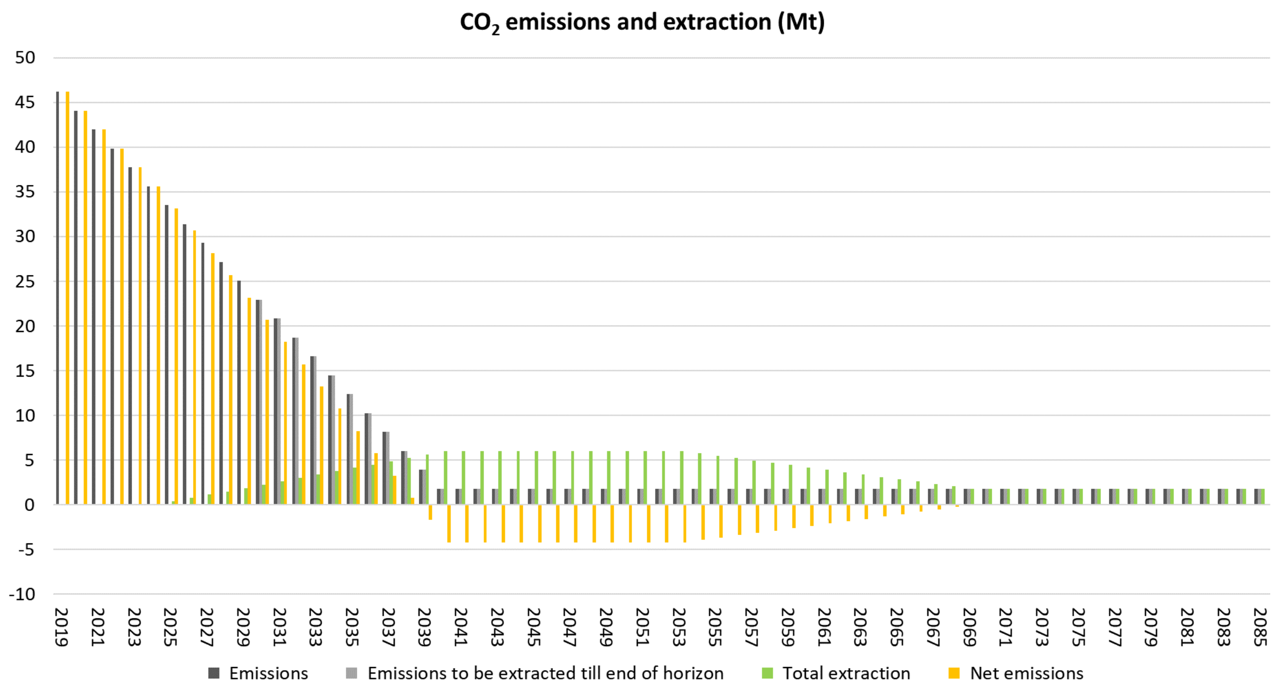

Figure 5.5: Simulation of CO_2 flows, more ambitious climate policy

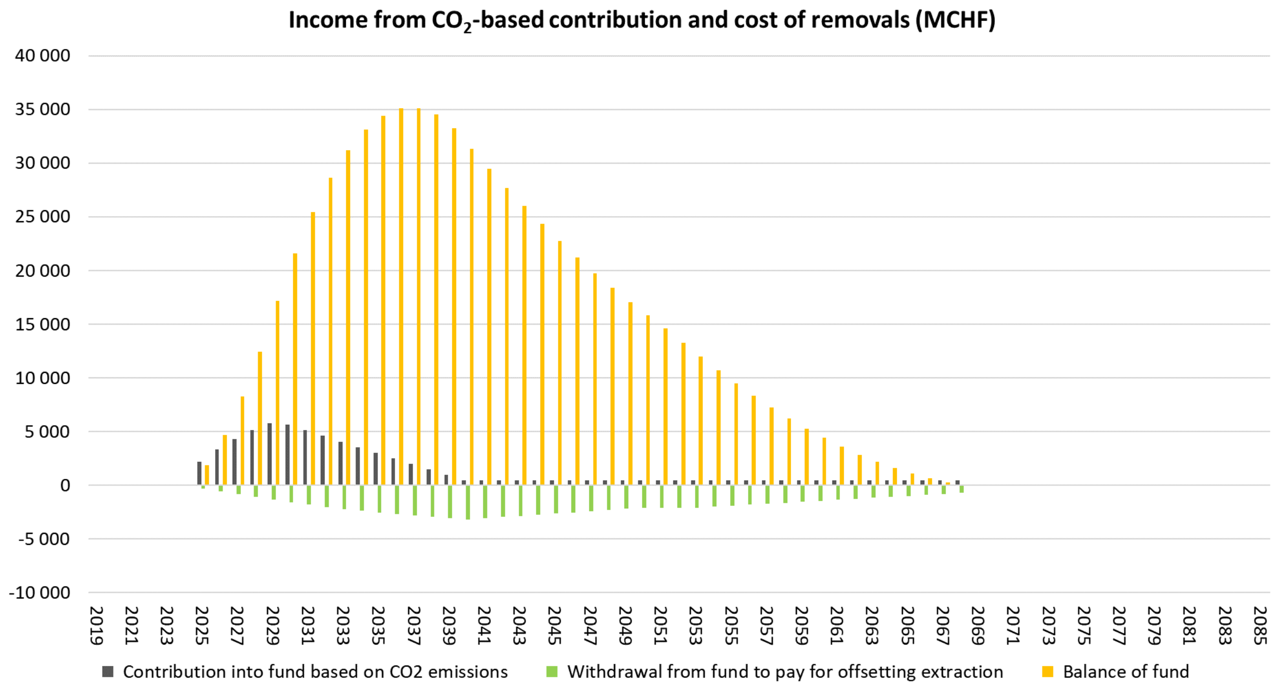

Figure 5.6: Simulation of financial flows, more ambitious climate policy

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.

5.6.3. Impact of aviation

The 2019 CO_2 emissions of Swiss international and domestic aviation (BAFU 2021), 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 (Neu 2021) 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 (Thalmann et al. 2021) "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 (Swiss Federal Council 2021) 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 (Lee et al. 2021). 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.

5.7. Getting started: proposed pilot fund

5.7.1. 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.

5.7.2. 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.

5.7.3. 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

5.7.4. 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), especially the chapters on community engagement and operationalizing resilience (Sudmeier-Rieux et al. 2019).

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

5.8. Appendix

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

This technical section 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 (Jardine et at 2004) 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 (Neu 2021) 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 (IPCC 2021, 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: $CO_2e^* = (105 \bullet \Delta E_m) + (7 \bullet E_m)$, 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 (BAFU 2021), 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*: $CO_2e^* \approx 7 \bullet E_m$. Based on Switzerland's Long-Term Climate Strategy (Swiss Federal Council 2021), 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.

5.8.2. Modeled scenarios, assumptions, and parameters

Table 5.1: Summary of the main inputs and outputs of the SNEF model

	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

6. Swiss Negative Emissions Fund Pilot - action and research

This chapter summarizes the rationale for a negative emissions pilot fund, and gives an overview of the logic, structure, and process of setting up such a fund. As a short stand-alone document, it is used in discussions with potential partners of the pilot fund.

6.1. Overview of the negative emissions pilot fund

Large-scale change in society often happens by accident, but if urgently needed as in the case of reaching net zero before 2050, it must be planned. Publishing and presenting papers is unlikely sufficient to initiate the required change, and prototyping solutions and widely engaging society are essential. How to do this effectively?

Our proposed Swiss Negative Emissions Fund (SNEF) is a large-scale change that could produce lasting effect: its implementation would restrict fossil fuels to reduce emissions by 90% in 15-20 years, make all polluters pay from 2025 partially and from 2030 on all emissions transferring wealth from corporation to communities, and engage citizens in all regions around nature-based solutions and ecosystem restoration. However, it is unlikely to be decided based on papers and discussions, especially as it requires a new law.

How useful would an intermediate step of prototyping the SNEF be?

While many theories of change could be useful to analyze climate action, Geels' (2011) multi-level perspective on sustainability transitions combines **niche innovations** co-created in networks which align over time, dynamically stable **socio-technical regimes** aligning elements of system structure and mental models (science, technology, industry, markets, policy, and culture), and the broader **socio-technical landscape**, putting pressure on regimes and eventually destabilizing them. If the pressure from above and the niche innovation alignment from below push in the same direction, the destabilized regime may recombine into a new, dynamically stable one.

From the perspective of the negative emissions pilot fund, niche innovations include the fund itself; measuring, monitoring, and modeling nature-based solutions; internal company decarbonization pathways and practices; local political support; citizens engagement; and many other initiatives.

Will it work? This will depend on the pressure from above (climate catastrophe, fossil energy shortage, geopolitics, or events we cannot predict), alignment from below (success of our pilot initiative, enabling processes and technologies, and other local initiatives), as well as the ability of existing institutions to support or hinder change. So we must try, and adapt as needed.

6.2. Swiss Negative Emissions Fund - summary of the pilot project

6.2.1. Introduction - purpose of SNEF and the Pilot Negative Emissions Fund

In our papers Carbon removal, net zero, and implications for Switzerland (Nick and Thalmann 2021) and Swiss Negative Emissions Fund – paying for Net Zero (Nick and Thalmann 2022a), we make the case for the importance of negative emissions in the Swiss climate policy, as an essential complement to other forms of climate action, such as sufficiency, efficiency, and clean energy, together needing to decarbonize Swiss society 90% by 2050 to be on track to limit warming to 1.5°C. Negative emissions could both accelerate the 90% decarbonization, and deliver the remaining 10% - if properly designed, focusing on biodiversity and societal co-benefits, and funded by today's emitters using the "polluter pays" principle. We further propose, model, and validate the Swiss Negative Emissions Fund (SNEF).

Figure 6.1: Renaturing wetlands protects biodiversity and creates local jobs - such projects would be included in the pilot NEF. Photo credit: Lena Gubler, WSL; reproduced with permission

The SNEF is a public fund, entirely emitter-funded, starting in 2030 or earlier (significantly reducing costs) and progressively reaching 100% of all territorial emissions in 5 years, which builds and governs a balanced portfolio of negative emissions projects in Switzerland, for the benefit of society and biodiversity. It replaces much of current Swiss climate policy, and requires a new CO_2 law. The approach is highly efficient, leading to a relatively low CO_2 price, which we model in the range of CHF 250-300 per ton, stable for the lifetime of the fund. Participants start by paying to remove a small portion of their emissions initially, increasing until all are covered. Faster decarbonization with a more ambitious climate policy is much more affordable, significantly reducing both risks and costs.

The fund is designed to work with additional policy instruments such as restricting imports of fossil fuels, and public investment in social cushioning measures.

Not only is the proposed approach effective as it reaches Swiss net zero around 2040, fair as 100% polluter-funded, and very affordable, but also an opportunity to build a societal agreement and unblock Swiss climate policy following the CO_2 law vote in June 2021, and re-establish Swiss climate leadership.To validate the SNEF and accelerate its implementation in the Swiss law, we propose a voluntary pilot fund, at around 1% of the scale of the full Swiss fund - and are currently seeking engaged organizations to join.

The pilot fund will deliver a range of benefits for participating organizations: faster and deeper decarbonization, higher employee engagement, significant knowledge and capacity building, giving it a head start of at least 5 years compared to non-participants, and public signaling of its climate leadership

Beyond participating organizations, the pilot fund will also benefit society, by accelerating the development of high-quality negative emission projects with biodiversity and societal co-benefits (including developing best-practice governance and monitoring), broad engagement of all main Swiss stakeholders, and validating the SNEF to facilitate the needed societal consensus and help pass the law.

6.2.2. Brief outline of the proposed implementation

Organizing principles of the fund [this section is adapted from Nick and Thalmann 2022a]

- Governance: the pilot fund is a foundation with three independent panels, accountable to the foundation board. Each panel includes one or more board members with outside experts:
    - **Membership panel** to supervise contributions of participants in proportion to their current GHG emissions, and ensure successful collaboration with member organizations
    - **Asset management panel** to supervise placement of funds, until needed for projects, to generate the required returns without interfering with the fund's climate and biodiversity objectives
    - **Project selection and monitoring panel**, which would build a diversified portfolio including both proven and novel negative emission projects, and monitor to ensure persistent climate, biodiversity and societal benefits of such projects

- Emissions:
    - All territorial GHG emissions are covered; methane is converted to CO_2e using GWP*
    - International flights are included, using the radiative forcing multiplier of 3, i.e. 3 times the emitted CO_2, as recommended by SCNAT (Neu 2021)
    - All negative emissions projects will be monitored and independently audited; suitable project certification methods will be developed in collaboration with federal offices (FOEN, SFOE)
- Payments:
    - 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.
    - The CO_2e price will be CHF 250 per ton when the fund starts, and be revised as needed.
- Progressive inclusion of CO_2 emissions; member organizations jointly choose Option 1 or 2:
    - 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.
    - 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.

How to build a diversified negative emissions project portfolio? The project selection will balance:

- 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: geological projects may include tradeoffs between CO_2 removed and biodiversity impact (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 any meaningful BECCS (negative emissions) and also CCS (emission reductions) from 2035-40

Given the small scale of the pilot fund at 1% of SNEF or ca. 50 kt CO_2 p.a., carbon removal projects can be developed quickly, limited only by money and efforts invested. Participating organizations will pay the full price on a growing percentage of their emissions. The time to select and implement negative emission projects can be expected to be several months. This setup will lead to rapid results, which is key for preparing the full-scale SNEF and quickly delivering benefits for participating organizations and the broader society.

6.2.3. Participating organizations - Benefits and commitments

The Pilot Negative Emissions Fund is seeking three types of support (separate or combined):

- [Ideal support] Organizations which find the concept of the fund valuable and **commit to promoting, supporting, sharing ideas, communicating, contacting** potential members etc.
- [Seed funding] Organizations or individuals **supporting the establishment of the fund, especially developing certification methods, standards** (permanence, biodiversity impact, etc.), and best practices**, as well as supporting broad stakeholder engagement** across the Swiss society (3-year commitment)
- [Operational funding] Organizations **committing to reaching net zero by rapidly decarbonizing, and investing in the pilot fund to provide negative emissions** corresponding to their residual emissions (5+ year commitment)

Each supporting organization will benefit from:

A. High visibility and public signaling of its climate leadership, as it will be visible in the broad outreach and stakeholder engagement program, including citizens, academia, public administration, civil society, media, and business.

B. Significant knowledge and capacity building giving it a head start, in all relevant area of decarbonization, negative emissions, societal transformation, via direct involvement of its employees.

C. Helping Swiss society get ready for its urgently needed net zero transition, by supporting the development of knowledge, methods, standards, and generally building capacity and improving resilience in all participating communities; as well as reaching out and building a shared awareness among stakeholders.

Additionally, organizations on the rapid net zero pathway will benefit from:

D. Faster and deeper decarbonization, improving organizational resilience (the ability to face future disruption), reducing financial and physical risks, and directly saving money: funding negative emissions is expensive, but by decarbonizing rapidly, an organization can save more than it invests in the pilot fund.

E. The key to decarbonization is a broad engagement of all its employees, in itself a benefit, which can be supported by the fund, especially by sharing best practices among participating organizations.

Commitments of participating organizations

To ensure these benefits are realized, each organization commits to the following:

1. To support rapid decarbonization:
   a. Publish and regularly update a credible net zero plan, focusing on sufficiency, efficiency, and clean energy
   b. Continuously monitor own territorial and flight emissions; report and pay quarterly to the pilot fund
   c. Personally and regularly engage all its employees, including regular internal communication, as well as climate and biodiversity education
   d. Create internal economic incentives at the lowest level of granularity (examples: departments or teams pay for negative emissions related to flights, individuals for those related to commuting and food)
   e. Regularly share best practices with other participating organizations and use this learning to decarbonize faster
   f. Help engage all stakeholders of society about decarbonization and negative emission projects with biodiversity and societal co-benefits, including a broader climate communication

2. To support the establishment of the fund:
   a. Fund the development of certification methods, standards, and best practices
   b. Fund and support communication and outreach
   c. Contribute to funding the fund team and governance costs

If interested, we'd be happy to help you estimate likely payments to the fund, depending on your organization's emissions, decarbonization pathways, possible internal engagement actions, and outreach focus.

For best-practice governance, we plan to separate the following:

- Financial governance of the fund from project certification governance (CO_2 flows, permanence, biodiversity impact, societal benefits)
- Institutional communication (roles, benefits, and leverage effects of negative emissions, feasibility of SNEF) from project communication (local biodiversity and societal impact)

While the scientific principles behind the fund are well established (see Introduction), the specific modalities of implementation will be decided jointly by participating organizations. We welcome any Swiss emitter >10 kt CO_2e p.a., genuinely committed to climate action (no size limit for supporting the establishment of the fund).

Please join the dialogue, even if still unsure if the Pilot Negative Emissions Fund is for you.

6.3. Setting up the SNEF Pilot

This document describes the main actions and challenges of setting up the Swiss Negative Emissions Fund Pilot in 2023.

6.3.1. How to set up the SNEF Pilot, main challenges

The SNEF Pilot aims to facilitate learning at three levels: (a) scientific, how to measure, validate, and ensure permanence of negative emissions (NE); (b) organizational, how to successfully manage the transition to net zero including internal deep decarbonization; and (c) societal, how to govern negative emission projects to generate co-benefits for biodiversity and local communities, including building general awareness. In addition to learning and capacity building, a successful SNEF Pilot will also establish participating organizations as pioneers of 1.5°C-level climate action, and help build societal support for the full national SNEF.

Reaching these goals requires the proper setup, especially ensuring scientific rigor in project selection and monitoring (-> Project selection and monitoring panel), a critical mass of participating organizations, and the engagement to decarbonize their operations in addition to funding the SNEF Pilot (-> Membership panel). The three panels (Membership, Asset management, Project selection and monitoring), the expected CO_2 price (CHF 250 per ton), as well as the potential to save more than the fund contribution through decarbonization, are described in the SNEF Pilot Summary (go.epfl.ch/pilot).

Given the ambition and multidisciplinarity of the SNEF Pilot, governance is key, with the foundation council representing partner organizations, science, and society, with the support of the “Activate Change” pillar of E4S.

6.3.2. Pilot launch criteria

To ensure credibility from the perspective of the broader society, ideally the SNEF Pilot would start with 3-5 highly visible organizations, with current annual CO_2e emissions over 20 kt each, for a total well over 100 kt, with a goal of eventually including organizations accounting for about 1% of Swiss territorial emissions (450 kt).

This could be achieved by signing conditional contractual commitments, which activate when this predefined threshold (3-5 contracts) is reached. The Pilot would start with these “Founding Partners”, and continue actively expanding until it covers 1% of Swiss emissions.

6.3.3. Actions and timeline

[Relative timeline, Q1 is the first quarter of operation, from the activation of conditional contracts]

Q1: Set up the SNEF Pilot Foundation. Set up the three panels and the overall governance structure. Open a bank account. Request and receive payments from the founding partners for year one. Set up an asset management process to invest the funds until needed for NE projects. Hire two main employees: overall project manager (incl. member coordination, new member acquisition, and their net zero plans), NE project manager (selection, development, monitoring, and scientific coordination). Additional budget is needed for admin and communication support. The employees could be initially hosted by EPFL. Contact multiple possible NE project holders: scientific institutions, project developers, cantons, and communes.

Q2: Select initial project(s). Open call for further projects. Start developing NE accounting methodology. Start developing permanence contingency plans. All three panels are operational.

Q3: Start initial project(s). Close call for year one additional projects and select the next 3-4 projects. Prepare monitoring. Set up independent verification and validation of NE. Engage the local community of the first NE projects (information, workshop, then communication). Start outreach to broader society, politics, and academia. Start actively seeking additional partners.

Q4: Validate and communicate the first results.

6.3.4. Setup costs

- Admin: set up foundation: CHF 20k
- Employees: CHF 300k per year incl. expenses
- Admin and communication: CHF 100k per year

Initially, the above costs are funded separately from the funding for NE projects via a seed support. When critical mass is reached, the fixed costs would be allocated to projects, directly for monitoring and as limited overhead costs for other expenses.

Additional funding will likely be required and raised to fund scientific research on measurement and monitoring methods, sensors, and data analysis.

7. Towards true climate-neutrality for global aviation: a Negative Emissions Fund for Airlines

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Contributions: Conceptualization, methodology, software, validation, formal analysis, investigation, resources: S.N. and P.T.; data curation, writing—original draft preparation: S.N.; writing—review and editing, visualization: S.N. and P.T.; supervision, project administration, funding acquisition: P.T. All authors have read and agreed to the published version of the manuscript.

Abstract: What would it take for aviation to become climate-neutral by 2050? We develop and model a trajectory for aviation to reduce its CO_2 emissions by 90% by 2050, down to a level where all residual emissions can be removed from the atmosphere without crowding out other sectors that also need negative emissions. To make emitters pay for the carbon removal, we propose and model a negative emissions fund for airlines (NEFA). We show that it can pay for the removal of all CO_2 emitted by aviation from 2030 onwards, for a contribution to the fund of USD 200–250 per ton CO_2 emitted. In our baseline simulation, USD 3.3 trillion is invested by the fund over 40 years in high-quality carbon removal projects designed for biodiversity and societal co-benefits. While we do propose a number of governance principles and concrete solutions, our main goal is to start a societal dialogue to ensure aviation becomes both responsible and broadly beneficial.

Keywords: climate action, net zero, negative emissions, polluter pays, nature based solutions

7.1. Introduction

7.1.1. The urgency of Making Aviation Climate Neutral

To remain within the critical 1.5 °C warming limit defined by the Intergovernmental Panel on Climate Change (IPCC 2018) and avoid the much more dangerous 2 °C warming, IPCC's 2021 Assessment Report 6, Working Group 1 estimates the remaining carbon budget at 300-400 Gt CO_2 (IPCC 2021). This requires rapid and far-reaching action in all sectors, in order to reduce emissions by half by the year 2030 and by around 90% by 2050, for all pathways with no or limited overshoot. Even more urgently, IPCC Assessment Report 6, Working Group 3 states that immediate action is required and global GHG emissions must peak "at the latest before 2025" (IPCC 2022). As climate scenarios are generally modeled in 5-year increments, this means that 2025 global GHG emissions must be lower than 2019 in all 1.5 °C, and even 2 °C, scenarios, as illustrated in Figure SPM.4 (IPCC 2022). As a consequence, global emissions must start falling immediately.

The aviation sector itself clearly aims for net zero by 2050. This goal is a central message carried by its two main organizations: International Air Transport Association (IATA), which prominently displays "Our Commitment to Fly Net Zero by 2050" (IATA 2021), and the International Civil Aviation Organization (ICAO), which declared in July 2022 "Countries support global 'Net-zero 2050′ emissions target to achieve sustainable aviation" (ICAO 2022), later adopted as "global aspirational goal" at the 41st ICAO Assembly. As we will elaborate, this is a significant challenge, particularly given the past track record of aviation.

7.1.2. Hypotheses and Methodology

In this paper, we will examine the action necessary for aviation to reach its own target, based on the most realistic assessment of the CO_2 and non-CO_2 climate impact of aviation, a perspective of alternative fuels, which includes their whole life-cycle and impact on society and biodiversity, as well as expected improvements in aircraft efficiency and load factors.

We postulate that the aviation sector reduces its CO_2 emissions in the same proportion as is required from all human activity to stay within a safe carbon budget, i.e., by 50% by 2030 and by 90% by 2050 compared to 2019. How this could be possible will be shown in the following. It still requires carbon removal of at least 10% of 2019's emissions. For non-CO_2 short-lived impacts, sufficient and sustained reductions will neutralize their effect. We shall analyze the impact of reduction pathways, alternative fuels, and possible routing changes on such short-lived climate impacts.

A major challenge of carbon removal is who is going to pay for it. Removal of current emissions can be paid for by current emitters, but if past emissions also need to be removed, as we shall show is necessary on a decarbonization pathway, then a polluter-pays rule requires that current polluters contribute to a fund that will pay for later removal. We describe how such a fund could work and provide estimates of its financial flows, based on a series of simulations with a broad range of initial conditions, using a simple financial model of the fund. We shall also examine the robustness of our proposal and identify input conditions leading to undesirable or unrealistic outcomes.

Finally, we shall address governance issues, for example, can the aviation sector be trusted to organize the transition to net-zero climate impact or is another organization called for? We propose and discuss a governance approach led by the aviation sector and supervised by participating countries to ensure compliance. We also discuss what level of country participation is required, and how to ensure it.

Technical terms such as "climate forcing" will be used when needed for precision, and defined when first used.

An analysis of ethical considerations, effects on inequality, the "optimal" level of globalization, moral hazard, and the purpose of aviation from the societal perspective is beyond the scope of this paper and will be published separately. Here, these topics will be mentioned only when useful for understanding.

7.2. Literature Review

7.2.1. Large and Growing Climate Impact of Aviation

The considerable contribution of CO_2 emissions of aviation reached 1.034 Gt in 2019 (Lee et al. 2021). This includes commercial passenger flights (71% of emissions), private passenger flights (4%), freight (17%), and military flights (8%) (Gössling and Humpe 2020). Domestic flights represent 39.6% of fuel and emissions, and international flights 60.4% (Gössling and Humpe 2020). Aviation's climate impact could actually be three times larger than measured by CO_2 emissions alone, due to the multiple effects of burning kerosene at high altitudes (Lee et al. 2021). Its climate impact is further increased by embodied emissions in the production of fuel, airplanes, infrastructure, maintenance, etc.

For the period 1940–2018, two-thirds of aviation's climate impact is based on non-CO_2 radiative forcing, often called climate forcing (Lee et al. 2021), with direct CO_2 emissions accounting for the remaining third. Radiative forcing represents the imbalance of energy entering and leaving the atmosphere, affecting the climate. It can be decomposed into contributing factors such as CO_2 or contrails, and is measured in Watt/m^2. This finding is essential and will be discussed in detail in the next section.

Growth of passenger air travel has been extraordinary by any measure (Figure 7.1, Table S2). Past revenue passenger-km (RPK) of global aviation peaked in 2019 at 8.7×10^{12} RPK, before declining in 2020 due to COVID-19 and slightly recovering in 2021 (Ritchie et al. 2020; Airlines for America 2022). CO_2 emissions followed the same pattern (Sausen and Schumann 2000; Lee et al. 2021), growing more slowly due to efficiency improvements, which we cover in Section 7.3. For comparison, future net-zero compatible projections for RPK and CO_2 are shown on the same graph and analyzed in Section 3.

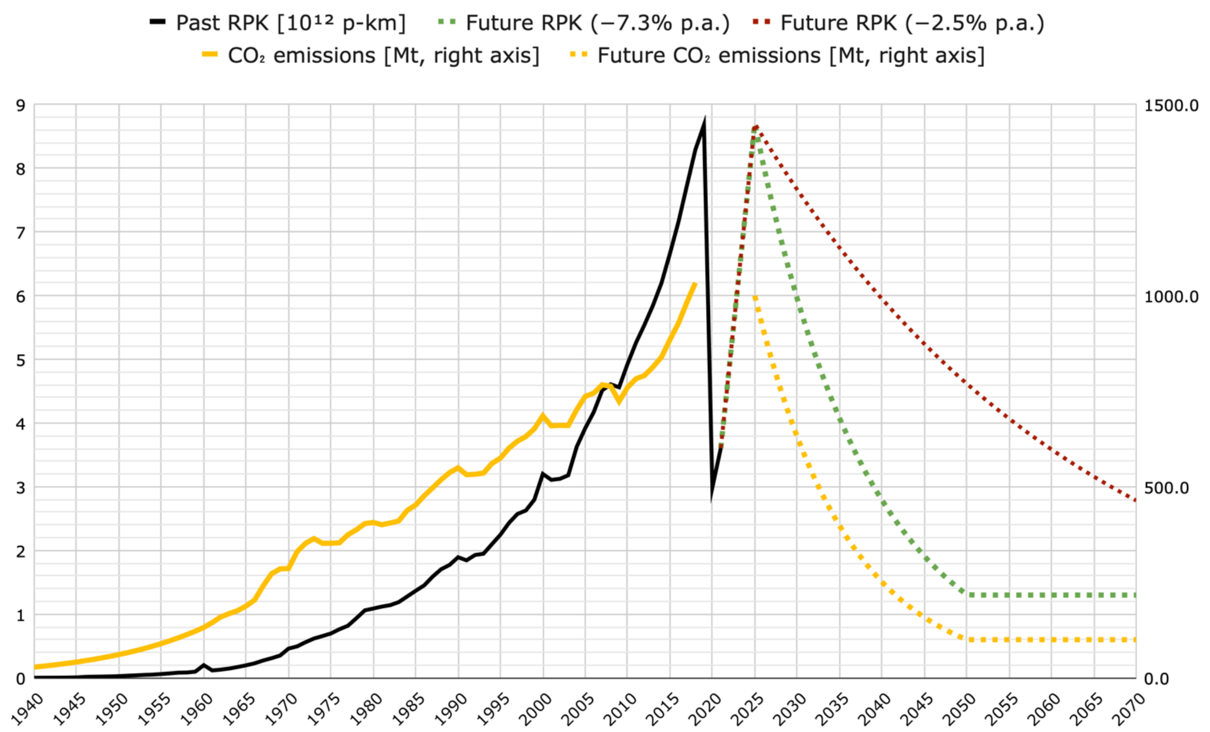


Figure 7.1: Revenue passenger-km (Ritchie et al. 2020; Airlines for America 2022) (black) and CO_2 emissions (Sausen and Schumann 2000; Lee et al. 2021) (yellow, right axis); future developments of RPK and CO_2 are discussed in Section 3 (dotted lines).

Pre-COVID projections for 2050 reach even more extraordinary levels of up to 34×10^{12} RPK (Gössling and Humpe 2020), i.e., +292% from 2019, although this has been revised more recently to 22×10^{12} RPK (ATAG 2021), corresponding to 3.1% p.a., or +153% increase from the 2019 value, in the “central” forecast.

Clearly, aviation is not yet on a path to net-zero climate impact. In this paper, we draft such a path, with special emphasis on the necessary emissions and activity reductions and on the role and funding of negative emissions. We also propose a two-level (airline and global) governance approach.

7.2.2. Long-Term and Short-Term Climate Impacts

The combined non-CO_2 climate impacts of aviation, especially from contrails, NO_x, and short-term ozone increase, are much greater than the impact of CO_2 alone (Lee et al. 2021; Neu 2021). However, they are mostly short-lived, i.e., they do not accumulate in the atmosphere like CO_2. This combination of short- and long-term effects complicates proper accounting and makes commonly used calculations (like those based on GWP_{100} factors—the global warming potential over 100 years) highly inaccurate and of limited help as a basis for the long-term climate neutrality of aviation.

The ratio of the total climate impact compared to that of CO_2 alone depends on the development of aviation. Based on the current growth rates, technical parameters (fuel composition and resulting gases and soot), and flight parameters (humidity, temperature, altitude), this ratio is around three (Lee et al. 2021). These conditions will continue if aviation continues to develop on a trajectory similar to the past, in particular with continued growth and fossil fuels use. The non-CO_2 climate impact is projected to be so significant with continued aviation growth, that even if zero-CO_2 fuels magically replaced all kerosene overnight, aviation alone would still contribute up to 0.4 °C additional warming globally by 2100 (Brazzola et al. 2022).

On the other hand, if aviation growth stopped, CO_2 would continue accumulating in the atmosphere, whereas the component related to short-lived climate impacts would eventually become constant (i.e., causing no further warming), more specifically, NO_x levels would stabilize after ~40 years and CH_4 after 60-70 years (Lee et al. 2021) (methane's steady-state 8–12 year lifetime in the atmosphere is extended via positive feedback from other trace elements). This means that the ratio of the total climate impact compared to that of CO_2 alone would shrink. For the relevant time-scale to stabilize the climate by 1.5 °C by 2050, the recommendation by the Swiss Academy of Natural Science, based on an extensive review of international scientific literature (Neu 2021) is to use a factor of three, corresponding to the current conditions described above. We will follow this recommendation in our paper.

It is important to note that, strictly speaking, a sustained reduction in total short-lived climate impacts such as contrails will cool the climate (analogous to reducing the power of an additional heater, leading to temperature stabilizing at a lower level), and at a sufficient reduction level, could temporarily cancel the effect of continued, but annually reduced CO_2 emissions. Based on various post-COVID recovery scenarios (Klöwer et al. 2021), an annual reduction in air traffic emissions of just 2.5% is sufficient to balance the cooling effect of reducing short-lived climate impacts with the progressively falling warming effect of remaining CO_2 emissions, which reach about 50% of the 2019 level in 2050 under this scenario. This model stops in 2050 and does not address how long aviation should continue shrinking by 2.5% p.a., or how to remove the accumulated CO_2.

7.2.3. The Possible Contribution of Alternative Fuels

Getting global aviation to net zero climate impact is an enormous challenge and we have not seen anything close to a credible plan to achieve it. Plans by airlines and their organizations such as IATA could be seen as wishful thinking (Beevor and Alexander 2022) given their reliance on "sustainable" fuels. Scientific literature quantifies in detail aviation's past and current impact (Lee et al. 2021; Gössling and Humpe 2020) and makes projections about possible futures (Klöwer et al. 2021), without suggesting how net zero impact could be achieved. Country long-term climate plans, even well-written plans (Swiss Federal Council 2021), may simply suggest that climate-neutral fuels would solve the problem, without much further analysis.

Could better fuels help, and if so, how much? Here, we examine alternative fuels, which include liquid fuels designed to be burned as a replacement for kerosene, such as synthetic aviation fuels and biofuels, which the industry refers to as “Sustainable Aviation Fuel” (SAF). It does not include hydrogen, which is still in early development and facing significant challenges for use in aviation, or batteries.

In 2019, global aviation burned 341 Mt of kerosene (2018 emissions (Lee et al. 2021), adjusted for 2019 growth: 1034 Mt CO_2, +4.2%, 3.16 kg CO_2 per kg kerosene). How much of this could be replaced by alternative fuels, and what would be the climate impact? Given the centrality of alternative fuels in all existing aviation initiatives, answering this question is key.

Proponents of SAF in their optimistic assessments (ATAG 2021; World Economic Forum 2021) estimate that 30–195 Mt of alternative fuels could be available by 2050. In 2020, 0.05 Mt were available and, if extending current growth and planned production facilities, assuming no delays and that current growth can be maintained at scale, in 2050 about 30 Mt might be available. This is optimistic, as it assumes a disproportionate share of available bio-feedstocks, which is estimated at 200 Mt (ATAG 2021), is used for aviation. Indeed, today, most of the identified potential feedstock sources are not used for various technical or cost reasons; instead palm oil is the main feedstock used, with often very large social and environmental impacts.

Given the very high energy requirements for synthetic fuels and their current low technology readiness, such fuels will likely play a very limited role in the next three climate-critical decades. Theoretically, the potential of power-to-liquids is very high and constrained only by available clean electricity (assuming technology readiness and capacity are developed). However, available clean energy is likely to be a serious constraint in the coming few decades, as we analyzed in our previous work (Nick and Thalmann 2021). Exploring “Energy limits and alternative uses”, we concluded that 15 GJ of clean energy, which is sufficient for all annual energy needs for one person, could instead be used to produce 6 GJ or 130 kg of aviation fuel, sufficient for one passenger flying 4400 km.

Now that we have an estimate of the quantity of alternative fuels, what could be their climate impact?

The findings of the previous section on short-term climate forcing of aviation are essential to effectively estimate the total impact of aviation and, thus, the impact of possible mitigation. Furthermore, any alternative fuel, when burned, will produce a similar quantity of NO_x and possibly contrails, still causing two-thirds of the direct warming effect of kerosene, even if the fuel itself is completely CO_2-neutral. Additionally, achieving full carbon neutrality over the whole lifecycle of SAF is almost impossible, as shown in a meta-analysis of 613 biofuel life-cycle assessment studies, including first-, second-, and third-generation biofuels (Jeswani et al. 2020).

Recent empirical evidence (Voigt et al. 2021), consistent with climate modeling of soot particles from burning fuel and contrail formation (Burkhardt et al. 2018), indicates that alternative fuels with lower aromatic content, especially naphthalene, can reduce soot by possibly 50–70%, as well as the associated ice crystal development, and contrail formation (aromatic rings are highly stable and are the last component of jet fuel to burn). If validated at large scale, the resulting lower contrail formation could reduce the total climate effect of aviation relative to CO_2 alone from three- to approximately two-fold, based on the central estimates for the effect of contrails (Lee et al. 2021) and a reduction of 60% of ice particle formation. There remains uncertainty to the applicability of these conclusions, as the measurements were based on two sets of flights with a single highly advanced experimental version of the Airbus A320, namely the D-ATRA of the Deutsches Zentrum für Luft- und Raumfahrt.

Additionally, the climate conditions and flight altitude significantly affect (modeled) contrail formation, with differences of two orders of magnitude, and 2.2% of flights forming 80% of all contrails, in a model (Teoh et al. 2020) based on actual flights in Japan for six weeks in 2012–2013. Re-routing these flights could reduce contrails by 59%, or by 20% if limited to re-routing without using more fuel and emitting more CO_2. However, this may not work in other climates.

In this paper, which focuses on policy proposals in the climate-critical period of 2022-2050, we will assume that synthetic or biofuels only emit 25% of the CO_2 of kerosene over their entire lifecycle, and that the total climate impact of synthetic or biofuels is 75% of kerosene's climate impact: the two-thirds of non-CO_2 impacts unchanged plus the one-third of CO_2 impact divided by four.

This is much better than the lifecycle impact of today's biofuels and assumes significant technological and sourcing progress. Palm-oil based commercial aviation biofuels, the only sort available in any usable quantity today, can have lifecycle emissions well over 100% of kerosene, in addition to significant biodiversity destruction. If, as is often the case, the palm oil comes from converted peat swamps (Cooper et al. 2020), then the climate impact averages 90 t CO_2e/ha/yr, for 3–4 t of palm oil, which is an order of magnitude higher than burning kerosene. There is almost no transparency in the biofuel industry, especially in regard to feedstock sourcing (Biofuelwatch 2018), and any reported information, often denied by the concerned companies, is very hard to verify independently. It is however well established that palm oil accounts for around 40% of all vegetable oil worldwide, with by far the highest growth rate, and is a significant driver of forest loss (Ritchie and Roser 2021). In a large commodity market, it is hard to separate good from bad practices; any demand drives pressure to produce more, and in the case of palm oil this ultimately also drives deforestation.

On the other hand, our estimates do not consider the effect of cleaner burning with less soot. As a mini-sensitivity analysis, assuming 50% CO_2 over the full lifecycle and a total climate impact of two instead of three times that of the CO_2 emissions alone for synthetic or biofuels, the total climate impact of these fuels is 50% compared to kerosene. The two-thirds of non-CO_2 impacts divided by two, plus the one-third of CO_2 impact divided by two. In this paper, we shall retain the first estimate of 75%.

In summary, recent literature published in the last two years provides a very detailed analysis of the climate impacts of aviation, especially of the non-CO_2 elements accounting for two-thirds of the total impact. Additionally, most key elements needed to estimate the potential and contribution of alternative fuels are well documented. What is missing are proposals, models, financing and governance mechanisms detailing how aviation could actually reach net-zero climate impact. We aim to address these gaps and to start a broader societal dialogue.

7.3. Reducing the Climate Impact of Aviation

In the past, fuel and CO_2 efficiency of air travel have improved significantly, from 2.5 kg CO_2 per revenue passenger kilometer (RPK) in 1950, to 1 kg CO_2/RPK in 1960, to 0.125 kg CO_2/RPK in 2018, a twenty-fold improvement (Ritchie et al. 2020). This led to lower fuel costs and, following deregulation, much lower prices (–90% over 70 years), which caused a major rebound effect ("Jevons paradox"). Consequently, total fuel consumption and emissions have increased 6.8 times over 58 years.

Future efficiency improvements are expected to continue at a much lower rate. The high energy demand of flying is a physical limitation of airplane design, which needs to generate sufficient lift to stay airborne and overcome air resistance. Airplanes are already almost as energy efficient as they possibly could be (MacKay 2011). Small improvements are still possible, mainly based on better air traffic management and fuller airplanes. They were on average 82.4% full in 2019, up from around 60% in 1960 (Lee et al. 2021). COVID-19 has since significantly reduced load factors (IATA 2022b), but this will recover. Engine improvement might contribute a few percent to energy and climate efficiency, and perhaps another 7 to 9% each can be obtained by blended wing-body design, and laminar flow control (MacKay 2011). None of this is even remotely sufficient to overcome the effect of expected growth of air traffic, or decarbonize today's volume of air traffic in line with the climate emergency described in the introduction. The only technology known today to potentially deliver an order of magnitude or more efficiency improvement are airships. If they are designed to be as fast and as long as trains (22 m/s and 400 m, respectively), then train-like efficiencies could be reached (MacKay 2011). This is not seriously on the books, though.

The prospect of reducing flights could lead to overcapacity. As a result, buying new airplanes might be limited, but given the large differences between airline fleets (Thalmann et al. 2021), simply using the most efficient existing airplanes could yield a significant improvement. By doing this and returning to previously reached load factors above 82%, a further 10% efficiency improvement could likely be achieved by 2030, relative to 2019.

In 2030, alternative fuels are likely to remain marginal. Therefore, to reduce the 2018 total aviation impact by half, given a 10% assumed total efficiency improvement, passenger-kilometers need to be reduced by around 44% (1–0.5/0.9) from 2018, or 47% (1–0.5/0.9/1.042) from 2019, based on 4.2% growth in 2019. We obtain an activity level of 4.6×10^{12} passenger-km in 2030, estimated to be compatible with 1.5 °C. This is slightly more than the activity level in 2021 (4.1×10^{12} RPK, IATA 2022a) and close to its level in 2005.

Estimating the aviation size in 2050 compatible with climate neutrality is trickier. We exclude possible developments in all-electric aircraft (battery, fuel cell, or other) or massive deployment of airships, simply because we have no basis for making such an estimate. All-electric aircraft and airships would allow for additional capacity, provided they are powered by clean electricity and do not burn any fuel, i.e., do not produce CO_2, NO_x, or contrails, and assuming they can be made climate neutral over their lifecycle. In the absence of such technological break-throughs, an ambitious estimate of possible efficiency improvement by 2050 relative to 2019 is 30%, which requires that all aircraft are better than best-in-class in 2019 and that the average load factor exceeds 90%.

As shown in the literature review, a reduction in climate impact by the middle of the century is expected from alternative fuels. In the “official” aviation growth scenarios, 30 Mt of biomass-based aviation fuels would be available in 2050 (ATAG 2021; World Economic Forum 2021). This limit is practical, not absolute, given a sufficient large-scale change in diet, agriculture, land use, cooking and heating practices around the world, a bigger portion of the current 25 Gt of (totally unsustainable) human appropriation of biomass could be used for energy conversion. This, however, is a matter of time and sectoral priorities. Given feedstock limitations and alternative uses and postulating that benefits for biodiversity and society are to be safeguarded, we assume biofuels to cover only 12 Mt of aviation fuels in 2050. We argued earlier that biofuels have a lower climate impact by 25% compared to kerosene, so that these 12 Mt of biofuels will have a climate impact comparable to reducing kerosene use by 3 Mt, or 1% of pre-COVID use.

With 30% fuel efficiency improvement and 3 Mt of kerosene’s impact saved through fuel substitution, the reduction in aviation’s climate impact in 2050 is only about 31% relative to 2019. The remaining 236 Mt of kerosene still account for 715 Mt CO_2 emissions, ignoring the short-lived climate effects of aviation, which will be neutralized by flight reductions. It is not impossible that this quantity of CO_2 could be extracted from the atmosphere every year by the middle of the century, but it is hardly acceptable that aviation monopolizes nearly all negative emissions, crowding out other sectors that also need them to become climate-neutral, in particular food production. In the absence of a general prescription for what an optimal or fair share of negative emissions for aviation would be, we postulate that this sector has to reduce its emissions in the same proportion as is needed by all sectors to remain within the critical 1.5 °C warming limit, i.e., by 90% (see our introduction).

To go from the 31% reduction obtained through fuel efficiency and partial substitution to the necessary 90%, the only actionable lever left is the number of flights by 85%. This may seem extreme when 31% are already obtained through technological measures, but that is because the efficiency improvement applies only to the significantly reduced level of activity in 2050. As a result, and if we assume that all types of air transportation decrease by the same proportion, the passenger transport activity must decrease to 1.32 trillion passenger-km by 2050. This is 15.2% of the activity level of 2019, or about the activity level of 1984. If the adjustment happens over 25 years, assuming full post-COVID recovery by 2025, the required annual reduction in passenger-km would be around 7.3%, allowing stabilization by around 2050 (Figure 7.1). When implemented, depending on the actual reduction pathway reached, the precise climate effect of non-CO_2 emissions can be recalculated, and the required stable size of aviation adjusted.

Looking well beyond 2050, once the global climate has hopefully been stabilized not far from the 1.5 °C warming limit with minimal overshoot, very different assumptions are possible, especially using a lower factor for long-term non-CO_2 climate forcing, technologies not yet in development today, long-distance high-speed rail, or a culture and societal organization demanding minimal travel. Our paper focuses on policy proposals to reach the required decarbonization and pay for negative emissions to remove the last 10% of 2019 emissions by 2050.

7.4. Paying for Negative Emissions

7.4.1. From a Country to an International Air Transport Perspective

In our proposal for a Swiss Negative Emissions Fund (Nick and Thalmann 2021, 2022), we describe and model a public fund to finance the removal of all Swiss territorial GHG emissions from 2030, based on the "polluter pays" principle. It would start in 2025 by setting aside funds for the removal of 5% of all territorial emissions, increasing this proportion by 5% each quarter until 100% is reached in 2030. Each emitter would either immediately reduce or remove their emissions or pay into the fund each quarter. The fund would develop a diversified portfolio of suitable biological and geological projects. The negative emissions fee would replace all existing CO_2 taxes and the Swiss Emissions Trading System, which is linked to the EU ETS. Our model estimates that the necessary fee per ton of CO_2e to pay for future removal is CHF 240–290, depending on the speed and ambition of decarbonization, with faster decarbonization leading to a lower CO_2 price.

International aviation is of course very different from a country and a number of factors have to be considered:

- Growth rate: aviation is projected to continue increasing emissions for decades unless the whole model changes, most likely as a result of change being imposed from outside. Rich countries' territorial emissions have been falling since at least 2005 and some since 1990, and other countries are expected to peak soon and then start decreasing.
- Non-CO_2 climate effects of aviation, on average, triple the climate impact. For countries, this impact is much smaller, a fraction of the impact of CO_2, mainly due to methane and nitrous oxide. However, due to their short-lived nature, these non-CO_2 effects will have a much lower impact if air travel starts declining, and a disproportionately large impact if current growth continues.
- Territoriality: it is unclear who is responsible for emissions in international airspace or when briefly flying over a third country.
- High-risk business/high default rate: due to high fixed costs, deregulation, cyclicality, and highly variable fuel costs, airlines are a very risky business. Additionally, due to the difficulty of getting creditors to pay across jurisdictions, any payment to a future negative emissions

fund would need to happen almost immediately, possibly even as a pre-payment before flights.

7.4.2. Proposed Concept

Despite these differences, we also propose the creation of a Negative Emissions Fund for Airlines (NEFA). The governance issues will be addressed in the next section. Here, we shall examine the operations of NEFA.

Each airline or flight operator of an international flight declares a flight route, time, aircraft, and fuel consumption (using IATA's existing Airline Handbook on CORSIA (IATA 2019)) to NEFA. The flight authorities of each participating country also report flights to NEFA, validating the airline declarations. Discrepancies are examined. At the end of each quarter, the calculated CO_2 emissions are invoiced to the airline. We distinguish two phases:

- The contraction phase: airlines must contract flights by at least 2.5% p.a. until 2050, as a condition for continued participation in NEFA. The 2.5% figure is the minimum to ensure the short-lived non-CO_2 effects balance the CO_2 emitted (Klöwer et al. 2021). However, when the contraction phase ends, this effect stops and the long-lived CO_2 must still be removed, which is the purpose of the payment into the fund.
- The steady-state phase: after a period of stabilization (which we do not model here), the short-lived non-CO_2 effects will stop affecting the climate; only long-lived GHG (in our model only CO_2) must be removed.

This allows NEFA to account for CO_2 removal only. Even if every airline reduces its flights by 2.5% every year, this eliminates climate warming for the year due to dynamic effects of short-lived climate forcing, but CO_2 still accumulates in the atmosphere and will stay there for thousands of years, unless removed. While the funding may be assured by payment to NEFA, the overall volume will exceed aviation's fair share of future available CO_2 removal capacity. Therefore, additional mechanisms are required to contract global aviation to a "fair" level in order to decarbonize by 90%, just as is necessary in other sectors of society, as we established above. An aggregate reduction in flights of 7.3% p.a. until 2050 is needed, as shown above.

NEFA will only pay for negative emissions in eligible countries (see below), with the right biodiversity and societal co-benefits, and an appropriate governance in place prior to investing. The suitable CO_2 price would be set at the start of the fund, which we here assume to be the year 2025. Airlines would have a 5-year transition period, where only part of their emissions would be subject to a NEFA payment, namely 5% in the first quarter, 10% in the second, until 100% is attained after 5 years in 2030. Given the large volume of aviation emissions, and the very low availability of good quality negative emissions projects today, there will inevitably be a time lag between each flight and the removal of corresponding emissions. This time lag contributes to the dangerous "overshoot", where global warming temporarily exceeds 1.5 °C, and should be minimized.

A NEFA based on such mechanisms could truly neutralize all direct climate impacts of global aviation. Given the strong levers proposed and the financial resources of frequent flyers, broadly coinciding with the world's richest 1%, NEFA could by 2030 mobilize resources to initially crowd out other sectors' negative emissions projects. However, this would only be a short-lived problem considering the 7.3% contraction mechanism, since every decade aviation would contract by more than half until a steady state in 2050 is reached. On the other hand, rapid mobilization of funds could significantly accelerate the development of negative emissions in many countries, probably on balance helping other sectors by making negative emissions capacity available. To avoid crowding out other sectors, we proposed capping negative emissions used for aviation to 400 Mt p.a., which is four times the stable level.

7.4.3. Model and Assumptions

To test the financial feasibility of the proposed Negative Emissions Fund for Airlines, we built a simple model, with the following assumptions:

- Fund launch 2025.
- 2025 CO_2 aviation emissions: 1000 Mt.
- Flights (i.e., RPK) reduction of 7.3% p.a. from 2025 until 2050.
- Flight CO_2 emissions reduction of 8.8% p.a. from 2025 until 2050, including efficiency gains of 1.5% p.a.
- Emissions stabilization in 2050 at 100 Mt CO_2.
- CO_2 payments increase by 5% per quarter from 2025 to 100% in 2030.
- First year of negative emissions: 1 Mt in 2026.
- Annual growth of negative emissions for 10 years: +50%.
- Annual growth of negative emissions after 10 years: +25%.
- Max annual negative emissions available for aviation (cap): 400 Mt.
- Negative emissions cost: $400/t CO_2 including project governance, in 2025.
- Negative emissions cost: $250/t CO_2 including project governance, from 2050.
- Interest rate: 2.00%.
- All prices and costs are adjusted for inflation (our model uses constant 2021 US dollars).

Our simulation assumes full participation of all countries and inclusion of both domestic and international aviation. In the real world, implementation in climate clubs is more likely, as we discuss below. Only CO_2 is removed; short-lived climate effects of aviation will be neutralized by the flight reductions required for effective CO_2 removal.

7.4.4. Results

Our simulation (Figures 7.2 and 7.3, Table S1) shows the feasibility of a fair, effective and affordable pathway towards climate neutrality for global aviation. While the model is simplified, we successfully tested it over a wide range of variations for the basic parameters, which we detail in the sensitivity analysis below, suggesting the proposed approach is sound.

The baseline simulation of CO_2 flows (Figure 7.2) shows the 2025–2030 ramp-up of emissions to be removed, the aggregate decarbonization of global aviation reaches its stable fair share along a 1.5 °C pathway by 2050 (dark gray), the 2025–2045 development of negative emission projects capped at aviation's share (green), and the resulting net emissions becoming negative from 2042 (yellow), until all CO_2 derived from aviation from 2030 has been removed by 2072; thereafter annual removals equal annual emissions.

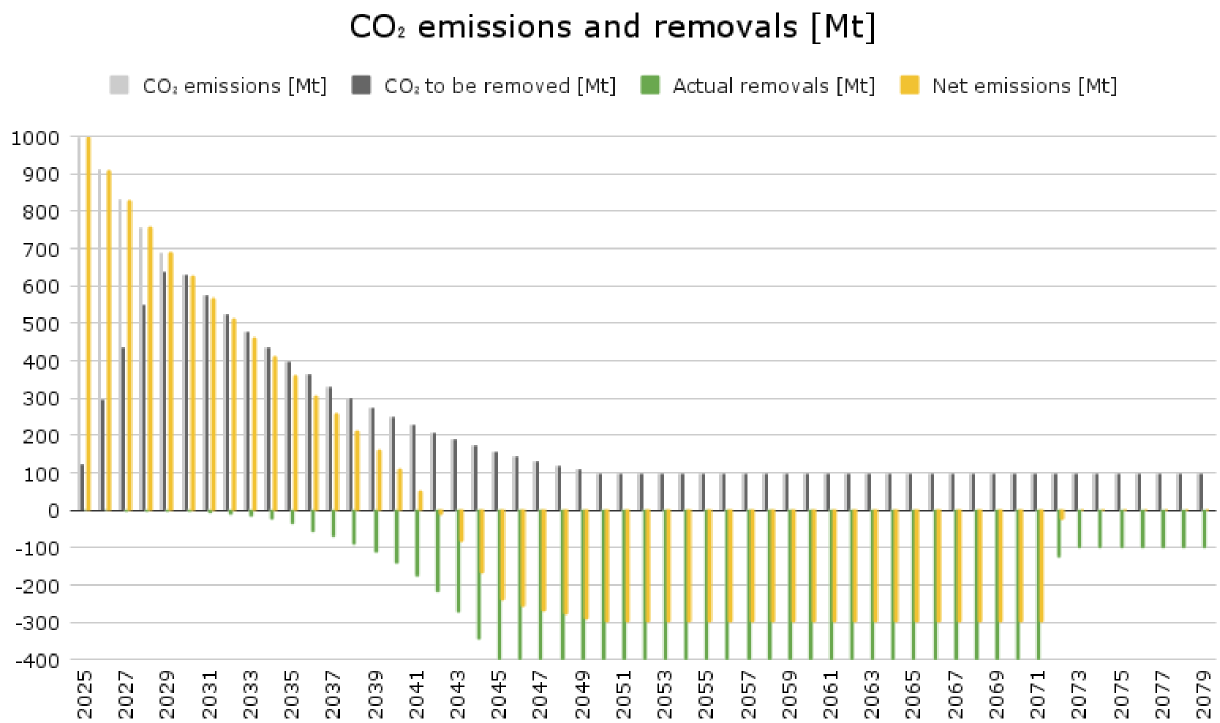


Figure 7.2: Simulated CO_2 flows showing global aviation reaching net zero in 2042 on an annual basis, and all aviation CO_2 from 2030 removed by 2072.

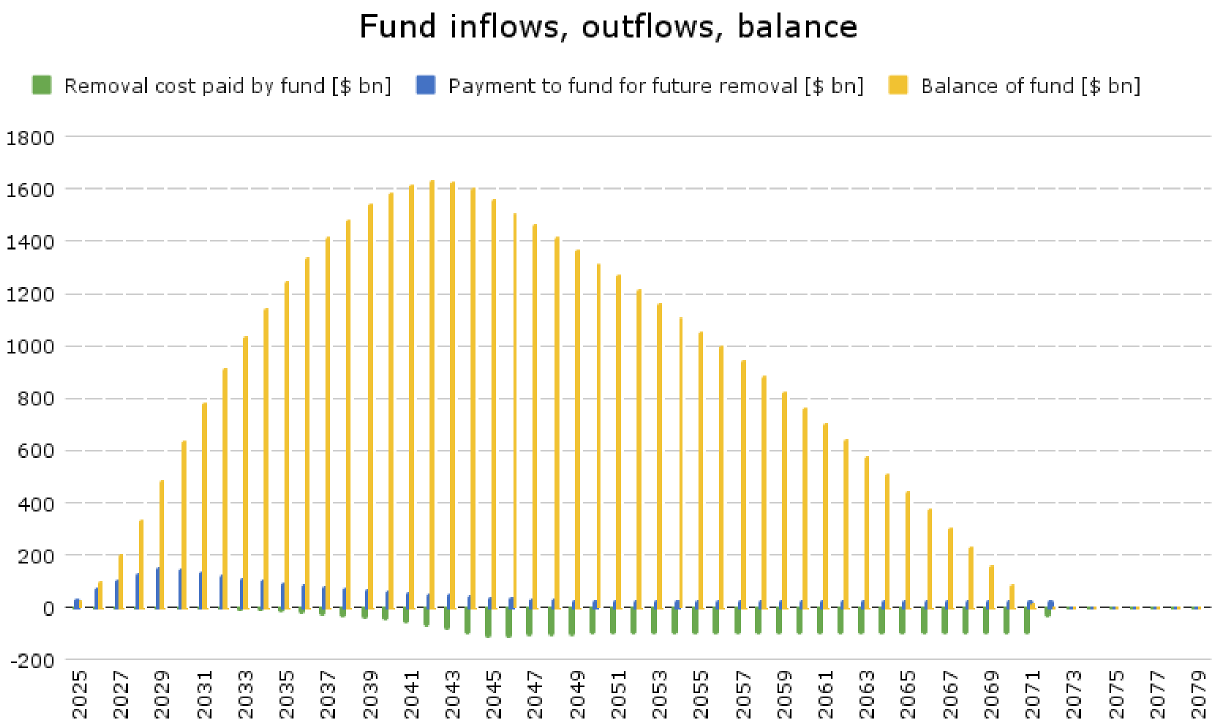


Figure 7.3: The baseline simulation of financial flows showing differentiated timing of early inflows (high emissions now) and payments for CO_2 removals, which need time to develop.

In detail, the approach is fair and effective on several levels, since aviation contributes its fair share of global decarbonization efforts by reaching net zero CO_2 in 2042, eventually removes all excess CO_2 emitted from 2030, and is climate neutral from 2025 onwards based on the dynamic effects of sustained reductions in short-lived climate forcing. Negative emissions for aviation are capped, which avoids crowding out other sectors that will need their own negative emissions (e.g., food production). Additionally, NEFA helps to kick-start the development of negative emissions solutions, including governance, monitoring, and helping participating countries clearly separate their own decarbonization from NEFA aviation projects.

The resulting CO_2 modeled price of USD 230, or USD 200–250 over a broad range of parameters, is entirely affordable for typical frequent flyers, largely overlapping with the global richest 1% of people. In fact, this CO_2 price is far too low to reduce demand to sustainable levels, which we estimate at an annual 7.3% reduction in flights. For example, a recent simulation for Switzerland (Thalmann et al. 2021, scenario “CO_2 Act with Growth”) suggests that a similar or slightly higher tax would reduce CO_2 emissions by 29–43% by 2050; whereas fairness requires at least a 90% reduction. This also means regulation and other public policy instruments are required (we propose flying rights auctions), in addition to pricing CO_2, if the CO_2 price is designed to exactly cover the costs of negative emissions.

The baseline simulation of financial flows shows annual payments to the fund peaking in 2030 at $145 bn, before declining to USD 23 bn in 2050 (blue bars in Figure 7.3); CO_2 removal needs time to develop and only peaks in 2045 at a cost of USD 112 bn, before stabilizing at USD 100 bn in

2050 (green); this delay allows NEFA to build reserves peaking at USD 1.63 trillion in 2042, before declining to zero in 2072 (yellow), when all CO_2 emitted by aviation from 2030 onwards has been removed.

7.4.5. Sensitivity Analysis and Robustness

We also performed a comprehensive sensitivity analysis of how changes in all parameters affect the baseline CO_2 price of USD 230, total payment and completion year, as summarized in Table 7.1. The level of initial emissions is unchanged at 1000 Mt.

Table 7.1: Sensitivity analysis using one-at-a-time variation of baseline parameters (green), affecting the three main outputs (yellow); “problematic” outputs and associated inputs (red) are discussed below.

Sensitivity Analysis		Range of Parameter		CO_2 Price [USD/t]		Σ CO_2 Removal Payments [USD bn]		Removed All Excess CO_2 by Year	
Simulation parameters	Baseline	Min.	Max.	Min. param.	Max. param.	Min. param.	Max. param.	Min. param.	Max. param.
Emission reductions p.a.	8.8%	2.5%	10.0%	160	239	9651	2953	2136	2069
Reductions, narrower range, p.a.		5.0%	7.3%	196	218	5177	3772	2091	2077
Final emissions [Mt/p.a.]	100	50	150	231	227	2979	3717	2069	2076
NE growth 2027-36	50.0%	33%	60%	203	246	3326	3217	2078	2068
NE growth 2037+	25.0%	10%	50%	204	243	3401	3228	2080	2069
Max removals [Mt p.a.]	400	200	800	186	249	4629	2897	2128	2057
Removal cost in 2025 [USD/t]	400	300	600	222	245	3173	3422	2072	2072
Removal cost from 2050 [USD/t]	250	200	300	190	270	2671	3841	2072	2072
Interest rate p.a.	2%	1%	3%	269	196	3256	3256	2072	2072
Interest rate, extreme range		0%	4%	314	168	3256	3256	2072	2072
Simulation results-baseline				230		3256		2072	

The model is clearly non-linear, as its main building blocks are exponential functions: rate of CO_2 reductions, interest rate, annual growth rate of negative emissions projects. The only linear relationship is between removal costs as input, and CO_2 price and the sum of payments for CO_2 removals as outputs. Within the parameter range defined in Table 7.1, all three outputs are “well-behaved” in the sense that they are defined everywhere, continuous, differentiable, and monotonic.

The two main “problematic” outputs highlighted in Table 7.1 in red either lead to an excessive contribution to overshooting the 1.5 °C warming limit and very high costs (USD 9.7 tn vs. USD 3.3 tn for the baseline), and/or simply take too long to remove the excessive CO_2 (around a century).

In summary, our sensitivity analysis shows a range for the final CO_2 price of USD 160–314, based on a broad range of parameter changes. If limited to “reasonable” parameter values, the CO_2 price remains fairly stable between USD 200 and USD 250, with a central estimate of USD 230 per ton CO_2. In most cases, the total cost of removal is between USD 2.9 and USD 3.8 trillion, with a central value of USD 3.3 trillion. All CO_2 emissions deriving from aviation are removed by a year in the range 2069–2080 (central value: 2072), ensuring effective carbon neutrality from 2030, with limited overshoot (short-lived non-CO_2 effects would be neutralized from 2025, based on the sustained contraction of flights).

7.5. Governance

7.5.1. Country vs. Airline Perspective, Nature of Risks, Role of Markets

Who should be responsible for reaching the climate-related objectives of aviation? Countries, aviation organizations, airlines, or some combination of the three? What is best decided at which level? While net zero CO_2 is relatively easy to define and monitor, climate neutrality is less straightforward as it can be defined in different ways, depending on which baseline is chosen (Brazzola et al. 2022), as sustained reductions in short-lived climate forcing will have a cooling effect. Additionally, how can an intermediate goal, such as a 50% reduction in CO_2 by 2030 be governed? Which baseline year is perceived as most favorable, when considering nationally determined contributions (NDCs)? How can companies gaming the system be prevented, such as buying failed airlines to access their past emission rights, or going bankrupt to avoid paying for accumulated negative emission liabilities?

There is no single good answer, but any good solution must include a number of elements.

First, all flight emissions must be accounted for in the United Nations Framework Convention on Climate Change (UNFCCC) process and included in NDCs. Aviation emissions could be included in national accounting and national NDCs. The easiest way to achieve this would be for each country to count all domestic flights (already included in country accounts) and all outbound international flights. However, this may generate significant resistance from countries and could become ungovernable if airlines move to avoid regulation. We therefore propose an intergovernmental management of the flying rights of international aviation (domestic flights remain within country climate commitments and their respective NDCs). This governance could be attached to ICAO (International Civil Aviation Organization, headquartered in Montreal) or possibly to the NEFA itself. Under UNFCCC, international aviation thus governed would be treated as another country with its own NDC.

Second, to limit the default risk of airlines, a payment for future negative emissions must be made to NEFA almost immediately for each flight. To limit the country default risk, NEFA could be made international and backed by suitable institutions such as the World Bank, ECB and multiple national central banks.

Third, to ensure that a smaller global aviation still delivers its main benefits, especially the essential components of globalization including knowledge transfer, connectivity, resilience and capacity building, and disaster response, suitable national and international regulation is required, since the highest-benefit use of limited aviation capacity is not necessarily the most profitable one, and might not be served under a pure market governance system. In practice, commercial airlines might buy flying rights at an auction and sell most available seats, with the remaining portion being set aside for priorities chosen democratically in the airline's country. Humanitarian or disaster-relief organizations operating their own flights might obtain their flying rights before the general auction of the remaining rights, with proper governance of flight use. Either way, more research and experimentation are needed to find the best allocation mechanisms.

Finally, for airlines, rapidly reaching net zero must become both the basis of their regulatory and moral "license to operate", and hopefully their market acceptance. Unless market acceptance is conditional on credible action to remain within the 1.5 °C warming limit, the market itself would be of limited use in the societal transition to a world respecting this limit, and will need to be regulated or restricted.

7.5.2. Failure of CORSIA

From today's perspective, global aviation is not on track to reach climate neutrality anytime soon, certainly not by 2050, and is definitely not on track to reduce emissions by half by 2030. The main industry initiative, Carbon Offsetting and Reduction Scheme for International Aviation or CORSIA (ICAO-CORSIA 2022), adopted in October 2016 by the 191 country members of the International Civil Aviation Organization (ICAO), is a very timid political compromise, which is likely to have an extremely limited climate impact, if any. Indeed, the stated goal of CORSIA is to ensure that growth of aviation after 2020 is carbon-neutral (not climate-neutral), making no mention of the Paris Agreement or the need to decarbonize, nor demonstrating why this is a scientifically valid goal. Furthermore, emissions below the 2019 baseline level are grandfathered, rewarding historical polluters and creating an incentive to buy failed airlines with past emissions. The many exceptions and loopholes, such as for Least Developed Countries, Small Island Developing States and Landlocked Developing Countries, create an incentive to base airlines or hubs there. Participation is voluntary until 2026, and then compulsory from 2027 to 2035, with major countries such as China, India, Russia, or Brazil not yet participating, and showing no sign that they might join by 2027. Another weakness of CORSIA is that the main reduction mechanisms are carbon credits to offset emissions, which will become largely unavailable as countries need to meet their own ambitious NDCs under the Paris Agreement. Furthermore, there is no universally accepted standard for the quality of offsets accepted by all CORSIA participants and no mechanism to ensure the quality of offsets. Even if offsets could be maintained at an adequate quality standard, the host country projects could be crowded out by CORSIA offsets, if their price is higher.

A further limitation of CORSIA is that it completely ignores non-CO_2 climate impacts, which represent two thirds of the total impact, as well as the dynamic effects of change in short-lived climate impacts. When promoting “sustainable aviation fuels”, meaning biofuels, in all its communications to date, CORSIA claims that they are climate-neutral, which is impossible due to non-CO_2 impact and biofuel lifecycle emissions.

Worse, CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels (ICAO 2021) allow palm oil-based fuels from Malaysia and Indonesia to generate 76.5–99.1 gCO_2e/MJ. As kerosene contains 43.1 MJ/kg (net, i.e., lower heating value) or 73.3 gCO_2e/MJ, the palm oil-based SAR is allowed under CORSIA to generate 104%-135% of kerosene emissions. If kerosene refining and other lifecycle emissions are included, kerosene reaches 85–95 gCO_2e/MJ, with a central value of 89 gCO_2e/MJ (UK Department for Transport 2021), meaning CORSIA accepts “sustainable aviation fuels” emitting 86–111% of kerosene.

Based on all of this, it is no surprise that, as of May 2022, Climate Action Tracker rates aviation’s carbon-neutral growth goal as “critically insufficient” and considers CORSIA “extremely unlikely” to reach this goal (Climate Action Tracker 2022).

7.5.3. History of Broken or Forgotten Promises

Historically, airlines have set relative targets (emissions per passenger-km) that, mainly due to better aircraft technology and higher load rates, have delivered impressive savings, but that are still dwarfed by much faster growth, as shown in Figure 7.1. This practice continues today with, for example, EasyJet—a major airline very vocal about its sustainability credentials—declaring a 35% CO_2 emissions intensity reduction target from 2020 to 2035 (EasyJet 2022). No mention is made of how much the airline plans to grow, but it doubled in the decade pre-COVID. At a similar future rate, absolute emissions would actually increase by 84% during this period. Beyond CO_2, airlines refuse to take any responsibility. For example, EasyJet states (EasyJet 2021): “We know that aviation also contributes to non-carbon dioxide climate effects in the atmosphere and despite recent studies highlighting these effects, more robust research is required to provide further guidance on how best to tackle these impacts”, straight out of the 1950s “Merchants of doubt” playbook (Oreskes and Conway 2011).

Beyond refusing to act on non-CO_2 climate effects and using relative targets, the airline sector, including IATA, has an almost perfect track record of missing or conveniently “forgetting” its own targets. In an impressive piece of detective work Beevor and Alexander (2022) covering the period 2000–2021, analyzed mostly deleted web pages with the Wayback Machine, for the UK-based NGO Possible. The authors found that all but one target have been missed, changed (usually set back a decade or so), or abandoned. In detail, efficiency targets, directly aligned with fuel cost reduction, were most frequently set but largely missed. Alternative fuel targets were all missed, often by a factor of 10 or more. This is despite alternative fuel targets being reduced and pushed back several times, from originally 10% for 2017 to 6% for 2020, then 4.5%, then 3% and finally to currently 2% for the year 2025.

No targets were linked to reducing the number of flights, or even the absolute level of emissions.

7.5.4. NEFA Governance and Participation Enforcement

We have developed and modeled a pathway leading to true climate neutrality for global aviation. Even if it works on paper, is there any realistic chance of reducing air transport and of NEFA ever being implemented?

To reach emission reduction goals, we propose annual auctions of flying rights, following a 7.3% p.a. flight reduction pathway until 2050. The proceeds of the auctions are invested in NEFA, enabling reducing the CO_2 price paid by airlines for removal, and allowing airlines to avoid paying twice. A small fraction of flying rights might be attributed to outside auctions, for priority missions, as suggested above.

As airlines could be based in any of the 200 countries of the world, the only way to ensure that they will buy flying rights and pay for their CO_2 emissions is to link payment to flight destinations. We propose that “climate clubs” of climate-conscious countries define an airline’s adherence to NEFA as a condition to gain access to their airports. Any two of the EU, China, Japan, and the US would be a good starting point and would send a strong signal. This lever is strongest for main flight destinations. Participation in such clubs could be encouraged by funding negative emissions projects by NEFA in member countries only, bringing them jobs, investments, biodiversity and societal co-benefits. This lever significantly expands the destination approach above. Each recipient country would need to show a credible net-zero action plan, as NEFA projects are additional to the country achieving its own net zero, and should not “crowd out” emission abatement projects. NEFA projects must ensure biodiversity and societal co-benefits, and proper governance must be in place before funds can be transferred.

NEFA might be much more acceptable to all aviation stakeholders if they could self-manage the system and its main components: cap and trade reducing available passenger-km by 7.3% p.a. including annual rights auctions; airline-level reporting rules, payments, and set a minimum target of 2.5% p.a. for flight reductions; reporting, regulation, and perhaps even a reward for airlines for avoiding contrail-forming zones; and finally access to airports only for those airlines participating in NEFA, and negative emissions funding access only for countries participating in NEFA to access its airports. Like CORSIA, this could be managed by ICAO with support from IATA and the Air Transport Action Group, which would limit the role of national states to setting the rules and objectives, and auditing the process and accounts (Figure 7.4).

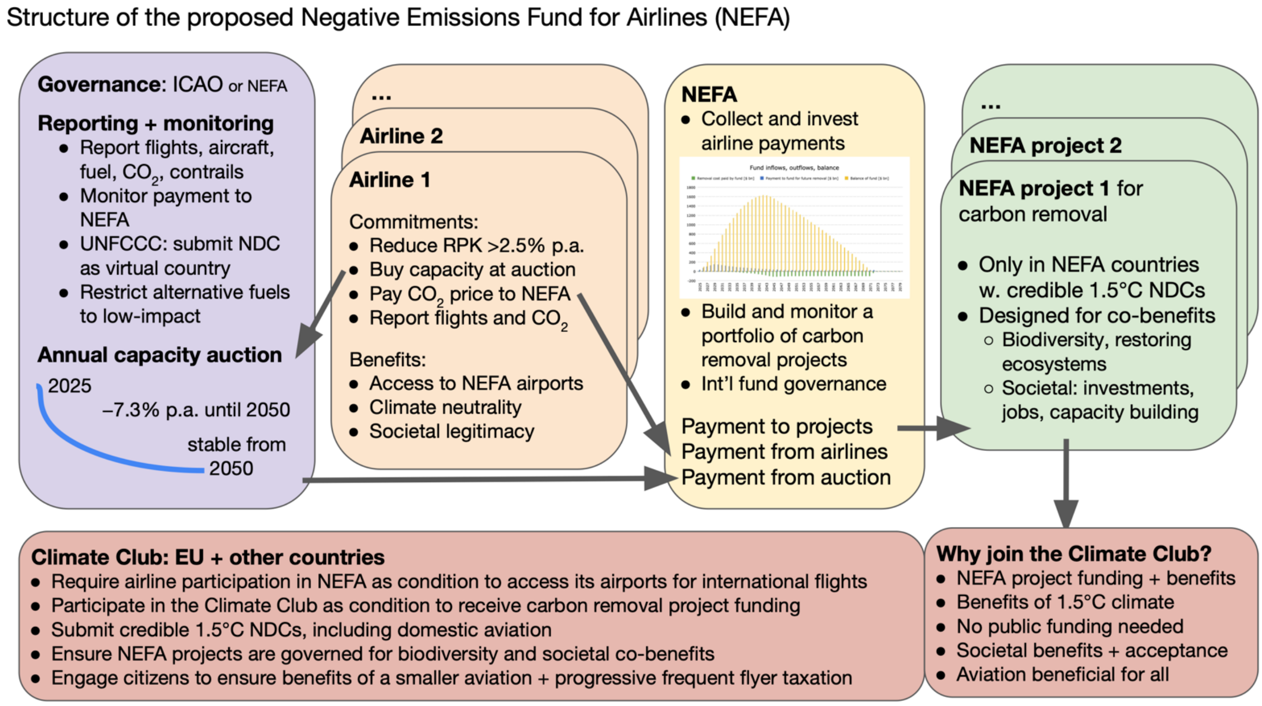


Figure 7.4: Links between the proposed governance structure, role of the fund, carbon removal projects, and benefits for countries, with arrows showing financial flows.

7.6. Discussion and Conclusion

7.6.1. Can NEFA Be Implemented in the Real World?

Despite numerous challenges coming especially from the extraterritorial character of international aviation, the proposed approach is very likely to work once a critical mass of countries can agree to jointly act. Obviously, a single country, even a large one, cannot achieve much alone; there is simply too much scope for airlines to avoid any regulation or constraint. What would be a critical mass to get started? Fully answering this question would require different modeling, which is beyond the scope of our paper, but we can provide some elements. A group of countries acting together ("climate club") can impose regulation on extraterritorial airlines, if access to its airports is sufficiently important and is conditional on participating in NEFA. Europe accounts for more than half of all international tourist arrivals worldwide, and would be costly for any large international airline to avoid. This gives the EU extraordinary leverage to single-handedly implement NEFA, although together with one additional large partner, the action would be much more effective: US or China would be ideal, but Japan or Mexico would be very helpful.

Other than the EU itself, in many areas including climate action, there are several initiatives aiming to enhance joint international environmental action, including the recent proposal (German Federal Government 2022) by Olaf Scholz, German Chancellor, of a G7-led Climate Club to decarbonize the industry, or the Responsible Minerals Initiative, started in 2008, covering almost all electronics players worldwide, and ensuring responsible sourcing of tin, tantalum, tungsten, cobalt, and gold.

Enforcement is led by major consumer electronics companies, participating to protect their own reputation, and requiring compliance by their suppliers.

Countries could join the EU climate club later, allowing for the flexibility needed to acquire domestic political alignment and parliamentary support. Fundamentally, the proposal is very attractive for many countries because: (1) it solves the problem of decarbonizing aviation, one of the most difficult sectors to decarbonize, without any initial investment other than regulation and monitoring, and (2) it opens the door to access well-funded investments into high-quality negative emission projects with significant biodiversity and societal co-benefits, creating jobs and potentially generating broad support within the country.

The immense role played by the EU also means that without its participation, another coalition would need to be very broad to succeed. From the EU's perspective, implementing NEFA would actually be relatively simple, and could be achieved by removing domestic aviation from the EU ETS and integrating it in NEFA or a similar EU fund. It would not affect the planned Carbon Border Adjustment Mechanism.

Any successful implementation must ensure accurate reporting, monitoring, payment collection, and fund governance. To increase its credibility, NEFA could be backed by suitable multilateral institutions such as the ECB, the World Bank, and possible national banks of main participating countries. Equally obvious, project quality must be ensured, to deliver verifiable and genuine negative emissions, persistent over time, and to avoid double-counting or crowding out of each host country's carbon removal projects, already part of that country's net zero plan and NDC.

Finally, a number of aviation stakeholders, especially investors and equipment manufacturers, may welcome and support a credible plan to reduce uncertainty, giving the aviation sector an assured future, even one with fewer flights, and positioning it as part of the solution instead of being a big driver of the problem.

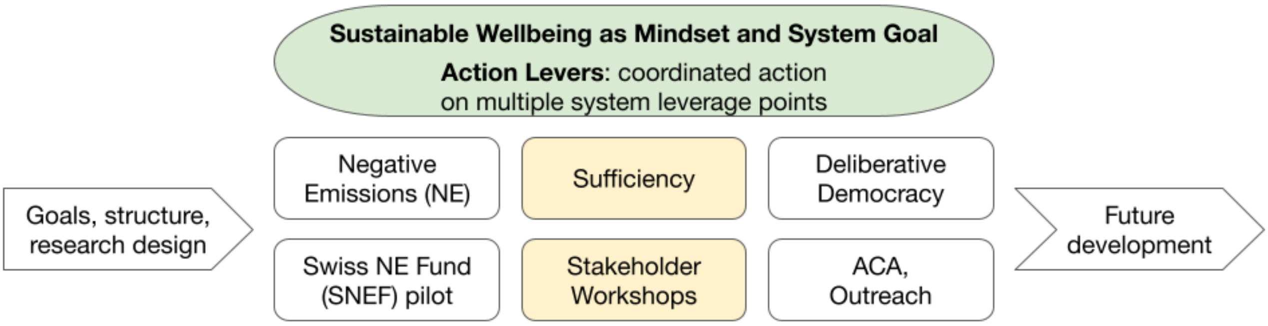
7.6.2 Conclusions—A New Vision for Aviation

A combination of rapid technology development, deregulation and partial exemption from responsibility by governments, airlines and investors playing the extraterritorial game of avoiding remaining regulation, rising inequalities, low-cost business models with culturally embedded (and purposefully designed) hypermobility, together with only recently understood non-CO_2 climate forcing—have together made aviation the intractable climate problem that it is today, risking nullifying any credible climate action in all other sectors of society. Yet, COVID-19 has shown the extraordinary fragility of today's aviation, and the rapidly worsening climate crisis adds significant uncertainty to any plans related to aviation, hindering investment and making almost any part of aviation excessively risky.

As identified by Donnella Meadows (1999) and repeatedly validated in various sectors, growth is indeed a key leverage point, but counter-intuitively for many, a negative one: less growth is needed to solve many problems, or in the case of global aviation, a significant reduction in flights to its size in the early 1980s, followed by a stable state. Once this main insight has been accepted, all the moving parts start falling into place, and responsible global aviation becomes possible, fairly contributing its part to solve the climate crisis, based on evolutionary low-risk technology and today's best practices, using resources well within the planetary boundaries.

Our NEFA proposal, validated using a simple financial model, indicates a fair, effective, and affordable way to make aviation truly climate neutral, which could rapidly be implemented with little public funding. For both rich and poor countries, it liberates public resources to focus on other sectors, which serve a much larger part of their population and for much more essential needs, and delivers a much-needed quick win for the climate. It also mobilizes significant private resources, as illustrated in our baseline simulation, a value of $3.3 trillion over 40 years that is mobilized to invest in high-quality carbon removal projects designed for biodiversity and societal co-benefits.

Part III: Sufficiency and wellbeing in the Swiss habitat



8. Introduction to sufficiency and wellbeing

Part III includes an overview of the research carried out on sufficiency and wellbeing, and includes the four most important contributions.

Chapter 8 summarizes the gaps in literature around wellbeing, sufficiency, and provisioning; approach and methodology; main results; and the main limitations.

It also includes two original short contributions: the main categories in which people think about sufficiency based on a series of stakeholder workshops, and a new framework to analyze sufficiency based on satisfier orders.

The other two contributions each have their own chapter: a position paper on wellbeing aiming for coherence of wellbeing research within the SWICE research consortium (chapter 9), and a top-down and sectoral case study of how sufficiency can help reach climate objectives in the Canton of Vaud (chapter 10).

8.1. How to think of sufficiency and wellbeing

Overall, Part III "Sufficiency and wellbeing in the Swiss habitat" aims to show how sufficiency, of the collective, societal, organizing-principle kind, can be a suitable action lever for transitioning the whole society. It is the most important type of climate action, and one of the most promising ways to engage society, based on stakeholder workshops and citizens' assemblies we conducted, thereby reinforcing the other two action levers explored in this thesis.

Geels' (2011) multi-level perspective on sustainability transitions is difficult to apply for exploring sufficiency, as most change happens at the level of mental models and less on systems structure level of the iceberg model (Monat and Gannon 2015).

The work on wellbeing and sufficiency is part of the SWICE consortium (Sustainable Wellbeing for the Individual and the Collectivity in the Energy transition), and a position paper on this topic is included in chapter 9.

There are many definitions of sufficiency (chapter 9), which have three elements in common:

1. Using less, reducing activity level, while ensuring human wellbeing
2. Ecological constraints, to ensure ecosystem integrity
3. Collective or society-level goals, organizing principles, policies, actions

It is important to recognize the normative dimension of any societal approach to sufficiency. For example, ensuring wellbeing for all (#1), humanity's survival (#2), or shared goals and associated policies are all normative. This thesis broadly follows the normative approach of a good life for all within planetary boundaries (O'Neill et al. 2018).

In terms of collective and individual freedom, both from an ethical and human needs perspective, this work sees **universal human wellbeing within the limits of the biosphere** as the goal of humanity, its highest good, and the basis from which all types of freedom are derived. Individual freedoms must be balanced with, but never override the overall goal. One way to think of it is to aim for the societal goal, while respecting the Universal Declaration of Human Rights (UN General Assembly 1948) and the Vienna Declaration (1993).

8.2. Literature contributions and gaps

An extensive and very complete body of scientific work covers the major topics of wellbeing and sufficiency, starting with Aristotle's Nicomachean Ethics (Crisp 2014), which asks what is a good life, and is at the origin of eudaimonic wellbeing. Ryan and Deci (2001) offer a comprehensive overview of both hedonic and eudaimonic traditions. There are many good reasons to choose eudaimonic wellbeing for studying societal transitions (Brand-Correa and Steinberger 2017).

All major theories of human needs build on the basis of eudaimonic wellbeing: Fundamental Human Needs (Max-Neef 1991), A Theory of Human Need (Doyal and Gough 1991; Gough 2015, 2017), and the Capability Approach (Robeyns et al. 2021). The main works covering sufficiency range from Princen (2005) to IPCC (2022), as well as many others detailed in the SWICE paper in the next chapter. Finally, the Decent Living Standards (DLS) body of work (Rao and Baer 2012, Rao and Min 2018, Rao et al. 2019, Millward-Hopkins et al. 2020, Kikstra et al. 2021) explores the energy and material prerequisites of decent living, i.e. satisfying all human needs. Finally, the LiLi (Living Well within Limits) project links planetary boundaries and resources with provisioning systems, satisfiers, and wellbeing (O'Neill et al. 2018).

It is not easy to find gaps in this extensive and complete body of work. However, when trying to answer the question defining the main challenge of the SWICE consortium, "How to transform the Swiss built environment towards high wellbeing with low energy use", gaps start to appear around the specific research questions. For example, what is the realistic level of DLS for Switzerland achievable within a climate-useful timeframe, or 15-20 years, starting from the existing building stock? How to build acceptance? What is the starting point of changing mental models, in terms of how people think of sufficiency today? What is the relative contribution of sufficiency vs. efficiency to energy savings and decarbonization? How to adapt the supply-side, especially companies and local municipalities and administrations? How to start operationalizing wellbeing and sufficiency to the societal transition? What would a successful 20-year transition plan look like? Several of the above are research questions of the SWICE project.

8.3. Methodology

From these identified gaps, I focused on the three most relevant to getting the SWICE consortium work started: (a) expanding the existing definitions of sufficiency to include satisfier orders, i.e. the level at which system transformation takes place; (b) understanding how stakeholders think of sufficiency today; and (c) reflecting on how to transform the existing building stock towards a suitable version of DLS for Switzerland.

Expanding the definitions of sufficiency is conceptual work, starting with literature, and looking for definition conflicts, where efficiency and sufficiency, or alternatively avoid-shift-improve, cannot clearly be distinguished. For example, is a smaller car more efficient (yes, less energy per km and less material) or more sufficient (yes, less space or "performance")? I identified a number of such examples within three broader categories, housing, mobility, and food, and tried to find which perspective is useful in which context. To make this work more robust, I structured it around satisfier orders (Brand Correa et al. 2020), and to validate consistency, added physical units, all summarized in Table 8.1.

To understand how stakeholders think of sufficiency today, I organized three stakeholder workshops, between June and October 2022 in Lausanne and Zurich. All three workshops broadly followed the same method in four steps: (1) A brief introduction to sufficiency, including what sufficiency is not and how it is different from efficiency, including a Q&A and short discussion, total about 20-30 min; (2) Group deliberation in groups of around 7-10 people, with a facilitator and a note-taker, for about 60-90 minutes, in one or two sessions; (3) A brief discussion and sharing of first impressions, with clarification questions and reactions, typically about 20 minutes; and (4) A written report based on group notes and final discussion, sent to all participants usually within a week, with feedback received incorporated in the final workshop report. The process overview and context is described in Appendix A1; Appendix A2-A3-A4 contains final workshop report for each of the three workshops, describing the specific structure, questions asked, timing, place, and number / profile of participants for each workshop, and the anonymized but otherwise unedited group notes.

Finally, I started the analysis of the transformation of the existing building stock by analyzing building area, type, energy efficiency, and use data from literature, and on this basis forming a hypothesis that a Swiss new building moratorium could rapidly refocus all building-related resources of society (workers, material, energy) to renovation, increase the renovation rate by an order of magnitude, and complete renovation of the whole building stock well before 2050, making a major contribution to Swiss net zero. On this basis, I designed a model of workers, buildings, renovation rates and learning curves, vacancy rates allowing whole neighborhood renovation and repurposing. The model results are not included in this thesis as they are still in development, although first results are very promising.

8.4. Results and main contributions

Much of my work on sufficiency and wellbeing summarizes the existing, very extensive literature and highlights elements that are useful to help a large research consortium start working together in a meaningful way towards common results on these complex topics. This includes organizing and conducting seminars, workshops, and presentations.

The link between sufficiency and wellbeing is also highlighted based on literature: sufficiency is only possible when wellbeing is understood as satisfaction of satiable human needs, as defined by major eudaimonic approaches to human needs, and analyzed in the position paper, chapter 9. Also, wellbeing for all within planetary boundaries is only possible with a strong focus on sufficiency. In the thesis, this is demonstrated for the case of global aviation (chapter 7), and for climate policy of the canton of Vaud (chapter 10).

Including the above, this thesis makes four original contributions around sufficiency and wellbeing: (a) the main categories in which people think about sufficiency based on a series of stakeholder workshops, (b) a new framework to analyze sufficiency based on satisfier orders, (c) a position paper on wellbeing aiming for coherence of wellbeing research within the SWICE research consortium, and (d) a top-down and sectoral case study of how sufficiency can help reach climate objectives in the Canton of Vaud.

The first two shorter contributions are in this chapter, sections §8.6 and §8.7, and the last two each have their own chapter (9 and 10).

8.5. Discussion and limitations

While this work directly contributes to the SWICE consortium since it started in May 2022, it only analyzes a very small part of the gaps identified in §8.2. Several others will be covered in the already planned SWICE work, of which the renovation, space, and labor modeling of the transition towards sufficiency of the Swiss built environment has already started.

In the big picture, it is the transitions towards sufficiency and more generally, transitions towards degrowth, that are both under-researched (Köhler et al. 2019, Kallis et al. 2018).

The main limitations within the narrow focus of this thesis can be classified in three areas: (a) incomplete work (one year completed of a five-year research project); (b) the analysis is somewhat standalone, and only weakly linked to other key policies such as climate, energy, territorial and urban planning; and (c) it is unclear how to build support for such a radical change in society in a democracy, in the absence of which the whole project may be scientifically interesting but not contribute to changing society. On the first point, much broader and more representative stakeholder workshops will be needed, to go beyond the diverse but generally very open-minded participants involved to date.

Regarding acceptance, stakeholder workshops conducted to date clearly show how participants imagine a sufficient society with high wellbeing, but not yet how to get there. Deliberative democracy (chapter 11) may be more promising, but a credible path cannot yet be defined.

8.6. Stakeholder workshops: how do people think of sufficiency?

What are the attitudes, knowledge, thoughts and emotions of the Swiss population about sufficiency? Based on three workshops with very different participant profiles (innovation / startup conference, neighborhood activist associations, climate professionals), several common findings begin to emerge:

- **Attitudes**: People are open minded, mixed but more positive than negative, at some level desiring a more connected and meaningful lifestyle, clearly being fed up with advertising and consumerism, and definitely wanting a more inclusive society. However, the attitude question is the most difficult one to answer, as our participants are not representative of the overall population.
- **Knowledge**: There is more knowledge on sufficiency than we expected to find, but this knowledge is almost entirely intuitive and not structured. Only after discussing the topic for a while, often an hour, do participants start asking themselves what exactly is sufficiency, and what it is not. In reality, there is a significant level of confusion with efficiency, and some confusion with deprivation. Very little knowledge on specifics, such as energy or material requirements for a good or decent life, human needs and satisfiers, wellbeing, or principles of organizing a sufficient society.
- **Thoughts**: There is a clear sequence of thoughts about sufficiency: first people reflect on their goals and priorities, and how they spend time; then moving to fairness, inclusion and (in)equality; after which they become a bit concerned about restrictions and how exactly to share resources in a more inclusive society. Finally, they realize that they have more questions than answers, and start reflecting on what they know, or don't know. One area which produced interesting results is the use of spaces, with a clear convergence on private, shared, and public spaces, contrary to the dominant private-public dichotomy.
- **Emotions**: Overall very positive, imagining a much more meaningful and happy life, lots of excitement, empathy, connection with own values; but also fear of the unknown, and sometimes fear of authoritarianism. It is important to note that our sample is more educated, and almost certainly more open-minded than the general population.

Several aspects were unexpected and worth highlighting here, in particular the relatively fixed sequence of thoughts about sufficiency, important for planning any collective process or deliberation; the mix of emotions, positive related to freedom and better balance of priorities, and negative related to restrictions or inequality; and the three types of space use (private - shared - public) opposed to the dominant discourse limited to private - public. Also, while a positive version of a sufficient society was relatively easy for participants to imagine and describe, very few people spoke of or imagined what a transition towards such a society would look like.

8.7. Satisfier orders and levels of provisioning and sufficiency

Which activity level can or should be reduced, what should society use less of? It is not trivial to answer this question, as the answer depends on the level or satisfier analyzed. The "satisfier order" framework proposed by Brand Correa et al. (2020) is a good place to start:

1. Socio-technical provisioning systems (highest leverage towards sufficiency)
2. Socially and culturally built activities
3. Energy and material services
4. Specific product or technology (lowest leverage towards sufficiency)

Let's apply this approach to the example of **mobility**. Mobility is not a human need itself, but an intermediate satisfier, allowing people to access work (a direct satisfier for the need of subsistence), learning (understanding), leisure (idleness), or social activities (creation, identity, participation, affection), etc. The satisfier order for mobility could be summarized as:

1. **Socio-technical provisioning systems**: where are buildings and essential services located, how is space and time organized in society? Sufficiency at this level means organizing space and time in society to reduce the need for mobility, and allow time and flexibility for "synergistic" residual mobility (combining multiple activities at destination, using active mobility, using time for work or rest). Examples: redesigning cities, repurposing buildings and neighborhoods, rethinking services, reorganizing working time.

2. **Socially and culturally built activities**: how is high mobility, specifically car or air travel, central to culture, meaning, identity, narratives? Sufficiency at this level means replacing all with non-mobility elements. Example: cars become culturally toxic, identity and meaning is linked to human relationships.

3. **Energy and material services**: Sufficiency at this level means reducing ton and passenger-km, which requires optimization, but is limited unless levels 1 and 2 change. Example: video-conferencing.

4. **Specific product or technology**: as an example, and based on level 2, the car has become a part of society, and has damaging characteristics such as size or speed, independent and often contrary to their benefit to mobility. Sufficiency at this level means reducing such characteristics, but its effect is limited unless levels 1 and 2 change. Example: smaller and lighter car.

For **housing**, zu Ermgassen et al. (2022) identify "demand for housing as a financial asset" as a major impediment to meeting housing needs within planetary boundaries, and the Foundational Economy Collective (De Boeck et al. 2020) proposes regulated not-for-profits as key to housing, based on a social license – a territorial franchise in exchange for social guarantees.

On this basis, Table 8.1 provides examples of the sufficiency-efficiency-substitution framework for mobility, housing, and food.

Table 8.1: Proposed sufficiency framework based on satisfier order

Satisfier Order	Status in 2023	Sufficiency	Efficiency	Substitution
0 - Conceptual	Limited wellbeing, inequalities	All fundamental human needs satisfied for all	Synergistic satisfiers	Lower resource use synergistic satisfier
Mobility				
1- Socio-technical provisioning system	Urban sprawl + zoning + car lock-in, car+oil lobby power	Compact 15-min city, high-quality local public services + restricted car use	Efficient public transport provision, soft mobility	Electrification, also electric car lock-in
2- Socially and culturally built activities	Car-centered, high-mobility culture	Unsuitable for measurement		
3 - Service: mobility	Widespread car ownership	[km]	[J / km]	[CO_2 / J]
4 - Product: car	Oversized, over-powered, multi-function car	[kg, m/s, $] car size, performance, price [cultural aspect irrelevant to mobility]	[kg ore / kg car]	[pollution / kg ore]
Housing				
1- Socio-technical provisioning system	Private promoters, profit maximization, political power / private luxury - public frugality, zoning	Public luxury - private frugality, limited m^2 per person, less heating+cooling	Energy efficient housing, universal basic services, foundational economy, regulated not-for-profits	Electrification, phase-out of fossil heating
2- Socially and culturally built activities	Housing as positional good	Unsuitable for measurement		
3 - Service: housing	Inflexible contracts, focus on private space	[m^2 per capita, heating / cooling temperature]	[$J/m^2/yr$]	[CO_2 / J]
4 - Product: house	Big, inefficient house	[m^2, $]	[$J/m^2/yr$]	[CO_2 / J]
Food				
1- Socio-technical provisioning system	Produce for market, highly processed, addictive NOVA-4, food waste >30%, "convenience"	Limited to seasonal, local, high-quality, unprocessed foods No food waste	Restricted animal products	No red meat
2- Socially and culturally built activities	Food as convenience, cost to be minimized, overfocus on identity	Unsuitable for measurement		
3 - Service: nutritious food		[J_{food}, nutrients] [$J_{handling}$ / J_{food}]	[trophic level]	[CO_2 / J_{food}]
4 - Product: food item		[J_{food}, nutrients, $]	[trophic level]	[CO_2 / J_{food}]

9. SWICE position paper on wellbeing

Author: Sascha Nick

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Abstract: Wellbeing is a central concept in sustainability and the focus of the SWICE consortium. This first position paper aims to provide a consistent approach to wellbeing for the whole consortium, and its link to human needs, satisfiers, provisioning systems, and sufficiency. The perspective of eudaimonic wellbeing is proposed, based on its main schools of thought which all build on human needs and satisfiers. Several ways to operationalize wellbeing are proposed, and a research agenda on wellbeing for the consortium defined.

Keywords: wellbeing, sufficiency, human needs, satisfiers, provisioning systems

sweet swiss energy research for the energy transition

SWICE

The research published in this report was carried out with the support of the Swiss Federal Office of Energy SFOE as part of the SWICE project.

9.1. Goal of this position paper

This document aims to help ensure consistent use of wellbeing in all work packages and activities of SWICE (Sustainable Wellbeing for the Individual and the Collectivity in the Energy transition).

Sustainability is usually defined as a practice that "*meets the needs of the present without compromising the ability of future generations to meet their own needs*" (Brundtland 1987), which corresponds to wellbeing for all within planetary boundaries. SWICE aims to answer the question for Switzerland: how to improve wellbeing for all with a much lower resource footprint, especially energy? While completely absent from political discourse, this question is probably the most important one the country is facing.

Simply constraining resource use without changing the way society is organized will reduce overall wellbeing. A positive outcome requires a culture of sufficiency, better provisioning systems, reduced inequalities, as well as adapting rules, laws, and institutions.

Identifying and validating such conditions is the focus of SWICE.

9.2. Main approaches to wellbeing

Wellbeing is a state of thriving, which involves full participation in society, a sense of prosperity and of leading a good life, based on the precondition of all needs being satisfied. Sustainable wellbeing extends this wellbeing to future generations.

The concept of human needs is central to wellbeing, and the only approach that can define wellbeing in a broad culturally meaningful way, relevant now and far in the future.

In contrast, today's dominant concept of "preference satisfaction", or the different but equally subjective one of hedonic happiness cannot be a basis for wellbeing, for many reasons such as limits to knowledge or rationality, adaptation, lack of moral distinction, or cultural differences (Gough 2015, 2017).

9.2.1. Eudaimonic vs. hedonic wellbeing

Most definitions of wellbeing can be traced back to two Greek philosophers who lived 2400 years ago, Aristotle and Epicurus (Brand-Correa & Steinberger 2017). Eudaimonic wellbeing broadly follows Aristotle's concept of (objective) flourishing, thriving, or a life well lived, based on full participation in society. Hedonic wellbeing is based on seeking (subjective) pleasure and avoiding fear and pain, as taught by Epicurus.

As SWICE aims to improve wellbeing by rethinking buildings, neighborhoods, spaces, and infrastructure, there are many good reasons to **focus on eudaimonic wellbeing**, as objective, taking a long-term perspective, and evaluative of life satisfaction (as opposed to momentary happiness). Based on needs and satisfiers, it allows the study of sufficiency and satiability, the very basis of sustainability.

In the two main scientific approaches to human needs (Max-Neef 1991, Doyal & Gough 1991), **needs** are required conditions to avoid serious harm, they are universal and constant over time and cultures, finite and classifiable, non-substitutable, objective and empirically validated, and satiable (i.e. beyond a threshold, additional resources do not contribute to better need satisfaction, and can be detrimental). On the other hand, **satisfiers** (goods, services, institutions, activities, or relationships used to satisfy a need) are culturally specific and change over time. This distinction is essential: if satisfying human needs is the aim, how this is done – with what satisfiers – is open for discussion and can be planned by society. Satisfiers can be singular (satisfy one need), synergistic (satisfy multiple needs), pseudo-satisfiers (give the false sense of satisfying a need), inhibitors and destroyers (partially or strongly impair the ability to satisfy other needs).

This distinction of needs and satisfiers, plus the satiability of needs, make wellbeing for all within planetary boundaries possible in principle. This is closely related to sufficiency, as explained in section 9.2.4.

9.2.2. Main concepts related to eudaimonic wellbeing

- **Subjective vs. objective** assessment of wellbeing: both eudaimonic and hedonic wellbeing can be evaluated by individuals themselves (subjective), or others, based on measurable indicators (objective). The self-assessment of life satisfaction is a subjective measure of both eudaimonic and hedonic wellbeing (Brand-Correa & Steinberger 2017).
- **Needs**: Satisfying fundamental human needs is a necessary precondition for wellbeing; otherwise serious harm is caused to people and societies.
- **Satisfiers**: There are numerous ways of satisfying each need, collectively defining a culture: material of immaterial, individual or collective; or how the main satisfiers are rooted in history, adapted to local climate and ecosystems; and how they are produced, including the associated provisioning systems.
- **Desires**: Potentially infinite, do not satiate, change over time or place, may or may not be linked to needs or satisfiers, culturally fabricated, often manipulated by private companies for financial gain. Systematically confused in everyday language: “I need X” may denote desire, not need. Totally unsuitable as a basis for analyzing, or planning for wellbeing.
- **Wealth / consumption**: Culturally dominant satisfiers, together with their provisioning systems, will determine the level of (monetary) wealth and (resource) consumption of a society needed to collectively satisfy its needs, and even its very ability to do so. More inclusive societies are better at satisfying individual needs, regardless of individuals’ wealth or ability to pay. Human needs are satiable (Lamb & Steinberger 2017, Gough 2015), but the consumer society perpetuates growth by satisfier substitution, identified as “the symbolic language of material goods” (Jackson 2016).
- **Happiness**: Eudaimonic wellbeing is not directly concerned with (momentary) happiness, and takes a long-term, multidimensional evaluative view of life satisfaction. Despite its

name, the World Happiness Report actually measures life satisfaction. Happiness is less useful for sustainability analysis, as it cannot easily be planned for.

9.2.3. Human needs: the main eudaimonic schools of thought

There are many different approaches to human needs. Here we present several of the main ones, useful for SWICE, with some overlap between them. See Table 9.3 for comparison.

- Max-Neef (1991), Fundamental Human Needs: "Human Scale Development" defines community wellbeing, based on nine axiological needs (related to values): ***Subsistence, Protection, Affection, Understanding, Participation, Idleness, Creation, Identity, and Freedom***, in four existential dimensions (Being, Having, Doing, Interacting), see Table 9.2. This forms a 9x4 matrix of satisfiers, developed in a series of workshops in Latin America and later Europe and Canada, and the satisfiers are further classified into destroyers, inhibitors, pseudo-, singular, and synergistic satisfiers. This essential distinction of needs and satisfiers is also the foundation of Doyal & Gough's work.

- Doyal & Gough (1991), Theory of Human Need: defines a hierarchy starting with the universal goal of ***Minimally impaired social participation***, with ***Physical health*** and ***Autonomy of agency*** as basic needs, and defining universal characteristics of needs satisfiers. Additionally, ***Critical participation*** (the ability to change society) requires Critical autonomy, based on Cross-cultural learning and Political freedoms, see Figure 9.2.

- Sen & Nussbaum, The Capability Approach (Robeyns et al. 2021): human wellbeing can be understood in terms of ***capabilities*** (real freedoms defining what people can do if they so choose) and ***functionings*** (realized capabilities). Martha Nussbaum famously defined ten "central capabilities": life; bodily health; bodily integrity; senses, imagination and thought; emotions; practical reason; affiliation; other species; play; and control over one's environment. The Human Development Index (HDI) is based on the Capability Approach.

- Di Giulio & Defila (2020), Protected Needs: they organize needs into three groups (Figure 9.3): material, person-focused, and community-focused, requiring "special protection". In other words, the approach focuses on the needs that society can plan for and protect, at a collective and institutional level. This list of needs has been tested in Switzerland through a representative survey, making this latest approach relevant to SWICE.

9.2.4. Sufficiency and wellbeing

Sufficiency is a central concept in sustainability theory and practice, building on the satiability of human needs, itself a central concept in all main theories of human needs. It is a necessary condition for reaching *wellbeing for all within planetary boundaries*, the main goal of sustainability. Being incompatible with neoclassical economics and numerous institutions, beliefs, and today's practices, sufficiency is widely misunderstood, and almost completely absent from national and regional policy.

At the most basic level, sufficiency is “an adequate amount of something, especially of something essential” (Oxford Dictionary). In the theory and practice of sustainability, it is used in the sense of eco-sufficiency, as a concept of reducing the energy and material use, and the environmental footprint of individuals and societies. “The Logic of Sufficiency” defines sufficiency as a desirable organizing principle of society, opposed to today’s dominant efficiency, as a basis for wellbeing within ecological constraints (Princen 2005).

IPCC AR6 WG3 SPM (IPCC 2022) states “*Sufficiency policies are a set of measures and daily practices that avoid demand for energy, materials, land and water while delivering human wellbeing for all within planetary boundaries*”.

Again we find the essential components of sufficiency:

- Using less, reducing activity level, while ensuring human wellbeing
- Ecological constraints, to ensure ecosystem integrity
- Collective or society-level goals, organizing principles, policies, actions

9.2.5. Analytical framework

For SWICE, we propose using the Living Well Within Limits (LiLi) analytical framework (Figure 9.1):

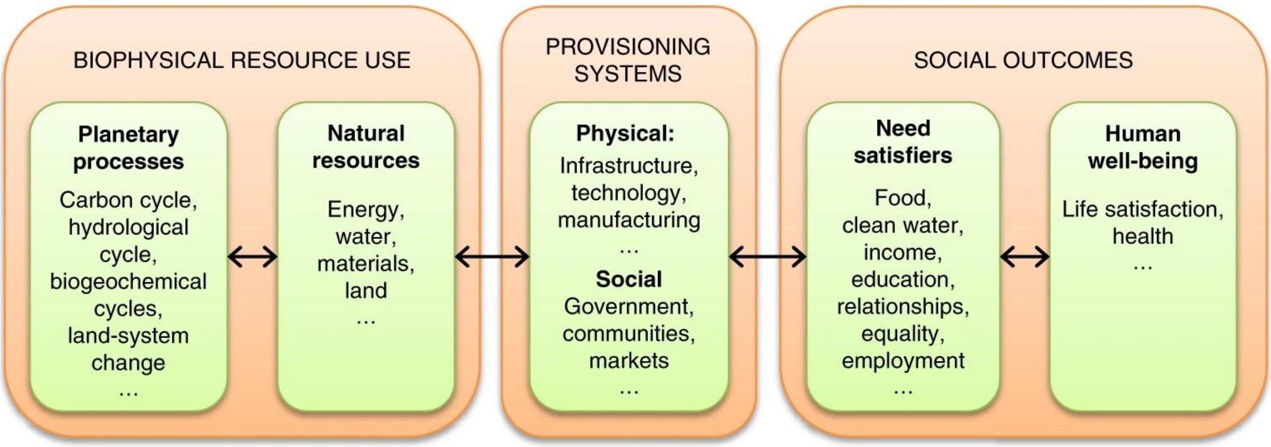


Figure 9.1: Living Well Within Limits (LiLi) analytical framework (O’Neill et al. 2018), reproduced with permission of Springer Nature

1. **Planetary processes**: C-N-H_2O-N-P cycles, land-system change
2. **Natural resources**: energy, water, materials, land, biomass
3. **Provisioning systems → collectively “economy”**: physical and social (gov’t, communities, markets)
4. **Need satisfiers → collectively “culture”**: food, clean water, education, relationships, equality, …
5. **Human wellbeing**: life satisfaction, health

9.2.6. The central role of provisioning systems

A provisioning system is a socio-technical system that transforms resources (energy, water, materials, land, ecosystem services) into satisfiers.

Provisioning systems have a positive component (satisfier provision) and a detrimental component (appropriation, or rent extraction, i.e. getting an excessive or unearned return). Both components use the same physical infrastructure and institutions (laws, power structures, culture, organizations, etc.). Appropriation systems can be presented as integrated or separate from provisioning systems (Fanning at al).

Key to provisioning systems and their transformation is a consideration for the institutional arrangements, power relations involved, and social practices that make some forms of provisioning more sustainable than others, create path-dependency dynamics and allow some needs to be satisfied above others (Stoddard et al, 2021; Plank et al, 2021).

Here we propose a **classification**, and separately a **descriptive framework**. The connections between the two could be an interesting focus of research.

Each provisioning system can be classified along several dimensions, such as:

- Geographic scale: globalized, regional, national, or local
- Local organization and scale: building group, neighborhood, low density zones
- Market, non-market, hybrid; public or private
- Related to the foundational economy or not

We propose the following **Descriptive Framework for Provisioning Systems**

Table 9.1: The proposed Descriptive Framework for Provisioning Systems

	Resources	Structure	Governance	Meaning	Appropriation	Satisfiers	Wellbeing
	(Input) Energy, water, materials, land, ecosystem services	Physical infrastructure Institutions, relations, information flows, laws	Power structure: who decides what and how	Culture, values, rituals, habits, associated narratives	Actual and potential rent extraction	**(Output)** Description and type of satifier (destroyer, pseudo-, simple, synergistic)	**(Outcome)** Health, life satisfaction, social participation, autonomy of agency
Satisfier 1							
Satisfier 2							
…							

Legend: provisioning system components, inputs - outputs - outcomes of the provisioning system
Adapted from Kalt at al 2019, Fanning et al. 2020, Doyal and Gough 1991.

9.2.7. Decent Living Standards (DLS)

The Decent Living Standards (DLS) approach identifies material prerequisites for wellbeing, as well as minimum energy and material requirements (Rao & Min 2018). DLS combines basic needs from Doyal & Gough with Nussbaum's central capabilities, and defines essential requirements at the household, community, and country level (see DLS structure in Figure 9.4). DLS energy requirements have been estimated for India, Brazil, and South Africa (Rao et al. 2020), and at a global level (Millward-Hopkins et al. 2020). The resulting energy requirement of approx. 15 GJ per capita per year is less than 10% of final energy used in rich countries today, while providing wellbeing for all.

9.3. State of knowledge, research agenda for SWICE

What do we know?

The main elements of section 2 are summarized here, to frame the research agenda below.

1. Wellbeing is the result of satisfying needs in all major human needs approaches.
2. Needs are universal, constant over time and cultures, classifiable, non-substitutable, and satiable.
3. Satisfiers, separate from needs, are culturally specific but have common characteristics. Resource need strongly depends on the dominant satisfiers.
4. Desires, potentially infinite, are often disconnected from needs, and are not useful in designing for wellbeing.
5. Multidimensional needs satisfaction is a necessary condition for and strongly correlates with wellbeing (O'Neill et al. 2018, Helliwell 2008).
6. The Decent Living Standards (DLS) approach shows that all material prerequisites for wellbeing can be satisfied with 10% of final energy used in rich countries today, while providing wellbeing for all.
7. Significant gaps in providing shelter, nutrition, health, mobility, and socialization remain in all world regions. Closing all DLS material provisioning gaps requires new infrastructure which could be built with a one-time investment of 290 EJ, or 9 months of world's final energy use (Kikstra et al. 2021).
8. Provisioning factors strongly affect the effectiveness of satisfier provision: positively (public service, public health, clean energy access, democracy, equality) or negatively (extractivism, economic growth) (Vogel et al. 2021)

What do we NOT know? (Gaps in literature and research questions for SWICE WP2)

1. How to design a provisioning system to create synergistic satisfiers with little resources. This includes minimizing rent extraction (appropriation).
2. DLS under "realistic" conditions, including residual non-zero inequality, or what technology can be installed within a useful timeframe, say 10-15 years.
3. Levers to start the required deep transformation of society.

4. How to gain broad stakeholder acceptance for the needed change towards wellbeing for all within planetary boundaries.

Many more gaps exist, some of which might be covered by SWICE:

- How to experiment with different ways of satisfying needs, using living labs?
- How to integrate power dynamics, social justice, etc.?
- How to deal with the potential (or perceived) tradeoff between establishing consumption corridors (DLS for instance) and the satisfaction of some of the more “liberal” needs / concepts used by several authors (“freedom” and “creation” in Max-Neef’s approach, “human agency” and a few central capabilities in Nussbaum’s approach, etc.)?
- From the perspective of architecture and urban planning we see that the concept of wellbeing is explored in relation to the socio-spatial built environment, but we still lack applicable concepts, context-relevant operationalization, and ways to measure and assess it, which are appropriate for specific urban scale and architectural typologies, and can be carried out with users across age-groups in a participatory fashion.

9.4. Operationalizing wellbeing

9.4.1. Measuring and modeling wellbeing

Depending on the context, wellbeing can be measured and modeled directly by estimating the level of satisfaction of each need, or indirectly, by asking about general or domain-specific life satisfaction:

1. Composite, measuring subjective life satisfaction using a single question (Cantril ladder / World Happiness Report): Please imagine a ladder, with steps numbered from 0 at the bottom to 10 at the top. The top of the ladder represents the best possible life for you and the bottom of the ladder represents the worst possible life for you. On which step of the ladder would you say you personally feel you stand at this time?
    a. **Existing data**: The World Happiness Report (Helliwell et al. 2022) measures life satisfaction and strongly correlates with objective conditions and need satisfaction. The index ranges from 7.8 for Finland, the happiest country in 2022, to 2.4 for Afghanistan, the least happy. The Taliban made things significantly worse: a later survey in August 2022 showed the index drop to 1.5 for men and 1.0 for women, hitting rock bottom (The Economist 2022).
2. Composite for life satisfaction, specifically asking about living conditions (Diener et al. 1985):
    a. “Satisfaction with Life Scale” asks five questions: (1) In most ways my life is close to my ideal; (2) The conditions of my life are excellent; (3) I am satisfied with my life; (4) So far I have gotten the important things I want in life; (5) If I could live my life over, I would change almost nothing. SWLS is widely cited, but its questions are hard to relate to human needs.

3. Intermediate approach, distinguishing technical and social systems (following O'Neill et al. 2018):
    a. How do you feel the physical infrastructure that you live in (especially housing and transport systems) enables you to satisfy your needs and flourish within your society?
    b. How do you feel the social systems that you live in (public services, social support, culture and community) enables you to satisfy your needs and flourish?
4. Measuring satisfaction of needs, following Max-Neef or Doyal & Gough:
    a. Do you feel our society makes it easy for you to satisfy your material needs, such as food or shelter? Why or why not?
    b. Do you feel our society makes it easy for you to live a healthy life? Why or why not?
    c. Do you feel our society makes it easy for you to satisfy your social needs, such as participating in society, creating, relaxing, or being who you want to be? Why or why not?
5. Combining descriptive and analytical satisfaction of needs:
    a. Asking people to describe their habits and everyday lives in order to then extrapolate in analysis how their needs are being met, based on a common list of needs.
    b. At the same time, asking people to react directly to a common list of needs, so as to state what needs are being satisfied in relation to certain practices (keeping warm, getting around, preparing a meal, etc.)

9.4.2. Existing data sources

Many other approaches exist; here is a selection, where detailed data for Switzerland is available:

6. Social Progress Index, SPI, socialprogress.org: launched in 2013, published annually, covers 169 countries and calculates three elements of social progress, Basic Human Needs, Foundations of Wellbeing, and Opportunity, in turn based on a total of components, based on around 50 indicators. It is an objective measure of wellbeing based on mostly national data. -> Switzerland

7. OECD Better Life Index, oecdbetterlifeindex.org: launched in 2011, published every two years, covers the 38 OECD member countries and for each country calculates 11 scores per topic: housing, income, jobs, community, education, environment, governance, health, life satisfaction, safety, and work-life balance. An interactive tool "Your Better Life Index" allows individuals to change weights of the 11 topics, initially equal. -> Switzerland, How's Life in Switzerland?

8. Swiss Federal Statistical Office, "Mesure du bien-être": this is a set of 27 indicators in 7 categories, adapted from "Stocks and flows framework for capitals, goods and services, and wellbeing" (Harper and Price 2011, Fig.1, p.6), basically a stock-flow model of provisioning, with wellbeing as a result of consumption, i.e. not at all based on human needs (see beginning of section 2). The data is of good quality, but only partly related to

wellbeing. We urge caution when using FSO > Material Deprivation, where only two indicators (cannot afford a full meal, cannot keep home warm) correspond to DLS, the rest being linked to societal organization or dominant (consumerist) satisfiers.

9. UNDP Human Development Index, HDI: this is the oldest and simplest index, measuring a composite of longevity, education, and income, calculated annually since 1990, for 190 countries. It is not suitable for analyzing wellbeing.

From the perspective of SWICE, we are interested in planning and policies for wellbeing, i.e needs satisfaction, hence the focus of our proposed questions on satisfiers and provisioning systems, in a language understandable to non-specialists.

9.5. Structure of the main eudaimonic approaches to wellbeing

Table 9.2: Max-Neef's (1991) matrix of needs and satisfiers

Max-Neef's matrix of needs and satisfiers		Existential needs			
		Being	Having	Doing	Interacting
Axiological needs	Subsistence	physical health, mental health, equilibrium, sense of humor, adaptability	food, shelter, work	feed, procreate, rest, work	living environment, social setting
	Protection	care, adaptability, autonomy, equilibrium, solidarity	insurance systems, savings, social security, health systems, rights, family, work	cooperate, prevent, plan, take care of, cure, help	living space, social environment, dwelling
	Affection	self-esteem, solidarity, respect, tolerance, generosity, receptiveness, passion, determination, sensuality, sense of humor	friendships, family, partnerships, pets, relationships with nature	make love, caress, express emotions, share, take care of, cultivate, appreciate	privacy, intimacy, home, space of togetherness
	Understanding	critical conscience, receptiveness, curiosity, astonishment, discipline, intuition, rationality	literature, teachers, method, educational policies, communication policies	investigate, study, experiment, educate, analyze, meditate	settings of formative interaction, schools, universities, academies, groups, communities, family
	Participation	adaptability, receptiveness, solidarity, willingness, determination, dedication, respect, passion, sense of humor	rights, responsibilities, duties, privileges, work	become affiliated, cooperate, propose, share, dissent, obey, interact, agree on, express opinions	settings of participative interaction, parties, associations, churches, communities, neighborhoods, family
	Idleness	curiosity, receptiveness, imagination, recklessness, sense of humor, tranquility, sensuality	games, spectacles, clubs, parties, peace of mind	daydream, brood, dream, recall old times, give way to fantasies, remember, relax, have fun, play	privacy, intimacy, spaces of closeness, free time, surroundings, landscapes
	Creation	passion, determination, intuition, imagination, boldness, rationality, autonomy, inventiveness, curiosity	abilities, skills, method, work	work, invent, build, design, compose, interpret	productive and feedback settings, workshops, cultural groups, audiences, spaces for expression, temporal freedom
	Identity	sense of belonging, consistency, differentiation, self-esteem, assertiveness	symbols, language, religion, habits, customs, reference groups, sexuality, values, norms, historical memory, work	commit oneself, integrate oneself, confront, decide on, get to know oneself, recognize oneself, actualize oneself, grow	social rhythms, everyday settings, settings which one belongs to, maturation stages
	Freedom	autonomy, self-esteem, determination, passion, assertiveness, open-mindedness, boldness, rebelliousness, tolerance	equal rights	dissent, choose, be different from, run risks, develop awareness, commit oneself, disobey	temporal/spatial plasticity

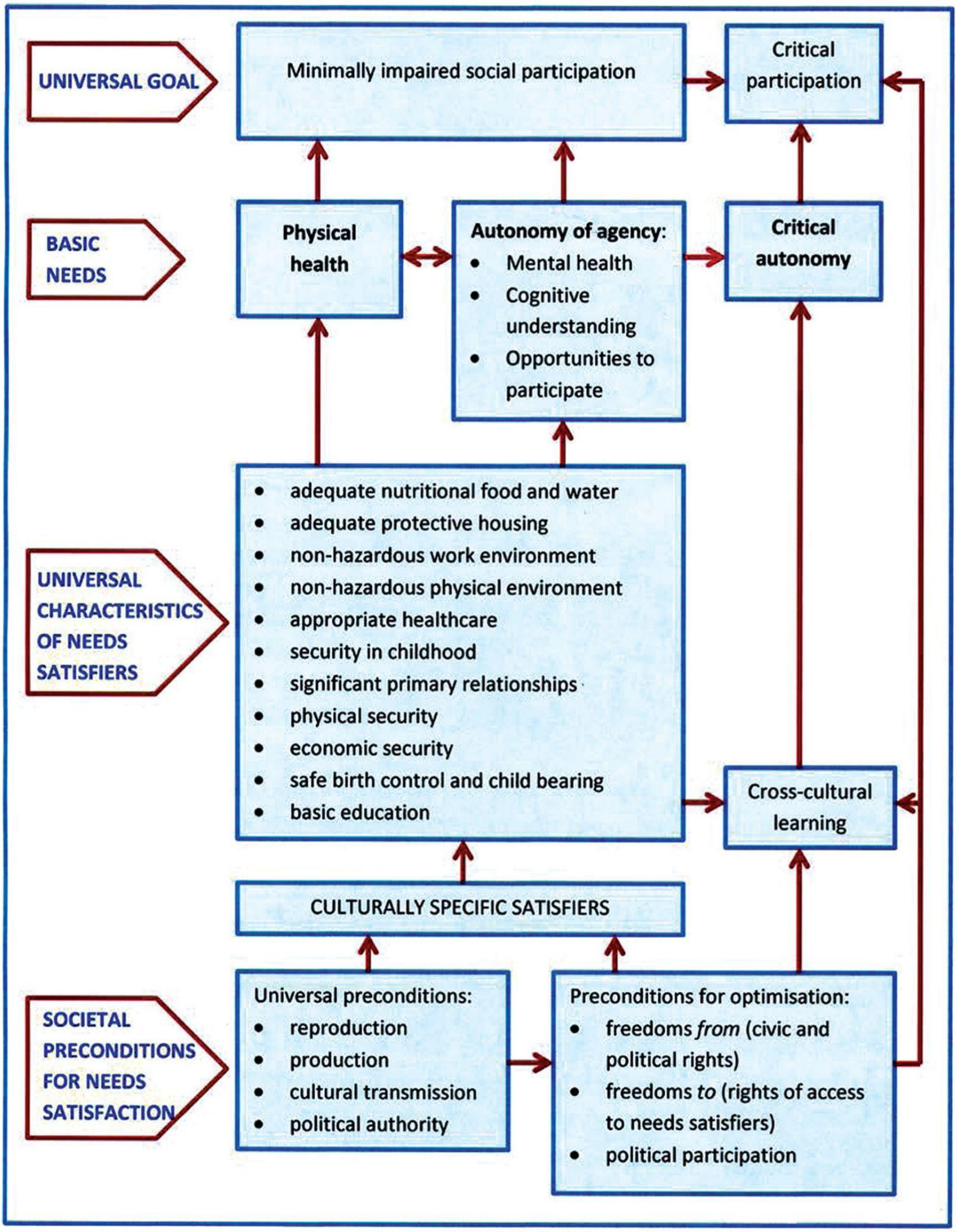


Figure 9.2: Outline of the theory of human need, reproduced from Gough 2015, reproduced with permission of Oxford University Press

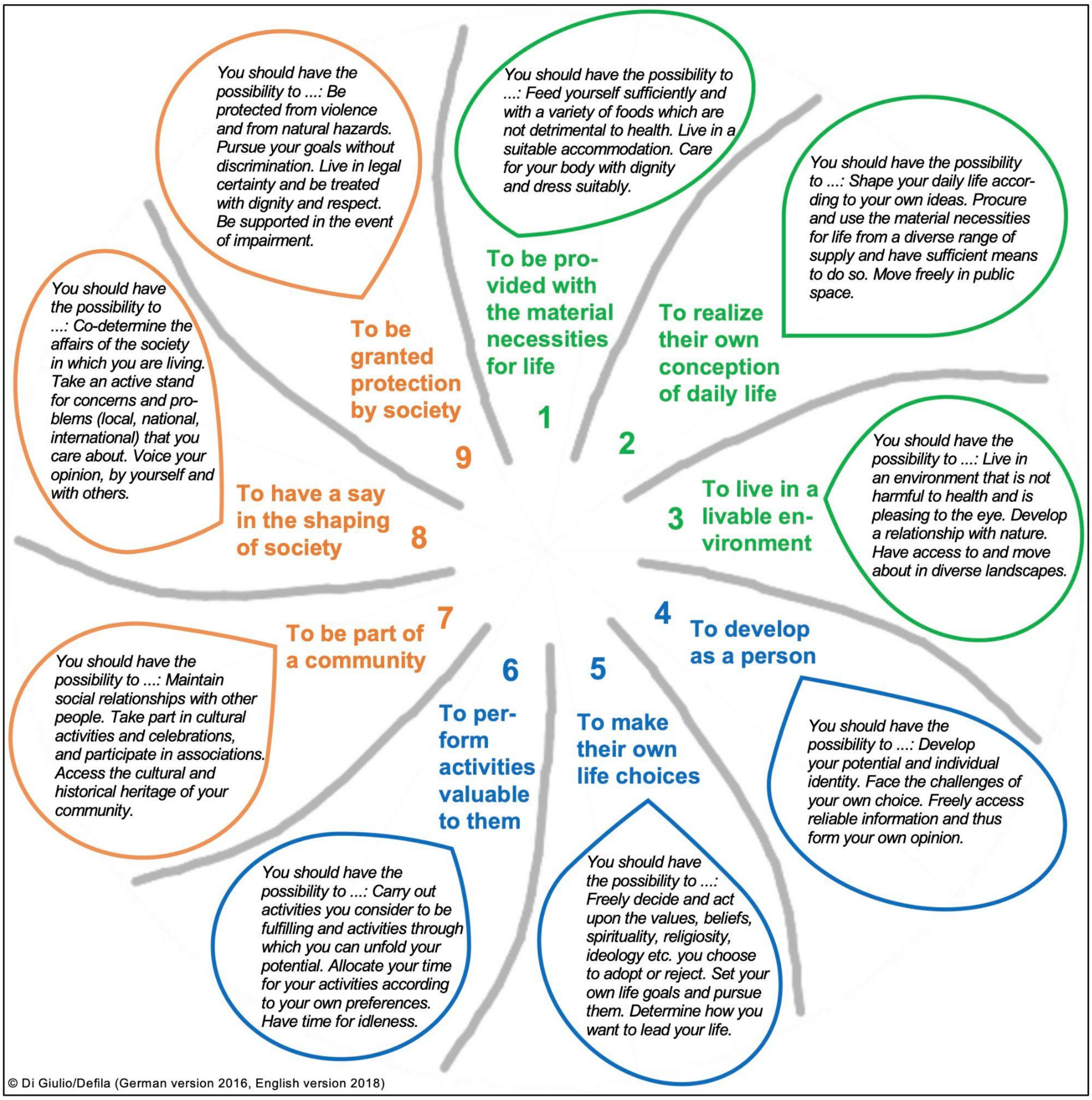


Figure 9.3: Mandala of Protected Needs (Di Giulio & Defila 2020, Anantharaman et al. 2023)

Table 9.3: Approximate comparison of the main eudaimonic approaches to wellbeing, reproduced from Lamb & Steinberger 2017

Nussbaum Central Human Capabilities	Max-Neef Axiological Categories of Human Need	Doyal and Gough Theory of Human Need	The Sustainable Development Goals
Life Bodily health		Physical health (BN) Appropriate health care (IN) Safe birth control/childbearing (IN)	3. Good health and well-being 5. Gender equality
	Subsistence	Adequate food/water (IN)	2. Zero hunger
Bodily integrity Control over one's environment	Protection	Protective housing (IN) Safe physical environment (IN) Safe work environment (IN) Physical security (IN) Security in childhood (IN)	6. Clean water and sanitation 7. Affordable and clean energy 16. Peace, justice and strong institutions
		Economic security (IN) Non-hazardous work environment (IN)	1. No poverty 5. Gender equality 8. Decent work and economic growth
Senses, thought, imagination Emotions	Creation	Mental health (BN) Cultural understanding (BN)	3. Good health and well-being
Practical reason	Understanding Identity	Cognitive understanding (BN) Appropriate education (IN)	4. Quality education
Affiliation	Participation Affection	Opportunities to participate (BN) Significant primary relationships (IN)	5. Gender equality
Play	Leisure Freedom	Critical autonomy (BN)	16. Peace, justice, and strong institutions
Other species		Sustainability preconditions	14. Life below water 15. Life on land 13. Climate action
	Satisfiers	Societal preconditions for need satisfaction (means, not ends)	9. Industry, innovation, and infrastructure 10. Reduced inequalities 11. Sustainable cities and communities 12. Responsible consumption and production 17. Partnerships for the goals

BN, basic needs; IN, intermediate needs.

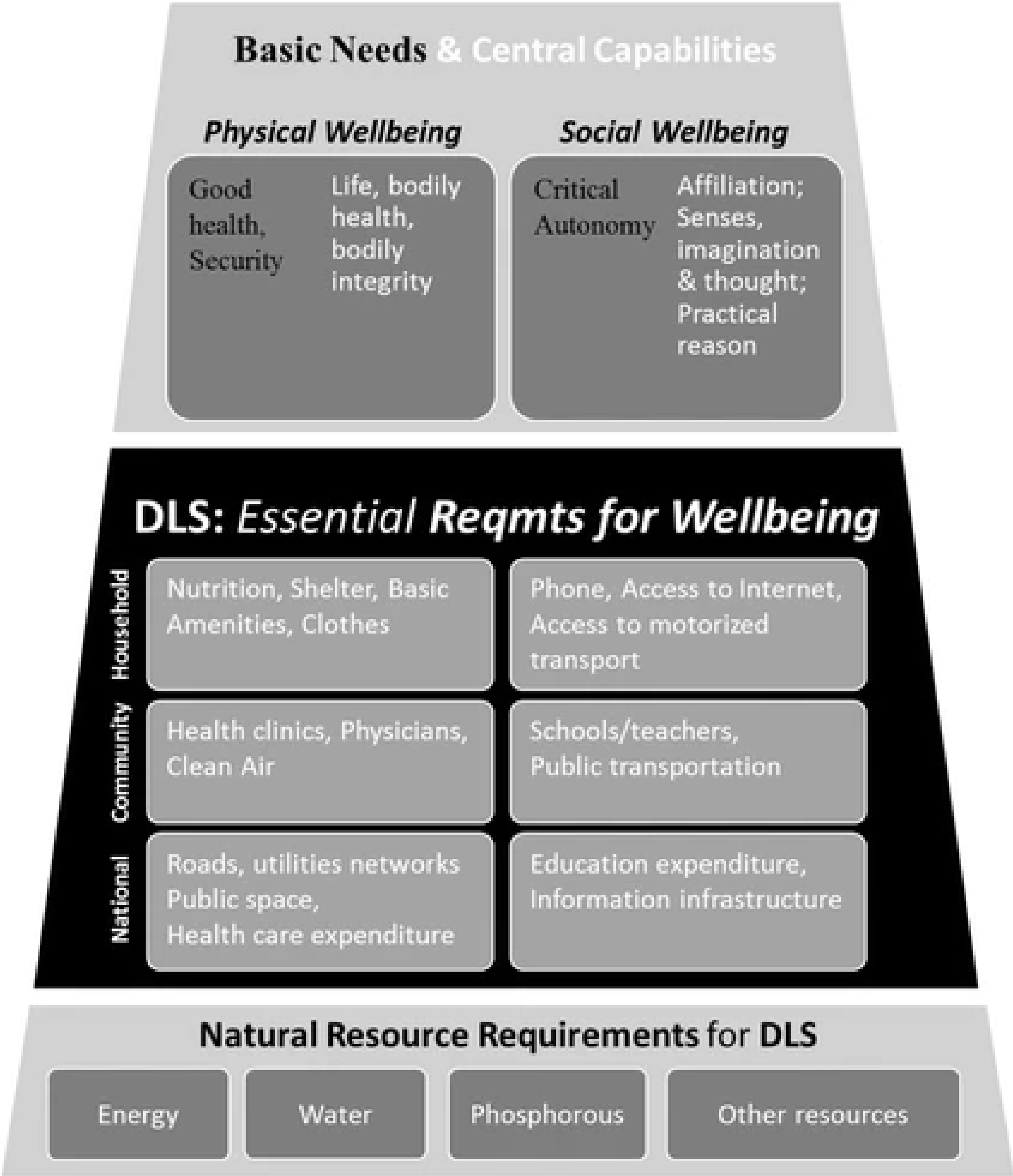


Figure 9.4: Structure of material requirements for Decent Living Standards, combining basic needs (Doyal & Gough) with Nussbaum's central capabilities, reproduced from Rao & Min 2018

10. Sufficiency pathways for the Canton of Vaud

Note: This chapter is entirely based on publicly available information. **No confidential data is included in this section, nor was used for the analysis**.

10.1. Approach and methods

What would be the required reductions by sector and 5-year period in order to reach the climate plan Vaud targets: minus 50% to 60% in 2030, relative to 1990, and carbon neutrality in 2050?

In this chapter, a viable decarbonization pathway is examined from three perspectives.

First, a top-down aggregate energy analysis is performed, to estimate the available final energy in 2030 in the canton of Vaud, assuming a 50% decarbonization. Separately analyzing fossil energy and electricity, the needed decarbonization, the planned development of new renewable electricity capacity, and comparing to past efficiency improvements, the resulting size of the economy is estimated. The purpose of this analysis is to estimate the scope of the challenge, and produce a plausibility check for the sectoral analysis in sections 10.3.-10.7.

Second, sectoral GHG reductions from Federal Council's Long-term climate strategy 2050 (Swiss Federal Council 2021), and Energy Perspectives 2050+ (BFE 2020), are adapted to the specificities of the Canton of Vaud in §10.4. These specificities are identified and estimated by comparing statistical data for Switzerland and Vaud on population, density, GDP per capita, final energy use and GHG emissions per person. Missing data for 1990 is estimated when possible from statistical co-evolution of cantonal and federal data (cantonal GDP or emissions) or avoided when necessary as for the sectoral emissions, by starting the analysis in 2019.

Third, consistent with literature on human needs and Decent Living Standards, which define the material and energy conditions of human wellbeing, the sufficiency-based decarbonization model for the United Kingdom, developed by CREDS at the University of Oxford (Barrett at al 2021, 2022), is adapted to the specificities of Vaud in §10.6, using a similar approach as above.

All cantonal data is public and was downloaded from the StatVD website, except renewable energy development projections for 2030, which were linear estimated from 2035 objectives defined in the Conception Cantonale de l'Energie - CoCEn (Conseil d'Etat Vaud 2019, pp. 27-31).

10.2. Top-down aggregate energy analysis

In 2018, territorial final energy consumption was 63.3 PJ for 793k residents, ca. 80 GJ per year or 2530 W continuous per capita. Electricity represented 24%, mostly low-carbon; the remaining 76% were almost entirely fossil-based. In 1990, the final energy consumption was 59.5 PJ, and electricity represented 18.5%. In 28 years, final energy of fossil origin declined from 48.5 PJ to 48.1 PJ, or -0.8%. During this time, the population increased from 572k to 793k residents.

However, increase in imported embodied CO_2 likely more than compensated for this nominal efficiency improvement. Based on Swiss data for embodied emissions for 2000-2019 (no data is available for Vaud, nor Switzerland before 2000), using the least squares method, Swiss domestic CO_2 emissions decreased by 414 kt p.a. or 0.85%, whereas embodied emissions of imports increased 468 kt p.a. or 0.70% (FSO 2022). This shows the limits of analyzing territorial emissions.

Reducing energy-related emissions by 50% from 2020 to 2030 simply means burning 50% less fossil fuels, and would, given the current Swiss and Vaud energy mix, limit the fossil final energy to about 24 PJ. Given the predominance of motor fuels for transportation, the scope for optimizing the mix of fossil fuels (replacing oil by gas) is limited. The total available energy would also include most of current electricity (as climate change would have limited impact on available hydropower used by Vaud before 2030, and no major nuclear plants are scheduled to shut down), plus new renewable energy sources deployed by 2030. New wind and solar could represent +1600 GWh by 2035, or perhaps ⅔ if this number by 2030: +3.8 PJ. In total, available final energy in the canton could be estimated as 43 PJ = 24 PJ (reduced fossil) + 15.2 PJ (today's electricity) + 3.8 PJ (new wind and solar, perhaps slightly higher at 5-6 PJ if biomass and geothermal were added). This represents a 32% reduction in available final energy.

At this macro-level perspective, the challenge becomes obvious: how to adapt the economy, in less than 10 years, to operate with 68% of today's final energy. Society-wide efficiency improvements of 3.8% p.a. are needed to keep the economy the same aggregate size as today. Per capita, based on a predicted population of 874k residents in 2030, efficiency improvements of 5% p.a. would be required. Such sustained economy-wide efficiency improvements have never been observed in practice.

Energieperspektiven 2050+ assumes annual final energy efficiency improvements of .47/.80 over 31 years, or 1.7% p.a., which is higher than the 1.2% p.a. of the 2000-2019 period (BFE 2020, p.6). Using 2020 as a starting point for reasons of consistency, and assuming the 1.7% p.a. final energy efficiency improvements, the economy using 68% of the 2020 final energy would be .68/.84 = 81% of the size of today's economy.

If the size of the economy cannot be maintained, the challenge becomes how to ensure the broadest satisfaction of human needs within a smaller economy. To gain sufficiently broad acceptance for implementation, the transformed society would probably need to be much more equal and improve human needs satisfaction compared to today.

Can the sectoral analysis of the sufficiency potential help deliver such a deep transformation?

10.3. Starting point for sectoral analysis

The analysis begins with the Swiss sectoral targets of the Federal Council's "Long-term Climate Strategy 2050" (Swiss Federal Council 2021), based on Energieperspektiven 2050+ (BFE 2020, Table 15, p.82), and refined on 24.05.2022: “21.501 | Indirect counter-proposal to the glacier initiative. Zero net greenhouse gas emissions by 2050” (Swiss Federal Parliament 2021; 2022 p.12). The figures in Table 10.1 (relative to 1990) are reproduced from the above mentioned documents, with an interpolation of the missing figures, indicated by (*).

For Vaud, it is important to recalculate these figures relative to 2019, as shown in Table 10.2, as: (a) the evolution of emissions 1990-2019 differs considerably between Switzerland (-14%) and Vaud (-5%), largely explained by population growth in Switzerland (+27.4%) and Vaud (+40.3%); and (b) the 1990 emissions for the Canton of Vaud are unknown and estimated only at the global level; no reliable sectoral estimates exist to our knowledge.

Table 10.1: Swiss sectoral GHG emission reductions compared to **1990**

Sector	2030	2035	2040	2045	2050	Main measures (Swiss Federal Council 2021, BFE 2020)
Buildings - Energy	-54%	-74%	-82%	-90%	-100%	Strong acceleration of efficiency and clean energy measures (renovation, heat pumps; public transport, electrification) Minimal sufficiency measures Territorial reduction potential close to 100%
Mobility	-27%	-39%	-57%	-78%	-100%	
Industry, incl. CCS	-28%	-38%	-50%	-72%	-90%	Opportunities for sufficiency, clean energy, and CCS, less potential for efficiency (as already highly efficient)
Agriculture	-20%*	-25%*	-30%	-35%*	-40%	Modest measures to change the composition of the diet, and to implement good agricultural practices and soil regeneration
NET [CO_2]	0	0	0.4 Mt	3.6 Mt*	6.8 Mt	
TOTAL	**-50%**	**-62%**	**-75%**	**-87%**	**-100%**	GHG reduction compared to 1990 including significant international offsets

(*) interpolated, no official figures available

In Table 10.2, comments summarize the implications for the canton of Vaud, if the recalculated Swiss objectives were applied uniformly. Globally, the reductions are insufficient to reach 50% by 2030, and both over- and under-ambitious, depending on the sector.

Table 10.2: Swiss sectoral GHG emission reductions compared to **2019**

Sector	2030	2035	2040	2045	2050	Comments - implication for Vaud
Building - Energy	-38%	-65%	-76%	-87%	-100%	Excessively ambitious for 2030 and 2035 compared to past building sector reductions of ca. 1% p.a.; impossible to achieve without strong sufficiency measures
Mobility	-28%	-40%	-58%	-78%	-100%	Modest reductions for 2030-2035 relative to the urgency of reduction and potential of sufficiency of this sector
Industry, incl. CCS	-30%	-40%	-52%	-73%	-90%	
Agriculture	-1%*	-7%*	-13%	-20%*	-26%	Very modest, given past reductions (HEPIA 2021) and fully funded reduction measures in place
NET [CO_2]	0	0	0.4 Mt	3.6 Mt*	6.8 Mt	
TOTAL	**-30%**	**-48%**	**-60%**	**-75%**	**-90%**	GHG reduction compared to 2019 Not counting international offsets

(*) interpolated, no official figures available

10.4. Specificities of Vaud and needed adjustments

Structurally, from the perspective of climate action analysis, the canton of Vaud is comparable to Switzerland. The proportions of territorial GHG emissions of the main sectors in 2019 (building, mobility, agriculture, industry) are similar, as is the probable impact of climate change (MétéoSuisse NCCS 2021).

The main differences between Vaud and Switzerland, relevant for climate action, are income, density, type of farms, and a structural difference between sources of emissions at the same income level.

Per capita income is lower in the canton of Vaud than in Switzerland: 87.9% in 2019, slightly higher than 86.7% in 1990. Density [people/km^2 in 2019] is higher, at VD: 251 vs. CH: 217, as is population growth [Δ 2019/1990]: VD: +40.3% vs. CH +27.7%.

Vaud has more farms “used for annual field crops, annual vegetables and berries, or annual aromatic and medicinal plants", more crops with significant climate impact (potatoes, beets, etc.), and consequently a very intensive mechanization in the canton of Vaud (OFS 2021).

Finally, despite the lower income level, GHG per capita of Vaud relative to Switzerland are higher by 15.7%, or 31.6% at constant GDP/cap., as calculated in Table 10.3, indicating other differences, such as size and relative efficiency of houses and cars, the density of agglomerations, different industrial base, and the cultural habits of mobility and consumption. As this ratio is likely to change slowly, we use it to estimate 1990 GHG emissions of Vaud, which are unknown. The final missing figure, the GDP of Vaud in 1990, is estimated from the historical co-evolution of GDP VD/CH, extrapolated from 1997, the first year in which the official GDP for Vaud was calculated.

Table 10.3: Estimating the Vaud 1990 GHG emissions (Data sources: FSO, StatVD, Quantis 2022, BCV 2016)

	unit	**1990**	1997	**2019**	**Δ 2019/1990**
Population CH (year end)	M	6.751	7.096	8.606	27.48%
Population VD (year end)	M	0.575	0.604	0.806	40.27%
Population VD/CH		8.51%	8.52%	9.37%	10.04%
GDP CH (current prices)	GCHF	369.5	428.3	727.21	96.80%
GDP VD (current prices)	GCHF	**27.27**	31.63	59.88	119.63%
GDP per capita VD/CH		86.69%	86.69%	87.91%	1.42%
GHG emissions CH (incl. LULUCF)	Mt CO2e	51.522	52.428	43.858	-14.87%
GHG/capita CH	t CO2e	7.632	7.388	5.096	-33.22%
GHG/capita VD	t CO2e	8.708	8.431	5.898	-32.28%
GHG/cap VD/CH (base 2019)		115.7%	115.7%	115.7%	0.00%
GHG/cap/GDP VD/CH (base 2019)		133.5%	133.5%	131.6%	-1.40%
GHG emissions VD (incl. LULUCF)	**Mt CO2e**	**5.004**	**5.096**	**4.754**	-5.00%

These differences between the canton of Vaud and Switzerland are rather positive for the potential of cantonal climate action, even if their impact will remain modest, as Switzerland and the canton of Vaud remain very similar. The main opportunities are related to sufficiency, mobility, and food.

The structurally higher GHG per capita at constant GDP (31.6%) suggests a great potential for sufficiency measures in all areas, not developed in existing or planned climate policy.

Mobility efficiency measures, such as public transit, carpooling, and efficient freight transportation, are easier to implement with higher density. With faster population growth, this advantage will become even more pronounced.

Intensive farming has more adverse effects on the climate (and biodiversity); from the perspective of climate action, the opportunities for better farming practices including diet, efficiency, clean energy, and soil carbon sequestration are therefore numerous and high.

Due to these differences, we believe that acceleration of decarbonization in Vaud is possible in buildings, mobility, and agriculture, including carbon sequestration in soils.

Table 10.4 adjusts the Swiss figures for 2019 from Table 10.2, taking into account the specificities of Vaud described above, notably -2% per 5-year period in mobility (density effect and demographic growth), as well as more ambitious reductions in agriculture by expanding existing action related to biogas and carbon sequestration in soils.

Table 10.4: More ambitious sectoral reductions for Vaud (except industry) [% compared to 2019]

Sector	2030	2035	2040	2045	2050	Assumptions (relative to Table 10.2)
Building - Energy	-20%	-40%	-60%	-80%	-100%	-20% per 5 years, starting less ambitious than the CH target because the latter is unrealistic without strong demand reduction
Mobility	-28%	-42%	-62%	-84%	-100%	-28% as CH in 2030, then -2% per 5-year period beyond the CH target
Industry, incl. CCS	-30%	-40%	-52%	-73%	-90%	Unchanged from Swiss targets
Agriculture	-15%	-23%	-31%	-39%	-47%	-15%, then -8% per 5 years, incl. soil carbon
TOTAL	**-24%**	**-39%**	**-57%**	**-78%**	**-93%**	No NET beyond soil carbon

10.5. Level of ambition of the federal climate strategy

In international comparison, the Federal Council's long-term climate strategy 2050 seems unambitious from several perspectives.

The level of so-called "unavoidable" emissions in 2050 is very high. These emissions are only unavoidable if no action is taken to avoid them. They represent 22% of 1990 emissions in Switzerland, compared to only 3% in Germany; or at the absolute level, 1150 kg CO_2e per capita in Switzerland compared to 465 kg CO_2e per capita in Germany.

The level of embodied emissions (contained in imported products) is very high, much higher than in most European countries, and no decarbonization is planned for these emissions.

Highly polluting practices are not questioned. Examples include the high consumption of concrete, and the growth of household waste, already at the highest level per capita in Europe.

There is no credible action plan to exit fossil fuels with any time horizon, and definitely not well before 2050, as is needed.

Complete dependence on foreign offsets, without which climate targets cannot be reached. This is problematic for several reasons: (a) low quality and transparency of international projects, with a high risk of double counting; (b) limited availability of such projects, as any country must achieve its own net zero and will not have sufficient additional negative emissions projects; (c) increased costs of decarbonization for host countries, because third countries use the best projects from these countries first; and (d) failure to assume its historical responsibility (as any other rich country) and to help (with funding, know-how, technology, etc.) poor countries to reach their own net zero, not to count the reductions obtained for its own NDC.

A more ambitious climate policy would decarbonize Switzerland faster (net zero by 2040 or 2045 at the latest, as is the case in several countries such as Germany), with very modest residual emissions and a negative emissions implementation plan to absorb them and reach net zero. A more in-depth analysis of all of these points is provided in "Swiss Negative Emissions Fund – Paying for Net Zero" (Nick and Thalmann 2022). The numerical model of the Negative Emissions Fund shows that a Swiss decarbonization completed by 2040, with a residual level of half of the official strategy (but still higher than other countries) would make decarbonization less risky, much more feasible, and significantly less expensive. Last but not least, a positive Swiss example could accelerate climate action far beyond its borders.

10.6. Estimating sectoral targets from demand reduction

In order to establish an estimate of a conceptual reduction pathway, based on technical, economic and social feasibility, we start from the scientific literature around energy needs and energy services.

The main scientific work on energy needs is based on human needs, which are universal, classifiable, finite, and satiable. There is a clear distinction between needs (invariable) and "satisfiers" or means of satisfying needs, which are culturally specific and change over time. The main scientific approaches are Manfred Max-Neef's "Fundamental Human Needs" and Len Doyal and Ian Gough's "Theory of Human Need", as well as Amartya Sen's and Martha Nussbaum's capability approach (Max-Neef 1991, Doyal and Gough 1991, Robeyns et al. 2021).

Decent Living Standards (DLS) build on this scientific foundation of human needs. DLS defines the minimum material prerequisites for a "decent" satisfaction of all human needs, including the work of Narasimha Rao, Arnulf Grubler, Julia Steinberger and others. Low Energy Demand (LED) approaches start from a global, regional and country perspective, and have been introduced in the IPCC SR15 report (2018), notably in the P1 reduction pathway. Key references: Rao and Baer 2012, Grubler et al. 2018, Rao et al. 2019, Millward-Hopkins et al. 2020, Kikstra et al. 2021.

10.6.1. Conclusions and recommendations of the CREDS analysis

For this analysis, we have adapted to the Vaud context the conclusions of a recent study (all sectors) of the Centre for Research into Energy Demand Solutions (CREDS) of Oxford University. This is the report "The role of energy demand reduction in achieving net-zero in the UK", also published in Nature Energy "Energy demand reduction options for meeting national zero-emission targets in the United Kingdom" (Barrett at al 2021, 2022), based on advanced modeling of the UK energy system. It reaches the following **five main conclusions**:

Frist, the UK's climate targets of -78% by 2035 (CH: -62%) are not achievable without a significant reduction in energy demand, which includes both sufficiency and efficiency

Second, a reduction in energy demand would have five notable effects: (a) an acceleration of decarbonization, as less fossil energy is used; (b) a smaller and therefore more feasible renewable energy system would be needed (Note: analysis by Züttel et al. (2022), which does not take sufficiency into account, shows that a complete replacement of fossil fuels is not feasible, which is 100% consistent with the CREDS conclusion); (c) a significant reduction of decarbonization cost; (d) a more ambitious future climate policy becomes possible; and (e) much less dependence on costly and uncertain NET technologies.

Third, the public policies required go far beyond the framework of energy policy and require a systemic rethinking of all public policies.

Fourth, it is necessary to evaluate any public policy for its value to society and its contribution to net zero, rather than looking at its economic efficiency.

Fifth, societal legitimacy is essential, including broad acceptance of the necessary lifestyle changes by the general population. To achieve this, deliberative methods such as those used during the Climate Assembly UK (2020) will be needed.

On this basis, the CREDS study develops these **key recommendations by sector**:

Agriculture and food: promote a healthy diet and reduce meat and total energy intake, with the necessary adjustments in production.

Industry: promote above all sufficiency, which involves reducing the consumption of industrial products (energy efficiency is already high in this sector).

Buildings: a three-pronged approach to the widespread use of heat pumps, building renovation, and reduction of the built area per person.

Mobility: above all sufficiency (reducing travel distances), in addition to the electrification of cars (which should not be the main measure) and stopping the expansion of the road network.

10.6.2. Application to the canton of Vaud

In order to apply these conclusions to the Vaud context, the following main Swiss and Vaud specificities must be kept in mind

Switzerland (and the canton of Vaud) has a 58% higher income (GDP/cap in PPP) than the UK, with a significantly lower poverty rate.

The electricity generation mix in the UK, despite an impressive decarbonization reducing emissions by a factor of three since 1990 and an almost complete exit from coal (-97.5%), continues to be based at 35% on natural gas (UK National Statistics 2021). Gas is not used to generate electricity in the canton of Vaud.

The average population density of the UK is slightly higher (271 vs. VD 251, CH 217); especially the large cities and sparsely populated regions must be distinguished.

The UK economy is more integrated than the Swiss and Vaud economy: in 2019, the ratio of CO_2 emissions from consumption to territorial emissions (Ritchie and Roser 2022) is twice as high in Switzerland because a larger share of consumption is imported. As a result, a complete decarbonization of the UK economy is much more difficult, as the share of the already efficient industry is larger: UK: 141%; CH: 316%; VD: 296% (=11.325/3.821).

10.6.3. Recommendations for the canton of Vaud

In conclusion, for the conceptual pathway to reduce sectoral GHG emissions in the canton of Vaud, we can recommend adopting the broad lines identified by CREDS, which would be even more feasible in the canton of Vaud than in the United Kingdom due to the lesser relative weight of industry, the already decarbonized electricity, and the wealth of the country. In concrete terms, we propose these measures, in addition to the measures included in the climate plan Vaud:

Buildings: reduce energy consumption for heating buildings by at least 38% in 2050 (10% in 2030, 20% in 2040, all compared to 2019; CREDS p.84 indicates 30%: in Switzerland the quality of renovation can be higher); significantly reduce new construction (and surface area per capita), and generalize zero-emission heating systems such as heat pumps.

Mobility: Reduce the distances traveled by individual cars by 55% in 2030, 62% in 2040, and 70% in 2050 (all compared to 2019), and move towards a 100% electric fleet as early as 2040, which requires rapidly stopping the sale of fossil cars (CREDS, p.83, "Transform" scenario).

Cement and waste: reduce production, consistent with the significant reduction in new construction. Where possible, make the cement sector carbon neutral, with CCS and improved weathering. Eliminate all non-biogenic waste and incineration over 15-20 years; thus incineration plants become BECCS facilities, provided there is geological CO_2 storage nearby.

Food and agriculture: adapt the diet and specifically reduce meat consumption, as proposed by EAT-Lancet (Willett et al. 2019), over a 15-20 year period, and universally adopt regenerative agricultural practices. Generalize the good practices detailed in the HEPIA study (2021).

Legal framework: this analysis does not take into account the legal framework and the cantonal and federal jurisdictions to date, nor the changes needed to achieve these objectives; a dedicated study is recommended.

Such a transformation would require significant changes in all sectors of society and should be based on broad (but not necessarily universal) public acceptance. We reiterate CREDS' recommendation to employ deliberative methods such as citizens' assemblies, allowing for socially shared learning and deliberation, and thus better decisions, better accepted by the population.

Table 10.5 provides an estimate of the potential impact of our recommendations. The assumptions for the estimate are detailed in the next section.

Table 10.5: Estimates of GHG emission reduction potential for the Canton of Vaud based on CREDS-inspired demand reduction, compared to 2019 and 1990

Sector	2030	2035	2040	2045	2050	Assumptions (details in §10.6.4)
Building - Energy	-34%	-54%	-71%	-87%	-100%	2019: 15% heat pumps, 10% wood/biomass heating (BM) 2030: -10% m^2 /cap, 30% heat pumps, 10% BM, -18% energy 2040: -20% m^2 /cap, 60% heat pumps, 10% BM, -28% energy 2050: -30% m^2 /cap, 90% heat pumps, 10% BM, -38% energy
Mobility	-71%	-85%	-100%	-100%	-100%	2030: -55% car-km, 35% electric 2040: -62% car km, 100% electric 2050: -70% car-km, 100% electric
Industry, incl. CCS	-40%	-52%	-65%	-77%	-90%	2050: -70% cement, -100% plastic waste, incl. CCS+EW (enhanced weathering)
Agriculture incl. LULUCF	-30%	-50%	-70%	-90%	-110%	2050: -67% meat, -50% total impact, NET (renaturation + sequestration) to reach net zero
Total compared to 2019	**-50%**	**-67%**	**-83%**	**-92%**	**-100%**	Without international offsets
Total compared to 1990	**-53%**	**-69%**	**-84%**	**-92%**	**-100%**	Without international offsets

This level of sectoral reduction is clearly compatible with the top-down analysis of §10.2.

10.6.4. Assumptions of sufficiency-related decarbonization per sector

Buildings and energy

Sufficiency / living space: -10 m^2/capita, per decade; at least offsetting population growth and household size reduction; faster reduction would be possible but is not included in our simple model

Energy efficiency, expressed as annual energy requirement per m^2 : -18%, -23%, -28%, -33%, -38% in 2030, 2035, 2040, 2045, 2050 respectively, compared to 2019

Clean energy: the energy mix goes from 15% heat pumps, 10% wood/biomass (BM), and 75% fossil in 2019 to:

30% heat pumps, 10% BM, 60% fossil in 2030
45% heat pumps, 10% BM, 45% fossil in 2035

60% heat pumps, 10% BM, 30% fossil in 2040
75% heat pumps, 10% BM, 15% fossil in 2045
90% heat pumps, 10% BM, 0% fossil in 2050

For example, in 2030, the sector's GHG emissions correspond to -34% =
(1-18%)(efficiency) * 60%/75%(fossil->heat pumps) - 1

Mobility

Sufficiency/car-km reduced by 55%, 62%, 70% in 2030, 2040, 2050 respectively, compared to 2019

Efficiency and clean energy: Electrification rate corresponds to 35% in 2030 and 100% in 2040 (acceleration of electrification)

For example, in 2030, the sector's GHG emissions correspond to -71% = -55% (reduced car km) - 45%*35% (electrification)

Limitation of the estimate: our simple model does not distinguish between trains (almost zero emissions) and buses (polluting if fossil; we did not estimate the rate of electrification).

Note: our methodology for embodied emissions follows that of the Confederation's climate strategy (territoriality of car production, fuels etc.), not the canton of Vaud.

Industry

Sufficiency: our model is based on -70% cement, and -100% plastic waste in 2050, based on linear reduction between 2025 and 2050

CCS+NET: We apply CCS+EW (enhanced weathering) in order to reach -90% of industrial emissions in 2050, which corresponds to the "Long Term Climate Strategy 2050" of the Federal Council

Agriculture

Sufficiency: our model is based on a reduction of meat consumption, especially beef, by at least 67% in 2050, compared to 2019. The reduction in climate and biodiversity impact of this change amounts to -50%.

NET: given the very high carbon sequestration potential in soils and other ecosystems such as wetlands, over several decades, the modeled target corresponds to -60% of 2019 emissions through NET approaches.

Together, sufficiency (-50%) and negative emissions (-60%) allow agriculture to reach -110% in 2050, compared to 2019

10.7. Recommendations for public policy instruments

No single sectoral public policy and no single instrument will be able to achieve all the objectives necessary to reach the net zero in Vaud, for example the objectives we propose. A combination of all types of instruments (economic, regulatory, voluntary, public investment) will be required. Without analyzing the cantonal and federal legal framework and its evolution, one possible combination of essential public policies is detailed below, as an illustration of what is needed.

Economic instruments

- Quickly introduce a payment on all GHG emissions according to the polluter-pays principle, to finance future negative emissions (Nick and Thalmann 2022)
- Introduce incentives (taxes + subsidies) to limit living space per person
- Eliminate all tax incentives leading to high emissions
- Make taxation fairer, e.g. more progressive taxation while eliminating exceptions, to make collective climate action more acceptable

Regulation

- Phase-out fossil fuels completely over 15-20 years, faster at the beginning, for example -80% in 10 years
- Ban the sale of fossil cars immediately, and by 2035 or 2040 latest also their use
- Restrict the use of biomass; this is a valuable resource, to be used in cascade for the greatest benefit of society
- Mandate the replacement of heating systems to make them zero-emission within 5-10 years (e.g. by heat pumps or district heating); at the same time restrict the purchase of gas and oil for heating
- Stop new building construction pending a cantonal master plan for eco-responsible construction
- Stop all construction outside of urbanized areas
- Restore and renaturalize all wetlands and organic soils over a 15-20 year period
- Restrict air travel to significantly reduce volume and ensure key benefits to society (Nick and Thalmann 2022b)
- Ban single-use packaging
- Restrict all plastics that have a negative impact on the biosphere

Public investment

Educate and create awareness in schools, municipalities, companies, administrations about living well with fewer environmental resources

Help people to transition to 1.5°C lifestyles, e.g. moving house, find a more suitable job, reduce transport

Help any person in difficulty due to the rapid changes in society (social cushioning)

Plan and fund climate adaptation measures, including for infrastructure and essential services, as well as strengthening for agriculture

Implement deliberative democracy processes at all levels

Voluntary measures

In view of the historical responsibility of rich countries, help other countries to reach their net zero, for example through financing, guarantees, debt cancellation, knowledge and technology transfer, sharing of best practices, etc., without including the reductions obtained in the balance sheet of the donor country

Implement inclusive, accessible, accountable and community-integrated local service delivery contracts "social license" (De Boeck et al. 2020)

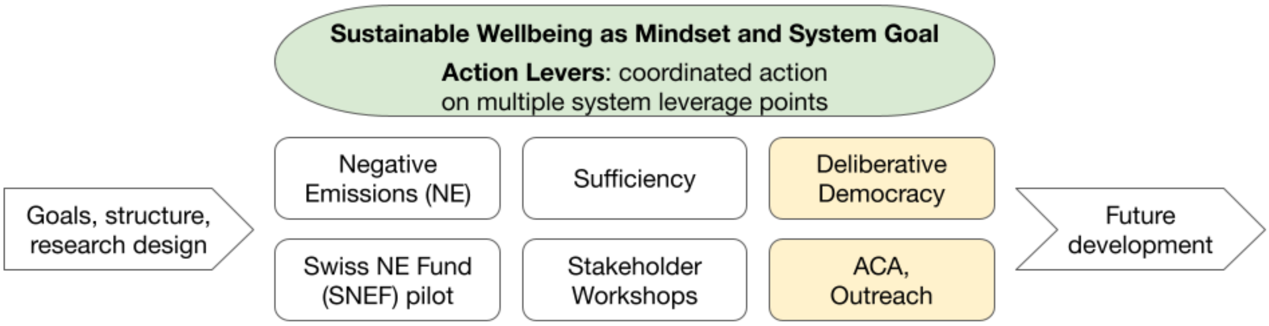
10.8. Discussion and limitations

The main contribution of this chapter is being the first, to my knowledge, sectoral estimate of sufficiency potential applied to Switzerland.

Using three methods, it shows that a cantonal decarbonization strategy cannot be successful without sufficiency, and even more, that sufficiency is the main lever in reaching net zero. While not specifically analyzed, the same is very likely true for all of Switzerland, given all the similarities that the analysis identified.

The main limitation is the simple methods used: instead of building an entirely new model, or configuring and re-running the CREDS model for Switzerland, the method consisted of extrapolating from the results of the UK model, which of course only produces meaningful results if the countries are sufficiently similar, which I tried to show in the analysis, and that any non-linearities are limited in the relevant range, which I did not analyze.

Part IV: Engaging society



11. Deliberative and participatory democracy for societal transitions

Part II showed that limited availability of negative emissions requires rapid decarbonization to reach net zero by 2050, made even more stringent by the inclusion of a 1.5°C-compatible remaining carbon budget (chapters 4 and 5). Part III showed that the short time available requires a strong focus on sufficiency, in this thesis modeled for global aviation and estimated for the canton of Vaud. Rapid decarbonization and sufficiency at the societal level both require governance capable of overcoming powerful vested interests.

This chapter investigates effective democratic governance and the potential of deliberation, and proposes a new deliberative assembly, the Academic Citizens' Assembly, designed to overcome two key limitations identified from literature, of scaling, and of integration in the existing political system. The assembly is then prototyped, tested, and improved over the five instances conducted in 2021, 2022, and 2023.

11.1. Introduction - why do we need deliberative democracy?

Since the late 1960s, system dynamics models, like World3 (Meadows et al. 1972), have consistently predicted the instability and collapse of an extractive growth society, above all from the accumulation of pollution in the biosphere.

From a systems perspective, limited NE are a constraint that could lead, with good governance, to a new system goal (deep and rapid decarbonization), new system rules (fossil fuel exit etc.), new information flows (carbon accounting complementing VAT), and new incentives (carbon price, payment for NE to communities), corresponding to leverage points 3-5-6-12 respectively.

In the absence of a suitable governance, urgent decisions will be blocked or delayed, leading to biodiversity loss, reduced or even collapsing ecosystem services, lower cooperation at all levels, breakdown of existing (limited) ecosystem protection, more destruction, etc., creating a dangerous positive (reinforcing) feedback loop. On the other hand, good governance might change the mindset, system goal, and the power to change system structure (leverage points 2-3-4), overcoming resistance from determined and powerful fossil fuel interests.

For a number of reasons, ranging from power structures, polarization, disinformation, dominant (hegemonic) mental models, as well as institutional, no large society has been successful in taking effective action to reduce extraction and stop pollution, although intentional communities like ecovillages have made much more progress.

The only global environmental problem ever solved, stratospheric ozone depletion, although global, was a very limited-scope problem concerning the use of about 100 chemicals, called “ozone depleting substances” (ODS), mainly used for cooling and refrigeration. Under the Montreal Protocol signed in 1987 (UN Environment Programme n.d.), plus nine subsequent revisions expanding the list of ODS, these chemicals were phased out over several years or decades (overall -98% in 2015 relative to 1990). Additionally, monitoring and reporting were implemented, as was a Multilateral Fund to help poor countries implement the protocol. To date, the fund distributed $3.9bn to 8600 projects. While extraordinarily successful, the Montreal Protocol did not require broad citizen engagement, democratic governance, nor any change in the economic system or structures of power. None of the major current sustainability challenges (climate, biodiversity, water, agriculture, inclusion and equality) can be solved in a similar way.

Yet even small actions producing real benefits could start changing the mindset at a local scale, leading to further improved governance. It would be important to estimate if the speed of such positive feedback loops leading to improvement is sufficient, given the urgency.

These essential questions are almost completely absent from today’s Swiss political debate, and unless something important changes, federal or cantonal parliaments are unlikely to vote for any remotely adequate climate action. On the other hand, we have seen that stakeholder workshop results (chapter 8 and Appendix A) suggest that many people are already thinking of radically different societies and might be ready for a change, under the right conditions.

What are these conditions, and how could they be created, tested, and broadly deployed?

11.2. Literature contributions and gaps

Unsurprisingly, literature on democracy is very broad. Here the focus is a narrow subset, at the intersection of deliberative democracy and sustainability action, especially on climate.

11.2.1. Democracy and the wicked problems of sustainability

As we have seen in the introduction, all main sustainability issues can all be considered wicked problems: complex, each unique, not having a definitive formulation, stopping rule or even knowing when or if the problem has been solved, and every problem can be seen as a symptom of another one (Rittel and Webber 1973).

Stoddard et al. (2021) identify nine global reasons why climate action has been ineffective: climate governance (power unbalance, missing leadership, deliberate politics), fossil industry interests, geopolitics and militarism, economics and financialization (deregulation, neoliberalism), mitigation modeling (cost focus of IAMs, excessive CDR), energy supply systems (additive energy sources), inequity, high-carbon lifestyles, and social imaginaries. All nine are manifestations of power accumulation and vested interests, precisely of the kind that a well-functioning democracy should be able to limit, or at least correct excess when it occurs.

Additionally, many countries contributing to the world's current problems are not considered to be democracies at all, so isn't looking at democracy too limited? No – as democracy is a continuum, not a binary category, with only a handful of countries like Norway and New Zealand being highly democratic, and another handful like Afghanistan totally authoritarian. Most of the 200 countries have some combination of strengths and weaknesses, based on an assessment of five dimensions (electoral process, government functioning, political participation, political culture, and civil liberties) by several methods: survey, political participation indicators, and expert assessment (Economist Intelligence Unit 2023). At a local level, deliberative democracy has been successfully practiced even in China (Fishkin et al. 2010). This suggests that, perhaps with a few exceptions, improving democracy is possible, in view of solving sustainability problems.

So why has democracy not been more effective?

Of the two main types of democracy, representative democracy is, as expected by its nature of concentrating power, less effective in confronting vested interests. Hélène Landemore (2020) identifies a double crisis of representative democracy: at an empirical (low voter turnout, decline of political parties, general polarization) and conceptual level (including many reasons which cannot be solved by reform, such as separation of elites, elected and administrative, and masses; as well as lack of deliberation).

On the other hand, direct democracy "never actually existed" (Landemore 2020, p.55), at least based on three main ideas used to define it: (a) giving voters the final say (but not the ability to set the agenda or engage in deliberation), (b) the need for representation in large modern societies (this is pure correlation, direct democracy is difficult from the size of several hundred people), and (c) viewing classical Athens as the model (in reality only a minority made decisions). Additionally, today's wicked problems (Rittel and Webber 1973) of society require time and knowledge to understand, and deliberation to fully apprehend - both made more difficult by populism, fake news, and growing polarization.

Modeling polarization and taking an interdisciplinary view including systems theory, environmental and complexity science, and evolutionary biology, Levin et al. (2021) point out that polarization leads to loss of diversity, subject to a reinforcing feedback loop, undermining the ability of any system including society to thrive, or even survive at all.

11.2.2. Values of democracy

Any effective democracy will include to some extent two different but often confused elements: deliberation and participation. Deliberation is a discussion or debate between citizens on public issues, ideally with a facilitator to ensure inclusion, respect, focus, etc. Participation is a form of empowering citizens to take action, vote, or make a decision. Deliberation is a form of "thick" engagement, requiring considerable time and effort. Participation is a "thin" engagement, much easier to organize, but usually does not create lasting engagement or change.

James Fishkin (2009) defines the trilemma of democracy as the difficulty of designing a democratic process which includes all three democratic values: (quality of) deliberation, political equality (equal consideration of political preferences), and (mass) participation. The three common approaches all fall short (**respected**, not respected):

1. Mass democracy: **Equality** **Participation** Deliberation
2. Mobilized deliberation: Equality **Participation** **Deliberation**
3. Microcosmic deliberation: **Equality** Participation **Deliberation**

Obviously, it would be very attractive to somehow combine all three democratic values.

Citizens' assemblies, corresponding to Fishkin's "microcosmic deliberation", have been conducted dozens of times in many countries, and have shown a remarkable ability to converge towards common positions. Successful examples from Bududa and Butaleja districts in Uganda (Fishkin 2018) and Zeguo in China (Fishkin et al. 2010) show that neither an educated population, nor an established culture of democracy are needed for deliberative democracy.

"America in one room" (Fishkin at el 2021) is a 2020 experiment in public deliberation involving 500 people, which produced spectacular results in one of the most polarized environments imaginable: the US just before the 2020 primary elections. The deliberation dramatically narrowed political differences between Democrats and Republicans on the issues they care most and were highly polarized. Fishkin's paper concludes by asking how to scale such a successful process.

11.2.3. Deliberative democracy

Deliberative democracy, which in principle should apply to both direct and representative democracy, sees the basis for legitimacy of laws and policies, according to Habermas (Landemore 2020, p.37), in their validation by public exchange of arguments among equal citizens. Habermas argues for two types of deliberation, among all citizens and among elected representatives, with the first setting the agenda for the second, and the second providing regular justification to the first. This "two-track deliberative democracy", attractive in theory, suffers from the same problems as any representative democracy (Landemore 2020. p.38).

In Max Weber's *disenchantment of the world* (Entzauberung der Welt) of modernity, the increasingly rationalized scientific, artistic, and legal spheres detached themselves from religious tradition, following their separate inner logics, creating tension in the process – leading to both loss of meaning and loss of liberty (Vitale 2006). Habermas disagreed, seeing the gap between elites (scientists, artists, jurists) and everyday life as responsible. There is no natural equilibrium between the three spheres, and today the capitalist system and the modern state are overdeveloped, at the expense of the *lifeworld* (Lebenswelt) - the lived (erlebt) world, as understood or experienced together. According to Habermas, the solution is to strengthen the *lifeworld* through communication, and only democracy can ensure mutual understanding leading to consensus, as well as check the expansion of capitalism and state. Furthermore, deliberative democracy replaces competition between interests of the market paradigm with dialogue, leading to opinion- and will-formation.

Landemore (2020, p.37) summarizes the main reasons why deliberation is so valuable, as it:

1. Provides support for laws and policies in reasoning, beyond the number of votes
2. Allows all citizens to speak and be heard
3. Educates people, builds a sense of community, promotes civic engagement
4. Generalizes interests (Habermas)
5. Facilitates solving collective problems

It is important to note that Landemore proposes a form of “democracy 3.0” named Open Democracy, based on deliberation, but including four other principles: participation rights (similar to Swiss direct democracy: citizens’ initiatives, referendum, right to participate in mini-publics), the majoritarian principle (a set of principle going beyond the majority vote to include collective judgment or evaluation, such as the Majority Judgment), democratic representation (such as lottocratic, combining sortition and rotation), and finally transparency (of process and results).

Ryfe (2005) defines three “modes”, or uses, for the output of deliberative talk: educative, consultative, or decision-making. All three are relevant for sustainability transitions, with challenges related to scale and inclusion, as well as integration in the existing political process.

11.2.4. Climate-related citizens’ assemblies

To date, no democratic state has submitted an adequate NDC under UNFCCC (Willis et al. 2022), and we have seen why (Stoddard et al. 2021) in the previous sections. At the same time, dozens of mini-publics or citizens’ assemblies related to climate have been successfully organized, including two high-profile assemblies, the Climate Assembly UK in 2020 and the French Convention Citoyenne pour le Climat in 2019-2020 (Cherry et al. 2021, Willis et al. 2022).

Cherry et al. (2021) analyze and compare the French and UK climate assemblies, and conclude that there are many good ways to conduct a successful assembly, and that outcomes will be determined by participating citizens’ values and experiences, but also strongly by the design of the assembly, and liberty given to participants to develop their own proposals vs. appraising predetermined policies pre-written by experts. This was also the main difference between the French assembly, given more freedom, and the UK assembly, constrained by experts’ inputs. These two approaches can also be characterized respectively as bottom-up and top-down. Either way, transparency of process and use of output is important.

Willis et al. (2022) start from a more theoretical perspective on deliberative mini-publics and citizens’ assemblies and the challenges of democracies in implementing climate strategies, identifying the biggest difficulty in mobilizing, to the extent needed, both political leadership and public support. While there is no guarantee that citizens’ assemblies will solve the climate crisis, they can overcome many common issues of democracy, such as polarization, party politics, or vested interests, and go beyond aggregating preferences to developing understanding and forming views - leading to much more ambitious positions and comprehensive responses to the climate crisis than governments. The open question remains how to integrate deliberative mini-publics into the existing political process, and ultimately make it mainstream. Finally, deliberation happens successfully around the world, often without being labeled as such, as illustrated in the example of involving poor communities affected by Typhoon Haiyan in the Philippines, to plan their relocation and rebuilding of sustainable housing and local economy.

Gough (2017, Ch.7) proposes using deliberative democracy to define suitable synergistic satisfiers, as well as lower and upper bounds for consumption corridors, named the "dual strategy" of combining codified knowledge of experts and the experientially grounded knowledge of citizens. It is important to note that this is a problem solving process, not a way to aggregate preferences. At the same time, this approach is limited by socio-technical structures, essentially existing provisioning systems, and unless these can be changed, the resulting consumption minima will still be too high, in the example cited, by a factor of three. Overcoming these constraints and changing provisioning systems will ultimately require citizens confronting power.

Finally, on the essential topic of sufficiency, the CLEVER network (2023) compares the share of sufficiency policies in national climate and energy plans to their share in citizens' assemblies reports, with the (planned) national policy share being between zero and 18%, typically 10%, and the assembly recommendation share between 33% and 82%, mostly >50%, suggesting citizens' assemblies are an essential instrument for developing effective climate policies.

11.2.5. Gaps in literature

Numerous gaps are identified in literature on deliberative democracy, mostly related to overcoming obstacles to making deliberation work in practice (Ryfe 2005).

Here I take a much narrower view of what is needed to significantly increase the impact of deliberative democracy and improve governance in the next two climate-critical decades.

As a result, I chose to focus on only two gaps: (1) how to link deliberation to the existing political system, mainly from a Swiss perspective; and (2) how to scale deliberative processes to full participation at the communal, cantonal, or federal level, and integrate with the Swiss tradition of direct democracy, i.e. create a fully inclusive direct deliberative democracy.

11.3. The Academic Citizens' Assembly

To contribute to the rapidly developing theory and practice of deliberative democracy outlined in the previous chapter, and for me personally much more importantly, to enable the timely implementation of the negative emissions and sufficiency projects developed in this thesis, and other key initiatives of the Swiss societal transition. The idea of the Academic Citizens' Assembly (ACA) emerged in multiple discussions at BSL and EPFL in 2020 to prototype a deliberation process for better democratic decision-making.

The name "Academic Citizens' Assembly" has been used from the beginning in 2020, indicating both its origins and principles, not being imitated to academia. As the majority of participants of the last three assemblies come from beyond academia, other names are being discussed, like universal, scalable, inclusive, or similar.

11.3.1. Contribution of the new assembly

Given the strong scientific consensus for climate and biodiversity action summarized by IPCC and IPBES respectively, and the very short time remaining for decisive action, it is easy to get the impression that there is only one meaningful way, which we should implement as soon as possible, and any further discussion is just a waste of time. Why create further delays to democratically discuss when we already know exactly what to do?

In reality very little is “set in stone” and non-negotiable if we want humanity to survive in good conditions, perhaps only two key actions: exit fossil fuels, and stop destroying ecosystems. Within these, much else is open, and likely to develop in locally very different ways. This includes culturally specific synergistic satisfiers, minimally extractive provisioning systems, and governance mechanisms ensuring inclusion, limits to appropriation, and a general focus on wellbeing.

Yet, each year of inaction narrows the possible pathways, and unless we act rapidly, no good options will remain (IPCC 2023, C.1, Figure SPM.6).

This means that in every city or community, there are (still) many possible good solutions, more or less different, all consistent with 1.5°C (perhaps with minimal overshoot) and biodiversity restoration. Which of those solutions is the “good” one? Any solution that has sufficiently broad democratic support and can be implemented rapidly is a good place to start.

As seen in the previous chapter, citizens’ assemblies converge remarkably well in very different conditions, overcoming polarization, complexity of topics, lack of education, ethically challenging situations, or lack of democratic tradition. What they converge on, however, cannot be predicted - this is a good thing in itself, as it limits the possibility of manipulation.

Based on the experience of past assemblies, if well designed and conducted, a **citizens’ assembly is likely to create a shared understanding that can converge on one of the possible solutions compatible with the stated goals, even if this convergence is in no way guaranteed**. And given the legitimacy gained, this solution can be rapidly implemented with significant engagement of citizens. Just as importantly, it will help educate people, build a sense of community, promote civic engagement (Landemore’s third argument for deliberation) - precisely the preconditions for successful implementation.

11.3.2. Goals and process

Building on the trilemma of democracy defined by Fishkin (2009) and introduced in the previous chapter, ACA aims to combine the strengths of existing approaches (**respected**, not respected):

1.	Mass democracy:	**Equality**	**Participation**	Deliberation
2.	Mobilized deliberation:	Equality	**Participation**	**Deliberation**
3.	Microcosmic deliberation:	**Equality**	Participation	**Deliberation**
4.	*ACA (stated goal)*	**Equality**	**Participation**	**Deliberation**

Specifically, ACA is modeled on citizens' assemblies ("microcosmic deliberation" above), consisting of a learning and deliberation phase, followed by voting, which satisfies both equality (through representative stratified sortition), and deliberation (as its main activity). Typical assemblies include several dozen to slightly over one hundred participants, which makes them far from mass participation, and strongly constrains the essential role of educating people, building a sense of community, or promoting civic engagement (Landemore 2020).

How to ensure mass participation?

Process - this is the true innovation of the ACA: combine deliberation in-person, with approximately ten people with a facilitator around a physical table. Learning and deliberation take place in this group, as does proposal writing. Proposals of each group are entered into a voting software, allowing people to vote individually and anonymously on their own group's and others' proposals. As interaction between groups is electronic, the assembly size is not limited. All citizens of a commune, city, canton, province, or country can participate. This ensures mass **participation**, **equality** (through universal participation, instead of representative sortition as common for assemblies), and of course **deliberation**, which remains central to the whole process.

Scaling beyond two hundred participants has not yet been tested. We have conducted four assemblies in 2021, 2022, and 2023 with less than one hundred participants each, another assembly with almost 200 participants in 2023; bigger ones are being discussed for 2024.

11.3.3. Development of the ACA

In November 2020, after further exchange during the First annual Symposium on Societal Transition Pathways, and exploring the idea from four perspectives (Visions of a good future; Energy transitions; Food transitions; Acceptance, Governance, Ethics, Narratives), the project started taking shape. In January 2021, the first team of seven people started working on scenarios, imagining and developing three plausible, but very different futures, which were used in the first assembly in June 2021.

This was the beginning of the **Academic Citizens' Assembly** (ACA), defined as a "*model of a citizens' assembly built on academic principles (evidence-based, lobby-free, no ideology), open to the whole society and, using a novel process and tools, scalable to potentially include millions of participants. This deliberative and participative approach builds on the Swiss tradition of direct* *democracy, and aims to bridge the gap between high-quality deliberation and decision-making of past citizens' assemblies, and the legitimacy of direct democracy*".

From the beginning, the goal of the ACA was to enable "*21st century democratic decision-making for the Swiss societal transition*", and "*Improve citizens' understanding and participation for advanced democratic decision-making, balancing and enhancing both collective and individual freedoms, in particular towards reaching societal goals of universal human wellbeing within the limits of the biosphere, while respecting human rights, building on the Universal Declaration of Human Rights and the 1993 Vienna Declaration*".

11.3. Methodology

The purpose of the project, from the beginning, was to develop a deliberative process or assembly that could directly contribute to the Swiss societal transition. It had to be testable as a prototype and scalable if successful. This section describes the main dimensions that had to be developed and the methods used.

Area of application: This analysis combined promising areas for sustainability action from parts II and III of the thesis missing from policy and public discourse today, especially sufficiency for deep decarbonization, with a literature review from the previous section, to develop assembly questions and contexts to focus on.

Scenarios: As consistent descriptions of possible futures, techno-economic scenarios are regularly used to plan for uncertainty. However they are missing the social or societal dimensions of change, essential for any transition. Here we used the scenario practitioner view, developed by Ulrich Golüke (2018), consisting of seven steps: driving question, interviews, analysis of the interviews, two most uncertain drivers, plotlines, causal stories with titles, and application to the problem being solved. Good scenario stories need to meet five criteria: stringent, challenging, novel, plausible, and divergent. We were fortunate that both Prof. Golüke and Liz Watson, a film and TV story writer, could join our scenario team. The resulting three scenarios were refined, properly laid out, and each presented in a short video by a member of the scenario team. The scenario team (seven people) conducted six internal workshops over two months in early 2021, all by video due to covid-19 restrictions.

Observers' discourse analysis: To properly observe and document the group and discourse dynamics, Jasmine Lorenzini, research fellow at the Institute of Citizenship Studies, University of Geneva, kindly offered to help in drafting an observer sheet, which we developed together over several iterations, testing and refining with each conducted assembly. The final observer sheet is a document on a shared drive, accessible during the assembly, with 18 questions, mostly with dropdown answers for more structured evaluation. A filled sample sheet is shown in Table 11.1.

Table 11.1: Sample observer discourse dynamic analysis sheet

Group 2	**ACA K3, 14.09.2022**	Comment
Number of female participants in each session	5	
Number of male participants in each session	2	
SYMMETRY – Do participants treat each other as equal discussants?	Symmetric (Most speakers treated others as equals)	
RECIPROCITY – To what extent participants refer to others' positions?	Medium (a significant number of speakers did not refer to others' positions)	people bring in new ideas without referring to the ideas of others
OPENNESS – Are participants generally open to deliberation?	Not open to change position according to other's arguments	no position changes observed, rather change subject
JUSTIFICATION – On average, what is the level of justification used?	Most or all participants provide no justification when they intervene	they didn't really intervene
DISAGREEMENT – Is there a conflict or a disagreement between participants?	Yes - one or more clashes of fundamental goals (ex. Net Zero CO2)	
POWER – What is the type of power that prevails? (hard power is based on position, soft power on knowledge and beliefs)	Rather soft power	
ATMOSPHERE – What is your impression about the general emotional atmosphere?	Mixed	
PARTICIPATION – How many participants actively participated in the discussion?	7	
FEMALE_PARTICIPATION – How many active participants are female?	5	
MALE_PARTICIPATION – How many active participants are male?	2	
FACILITATION – Is the facilitator rather active or passive?	Passive facilitation = Facilitator understands his/her role limited to a minimum of tasks	facilitator participates in discussion, but doesn't lead direction. Other participant mentioned time frame
FACILITATOR – To what degree the facilitator shapes the discussion according to his/her beliefs?	Rarely	but other participants did
N_PROPOSALS – How many proposals resulted from this round of discussion?	6	
CONVERGENCE – how many participants converged on the proposal(s)?	All or most of them converged on the proposals	
POLARIZATION – Did the participants polarize around different proposals? Write number of polarized groups observed	3	3 participants were rather dominant on their suggested topics
PROPOSALS - What is/are the proposal/outcome of the discussion?	*Community-based multigenerational housing projects, reduce regular working hours to 30, taxes geared to the common good, car-free Sundays, advocate for sufficiency in international organizations. Education campaign: set the heating 1 degree lower*	

Assembly process: Learning from successful assemblies (Cherry et al. 2021, Willis et al. 2022), the ACA process was designed to include all key elements: participant selection, carefully designed questions, preparation and learning with expert input and opportunity to ask questions, facilitated deliberation, and anonymous voting. The main process innovation is full scalability, by combining physical presence in the learning and facilitated deliberation phases, with electronic voting. There is no a priori size limitation. The sizes we tested range from 20 to 200 participants, which is already very large for citizens' assemblies (the two best known, in France and the UK, had 150 and 108 participants respectively).

Participant selection, representativity, and inclusiveness: Contrary to typical assemblies which ensure representativeness by a process called stratified sortition (Cherry et al. 2021), the ACA uses universal participation to ensure both inclusion and representativeness. For this to work, the process needs to be very scalable, up to the full group size that participates in the assembly.

Proposal writing: The source of proposals, i.e. who writes them, determines the nature and outcomes of any assembly, and is one of the most important choices in the planning phase. Typically this is done by experts before, or participants during the assembly. ACA supports both, but in all five assemblies to date, we only used participant-written proposals. In this case, we integrated proposal writing at the end of the deliberation phase, similar to the French climate assembly, where this happened in groups.

Voting: Voting is individual and anonymous, and happens in all assemblies after the learning and deliberation. Each participant can vote once on each proposal: yes, no, or pass. The software learns patterns and identifies groups of people who vote in a similar way, and identifies different or dissenting opinions. This is important as it allows each participant to vote on only a subset of all proposals, and still obtain a statistically meaningful result. This in turn allows it to scale to large group sizes and many proposals, while each participant typically votes on 30-100 proposals only.

Tools, IT platform: We use the pol.is open source platform developed by The Computational Democracy Project, a nonprofit, by using the server instance provided. For larger future assemblies, it is planned to run the software on our servers. The code is available on GitHub. Beyond pol.is, we developed a dedicated website (academiccitizensassembly.ch) running on the hosting site Squarespace, and multiple Google tools on the EPFL Google account: drive, docs, sheets, forms. Additionally, in longer, all-day assemblies, we use the quadratic voting software QV Geek (qv.geek.sg), to allow all participants to personally validate all decisions of the assembly in an additional final voting round. This avoids potential legitimacy problems if the final decision is obtained using statistical methods.

Data analysis: This setup generates large quantities of data - observers sheets, one per group and session; opening and closing surveys: voting data, one pol.is report per session and the final quadratic voting report; and unstructured data, like team notes, one text document per group. Most of it is analyzed statistically, except team notes, which have been used only to clarify understanding of proposals, to be able to reformulate them between sessions, but no further analysis has been performed.

11.4. Results

11.4.1. Evaluation of 2022-2023 assemblies - key metrics

The detailed reports of the second, third, and fourth ACA, including results, are in Appendix B1, A4, and B2 respectively. The main results are summarized in Table 11.1 below.

Table 11.2: Results of the three assemblies organized in 2022-2023

	ACA 04-2022 EPFL	**ACA 09-2022 Zurich**	**ACA 04-2023 Lausanne**
Topic	Building a societal consensus for 1.5°C	Making sufficiency central to the national climate strategy	How to organize Lausanne 2030 for energy sufficiency?
Participants / Survey(*)	70 / 59	21 / 10	31 / 24
# groups x group size	8 groups of 8-9	3 groups of 7	4 groups of 7-9
% male-female	48-52	43-57	42-58
Quality of organization /10, STDEV (σ)	**7.2**, 1.8	**6.4**, 1.9	**8.0**, 1.3
"Did the voting work well? /10, STDEV (σ)	**7.1**, 2.3	**8.2**, 1.1	**8.1**, 2.6
Were you heard? /10, σ	**8.7**, 1.6	**8.0**, 0.9	**9.2**, 1.3
Treated with respect /10, STDEV (σ)	**9.8**, 0.4	**9.0**, 0.5	**9.6**, 0.8
Quality of discussion /10, STDEV (σ)	(not asked)	**7.6**, 1.2	**8.5**, 1.9
Polarization % of the time	25%	67%	0
Treated each other as equals	80%	100%	100%
Feeling (selected quotes)	well, great, collaborative, relaxed, stimulated, listened to, tired	energized, great experience, excited, interested	energized, engaged, happy, thankful, excited, interested
Total votes	11'971	672	633
Proposals - total	216	29	23
Proposals - accepted	40	12	10
Consensus for acceptance	75%	85%	70%
Number of proposals within 45-55%	1	0	0

(*) survey covers the five questions w. STDEV, other data from voting or observers

The notable outcome of these two assemblies is the level of consensus for accepted proposals (>75% for the first, >85% for the second, >70% for the third assembly). Also, contrary to public initiatives, for only *one* of the total 268 proposals were the YES-NO votes within 5%. This shows the remarkable power of deliberation to help people converge on shared views and opinions, reflecting results from literature.

11.4.2. Voting results of 2022-2023 assemblies

04-2022, Building a societal consensus for 1.5°C, selection of accepted proposals:

Transport+Urban Planning

1. Concept of 15' city: everything reachable within 15' + Encourage sustainable urban planning: services, living & work are concentrated
2. Encourage biking/walking by replacing car lanes with bike/pedestrian spaces and trees + Improve bike culture/skills/behaviors
3. Reallocate climate-harmful transport subsidies towards clean and affordable transportation

Agriculture+Food

4. Adapt food-type consumption to anticipated future conditions: much less meat, select climate-resistant crops
5. Link subsides to good farming practices (biodiversity and carbon footprint) + Carbon tax on imported food
6. Reduce meat consumption in schools by introducing progressively more vegan options, until 100% vegan, bio, regional, seasonal

Education+Engagement

7. Every Swiss resident (CH, permit B, C) participates in a Citizens Assembly organized by municipality (1 day off/year)
8. A quota in mainstream media (some minutes per day, advertising space) to raise awareness on climate change and on solutions
9. Promote culture and arts to change paradigm from consumption society to sustainable one; different media (movie, books, theater)

Buildings

10. Replace housing heating in Switzerland within 5 years

Critical analysis

Strengths: The assembly made transformative proposals concerning the main territorial GHG emission sources: mobility, housing, food. Most of these proposals restrict harmful activities such as cars, fossil fuel heating, or meat consumption. Very importantly, educational and engagement activities were proposed (#7-8-9), with the potential to start changing mindsets; these were also the most creative proposals.

Weaknesses: Consumption and air travel emissions are missing. Proposals are a mix of implementable policy blueprints (#6-7-8) and workable intentions (#3-4-5-6-9), all the way to (too) general principles (#1) or unworkable proposals (#10 - only meaningful with thermal renovation, and this cannot be done for the whole Swiss building stock in 5 years). Also, power and its manifestations are not directly confronted.

09-2022, Making sufficiency central to the national climate strategy, accepted proposals:

Legend: Transport+Urban Planning-Agriculture+Food-Buildings-Degrowth

100%

1. Modular architecture and forms of living - “breathing” apartments, with the aim of reducing m^2 per person

95%

2. CO_2 tax on fuels, make transport more expensive, abolish subsidies on fossil fuels
3. Change the use of car infrastructure for pedestrians and bicycles, give pedestrians and bicycles priority
4. Basic needs: vegan dishes as standard in public canteens at the lowest price
5. Create incentives: reverse commuter allowance for short distances, holidays nearby
6. Create incentives: differentiated taxation for communal living space

90%

7. Support multi-generational housing projects financially and politically, build/modernize energy-efficiently
8. Make parking more expensive
9. Strengthen communities, promote sharing models
10. Cap subsidies for insufficiency (e.g. single-family house) or make conditional (energy efficiency, etc.)

85%

11. Progressive taxation of living space per person above a certain size
12. Reduce working hours to increase self-sufficiency and reduce consumption

Critical analysis

Strengths: Strong proposals, especially in buildings (#1-6-7-9-10-11). Includes a degrowth measure (#12). While this was the shortest assembly organized to date, the expertise of the participants, mostly climate professionals, allowed them to develop and vote for precise and effective proposals.

Weaknesses: Both mobility and food likely to be too limited in scope (#4) or impact (#3-5-8). No measure to reduce the structural need for mobility, so if the fuel tax (#2) is high enough, it will cause serious hardship. Power and its manifestations are not directly confronted.

04-2023, Organizing Lausanne 2030 for energy sufficiency, accepted proposals:

Legend: Education-Buildings-Agriculture+Food-Transport+Urban Planning

>90%

1. Mandatory sustainability courses for all elected officials
2. Replace high fossil energy use heating in old buildings

>85%

3. Make public transport accessible for bikes

>80%

4. More comprehensive sustainability education for everyone, obligatory at all levels
5. Roof greening mandatory for new buildings, incentives for existing buildings
6. Incentivize remote work for companies in the tertiary sector

>70%

7. Product label to make buyers aware of the adverse effects of their actions
8. Pop-up truck shops for fresh food in local neighborhoods
9. Expand public transports in Lausanne to reduce needs of car
10. Tax on energy-inefficient cars to fund public transport

Critical analysis

Strengths: Focus on education for elected officials and the general population (#1-4). Creative proposal to provide local fresh food (#8), with the potential to start changing mindsets.

Weaknesses: Mostly well known, rather timid, and non-specific proposals. Even if implemented, the impact of the proposed measures would be limited. Power and its manifestations are not directly confronted. This ACA was relatively short with a general audience , with participants learning about sufficiency at the beginning of the assembly. For most people, it was difficult to apply this knowledge in the short time available.

11.5. Main contributions and limitations

The analysis on deliberative democracy and the Academic Citizens' Assembly make several important **contributions** to the theory and practice of governance.

First, it identifies gaps preventing deliberative assemblies from better contributing to solving urgent challenges of societal transitions.

Second, it proposes a novel concept, process, and tools for a universally inclusive, fully scalable assembly, deriving its legitimacy and representativeness from full participation, instead of the usual stratified sortition. To the best of my knowledge, this has bever been proposed or tried.

Third, it defines the main dimensions to be developed for a successful assembly, and proposes a method for each.

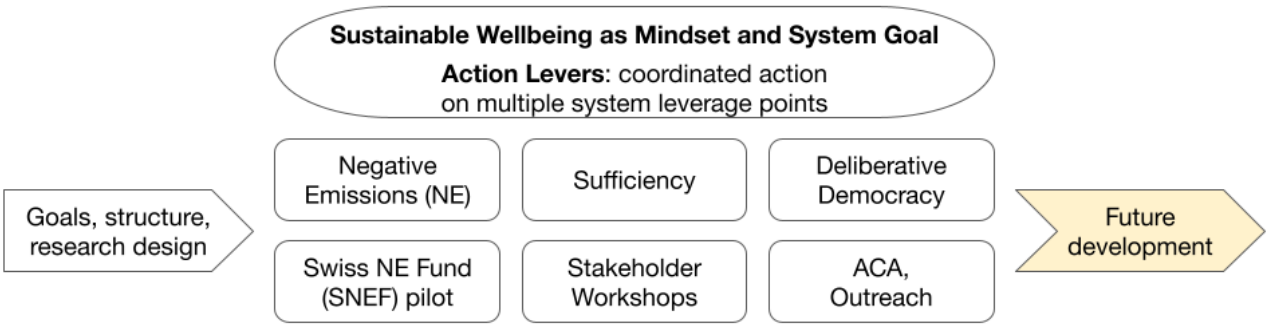
Fourth, on this basis it builds a prototype of a new assembly, the Academic Citizens' Assembly, tests it on five different occasions over almost three years, each time improving on the process, tools, preparation materials, and assembly questions. The process is now sufficiently well defined that a new assembly can be ready in only several half-days of work, a significant improvement over the six months needed to prepare the first edition. This is a significant step towards operationalizing a new model of deliberative democracy.

Five assemblies were conducted to date, further assemblies for 2024 are being discussed:
- June 2021: online, on the first 5 years of a societal transition in food and energy
- April 2022: at EPFL, on building a societal consensus for 1.5°C
- September 2022: at the Tony Areal in Zurich, on making sufficiency central to the national climate strategy
- April 2023, with MyBluePlanet, at Impact Hub Lausanne, on sufficiency at the local level
- June 2023, with the Swiss Academy of Medical Sciences, in Bern, on implementing a roadmap towards sustainable health services for Switzerland

The approach also has a number on **limitations**: **(a)** no method has been developed to ensure or at least make highly probable that the assembly will converge on workable and specific proposals; **(b)** it is unclear how to effectively build a multi-session assembly, where each session builds on the structured and refined output of the previous session (automatically, to scale to large assemblies); **(c)** how to translate the full richness of deliberation in the voting process; **(d)** how to integrate in the political process in the decision-making mode (Ryfe 2005), beyond the obvious solution of organizing a deliberation before a scheduled popular initiative or referendum; and **(e)** it is unclear how to design a process that produces sufficiently ambitious proposals, given the climate and biodiversity urgency.

Of course, a practical challenge remains finding pioneering organizations ready to trust and support a new process.

Part V: Conclusions and future development



12. Summary and main contributions

This research project has been motivated by the growing gap between the scientific knowledge and its ever deeper understanding of the nature, interconnectedness, development, and effects of the sustainability crisis – and the “too little, too late” societal response.

If Switzerland, one of the richest, well governed, democratic, best educated, and probably at least superficially sustainability-aware countries cannot agree upon and implement a half-decent action plan for climate and biodiversity, what hope do we have for the world?

After completing this thesis and planning for the next steps (chapter 13), I feel hopeful. The main hypothesis has been validated, and the research questions formulated in section 2.1 have all been positively answered.

In summary: taking a different path is feasible, affordable, relatively rapid, and would immediately start solving the many interconnected facets of our societal wicked problem – in the process creating multiple co-benefits for ecosystems and human society. All this could start within the existing system with its dominant market-liberal mindset, highly polarized and unequal society, and structural lock-in of excessive and fossil-powered mobility, floor space, and consumption.

12.1. Key findings

Starting this thesis, I asked: how could systems thinking help identify areas where coordinated action is likely to start a transition, reconfiguring essential aspects of society for decades?

Let’s examine the research questions.

Research question 1: Do limited negative emissions have the potential to significantly accelerate a country’s transition to net zero? What is needed to make the transition ecologically and socially beneficial and fair? Can the governance and financial model be adapted to extra-territorial sectors like global aviation?

Answer: **Yes, but only with fast and deep decarbonization, polluter funding, decentralized decision-making and implementation using nature-based solutions, and excellent monitoring and governance**. Negative emissions are very hard to implement in a credible and reliable way, without adverse effects for ecosystems and society. The quantity and type are strongly constrained by the need to preserve and enhance biodiversity, and not impair food production. Significant resources (land, manpower, monitoring and governance, and funding) and time are required. For all technological components, there are major feasibility and path-dependency risks, leading to potentially massive value appropriation by corporations, worsening inequality. In a world of constrained energy supply, many technologies are impossible at scale. Only under the conditions stated above can all the constraints be respected, and the risks minimized. Extra-territorial sectors like aviation need suitable governance mechanisms, such as the proposed NEFA. The transition to net zero can be entirely polluter-funded, with a likely CO_2 price of $230, relatively stable over a wide range of possible input conditions. Generalized adoption of sufficiency is a precondition for the required decarbonization. See Part I for details.

Research question 2: Can sufficiency deliver high wellbeing for all with low resource use in Switzerland? Under which conditions?

Answer: **Yes, but only if used as an organizing principle of society, allocating resources based on needs rather than desires or preferences, shifting to low-resource synergistic satisfiers, and rethinking provisioning**. More work is needed and planned (project SWICE, chapter 13), but initial stakeholder workshops and estimates show significant potential to simultaneously reduce resource use and improve quality of life. Rethinking the Swiss habitat including buildings, local services, and induced mobility looks very promising, as do the foundational economy and social license approach. Sufficiency is a key component of climate and biodiversity action, and can reduce resource use much faster than efficiency or substitution. Deliberative democracy is key for acceptance and successful governance. See Part II for details.

Research question 3: Can deliberative and participatory democracy provide the needed governance? How?

Answer: **Yes, based on three successful assemblies, deliberative democracy can find common ground and high acceptance on polarized value-driven issues; this is consistent with the work of leading thinkers such as Habermas, Fishkin, or Landemore**. Deliberative democracy is possibly the most promising and legitimate solution to problems of modernity, with the open challenge of combining equality, participation, and deliberation. The Academic Citizens' Assembly is one promising model, with further testing planned. See Part III for details.

This validates the research hypothesis: **Negative emissions, sufficiency, and deliberative democracy are suitable "action levers", or areas in which coordinated action on multiple leverage points could produce a positive and lasting change to our society, and the three action levers reinforce each other**.

12.2. Main contributions

This thesis makes several significant contributions to the theory and practice of transitions towards sustainable wellbeing.

Swiss Negative Emissions Fund: a credible and simple Swiss pathway to net zero, a decade faster than the official climate strategy of the Federal Council, much less risky and less expensive, entirely funded by polluters, using nature-based solutions for negative emissions, with significant biodiversity and societal co-benefits. This is possibly the most ambitious and least risky Swiss net zero plan we are aware of.

Negative Emissions Fund for Airlines: this is the only comprehensive proposal we have identified that reaches climate neutrality for this notoriously hard-to-decarbonize sector. Our proposal considers the contribution of non-CO_2 climate effects, includes expected efficiency improvements, examines the ethics of a sector mainly serving the richest 1% of the world population, is entirely polluter-funded, creates significant biodiversity and societal co-benefits, potentially transfers more money to countries affected by climate change than today's global climate finance, and reaches net zero GHG by 2042 for global aviation.

Sufficiency frameworks are developed using theoretical analysis, extending the definition of sufficiency based on satisfier orders, and validated in stakeholder workshops. This work is used to ensure consistency of the wellbeing approach of the SWICE consortium.

The **Academic Citizens' Assembly** brings innovation to deliberative mini-publics, and is the first and only model of democracy, as far as we know, to combine Fishkin's three values of democracy: equality, participation, and deliberation. This makes deliberation potentially scalable to large numbers of participants. To date, the assembly has been prototyped and conducted five times on a small to medium scale. Larger assemblies, with possibly thousands of participants, are in discussion for 2024.

Pilot Negative Emissions Fund: this voluntary, 1%-scale version of SNEF is designed to test and pave the way for the required law change for the full-scale SNEF to become reality. Currently in discussion with potential partners.

12.3. Limitations

As may be expected for a thesis analyzing and trying to connect several broad and very different topics, there is potentially a long list of limitations.

To make the limitations section meaningful and useful for future research, Ross and Zaidi (2019) propose a three-step process to (a) describe the limitations, including study design, data collection and analysis, and results; (b) explain the implications for each limitation; and (c) suggest alternative approaches. Lingard and Watling (2021) identify three commonly used approaches to the limitation section (confession, dismissal, and reflection), and propose an analysis based on three reflective questions on limitations of the research: (a) design, (b) process, and (c) people.

On this basis and additionally taking into account suggestions of the thesis jury, this section will identify the main limitations likely to affect the quality of the results or the ability to answer research questions, explain this impact, and suggest how future work may overcome some of these limitations. This is a "pig picture" view summarizing and building on limitations described in the main chapters of this work, especially §3.5, §8.5, §11.5, where more detail is provided.

12.3.1. Identification and description of limitations

Most limitations relate to **research design**.

The reviewed literature, while broad, is concentrated in several areas, such as high-level, IPCC-style climate and negative emissions analysis, ecological economics, sufficiency, decent living standards, human needs, and deliberative democracy. Literature on ecosystem impacts of large-scale nature-based solutions; NE technology development; effectiveness, acceptance, and societal impacts of policy interventions; and the broad field of democracy and governance have only been included to a very limited extent.

The systems approach is mainly focused on a conceptual analysis of leverage points and the iceberg model, including limited system structure and feedback loop elements; causal loop diagrams or a system dynamics model were not developed. As a result, the systems analysis is qualitative and the strengths of the described effects have not been estimated.

The public policy analysis is limited to NE funding, aviation governance, and sufficiency measures; regulation to restrict fossil fuels, change diets and agriculture, territorial planning, adapt financial systems, or support people negatively affected by rapid societal change, are all not covered.

Wellbeing is studied from a human needs, eudaimonic perspective; other approaches such as hedonic or preference satisfaction are briefly discussed but not used in the analysis.

The territorial sufficiency estimates in chapter 10 have not been directly modeled; rather the results of a model for a different territory were adapted.

Perhaps most importantly, social acceptance of the proposed transitions has not been broadly reviewed from literature, nor developed theoretically, estimated or modeled, and only included to a limited degree in stakeholder discussions and workshops.

In terms of limitations of **research process and people**, stakeholder workshops and the first citizens' assemblies were all conducted with samples of participants not representative of the Swiss population: while age, gender, professions, interests, and Swiss language regions were all reasonably balanced, our samples were urban and better educated than the general population.

12.3.2. Impact of and overcoming limitations

These limitations have impacted the work in the thesis in several ways.

Validity of results: Separating the negative emissions, deep decarbonization, and sufficiency measures from the social dynamics makes the analysis possible, but could miss important links. Will companies mostly decarbonize when forced by regulation, and accept NE payments as cost of business? This would place importance on regulation like restricting fossil fuels, little explored in the thesis. Or will the community-based NE projects start changing mindsets quickly enough to accelerate decarbonization action in companies and communes? Serious fossil fuel restrictions would fundamentally change most companies and people's lives; if well supported, acceptance could increase, but much could go wrong. What are the good speed, support, sequence of action? In other words, in such large-scale transitions, everything influences everything else, so which effects will be dominant? In systems language this would reflect the relative gains of positive and negative feedback loops, corresponding to leverage points 7 and 8. The thesis results will be valid within a certain range of these feedback loop gains, where deliberative democracy is strong enough to destabilize incumbent power and generalize sufficiency as organizing principle of society, making NE feasible. While the logic is sound, is such a combination realistic? There is no way to be certain about social dynamics, but system dynamics modeling could help.

Reliability of results: The simulations related to the NE funds (SNEF and NEFA) are relatively simple, well documented, and should be easy to reproduce. On the other hand, sufficiency and deliberative democracy have been partly analyzed based on small stakeholder groups with limited representativity, using a process, the ACA, which has evolved over time. Both the limited representativity and the changing process will limit reproducibility. However, in the context of this thesis, the limited reproducibility of the initial results is not necessarily a problem. For the SWICE project, the initial stakeholder workshops analyzed in the thesis are an input to designing future urban scenarios for high wellbeing with low energy use; both the resulting scenarios and the transition pathways will be tested with stakeholders in a more robust way. For deliberative democracy, a workable process and tools defining the Academic Citizens' Assembly is itself the output, not the results of individual assemblies.

Generalizability of conclusions: The non-representative composition of stakeholder workshops (i.e. population validity) is discussed in the previous paragraph. The ability of citizens' assemblies to converge towards consensus has been well documented in literature (overview in section §11.2), and as the ACA follows the same design, this is likely to hold beyond our limited sample of five assemblies conducted. On the other hand, there could be an issue of combining a large-scale assembly with decision-making, in a polarized, hostile environment (ecological validity). This is hard to extrapolate from published results and should be experimentally tested, as we plan to do. Finally, for NE, can the Swiss and global aviation case studies be applied to all of the world's emissions? Conceptually yes, as all emissions are either territorial or extra-territorial. For the first group, countries, each country can, and based on our and other work, probably should set separate targets and governance for NE and decarbonization, although specifics might be very different from Switzerland. For extraterritorial sectors, most emissions are in global aviation and global shipping, both following a very similar logic, although shipping offers many more technological solutions to decarbonize compared to aviation.

Impact of the work: The lack of integration of proposed NE public policies with other domains made it often difficult to communicate beyond a specialist audience, as current climate plans and legislation follow a different logic. For sufficiency and wellbeing, the focus on universal and satiable human needs, separate from satisfiers, which represents a normative logic both very different from today's society and not well known, has often been a challenge, even in an academic context with engineers, architects, or scientists from different disciplines. This made it essential to develop better ways to engage other researchers, and is still an ongoing process.

Overcoming limitations: Building on this analysis, the next chapter proposes future research, practice, and engaging society work to overcome the main limitations.

13. Future development of the work presented in the thesis

The goal of this thesis was to develop "Action Levers towards Sustainable Wellbeing: Re-Thinking Negative Emissions, Sufficiency, Deliberative Democracy". The three levers were explored, developed, and validated as promising avenues towards a better society.

This is of course insufficient, as sustainable wellbeing for all is not at all reality today.

Any meaningful future work, building on this thesis, should make this desired reality a step closer.

This chapter explores what this could mean for research, practice, and engaging society.

13.1. Research

On **negative emissions**, the next step is linking our somewhat "stand-alone" research (as it proposes replacing most policy instruments with SNEF or NEFA) with the existing and developing body of research on climate policy. Also, our policy suggestions beyond the fund, especially how to restrict and phase out fossil fuels, as well as the required social cushioning measures to help people adapt to a very different society in a relatively short time and "leave no-one behind" could and should be developed. These are essential for any sufficiently ambitious climate policy scenario, beyond our SNEF proposal.

In January 2023, we submitted a project to the EPFL call "Solutions4Sustainability" to monitor negative emissions in wetlands, as a solid scientific basis for the future fund. Our project "Monitoring the impact of nature-based solutions on carbon sequestration in wetland soils" was sadly not funded as judged not entirely aligned with the call, but the project is scientifically sound and will be re-submitted for future funding opportunities.

Sufficiency is the area where most research is needed. Fortunately, the SWICE consortium, led by EPFL, provides a collaboration platform and four more years of funding for my research. This is the focus of work package 2 (WP2), on which I will stay as a postdoctoral researcher. WP2 will develop better provisioning models for the Swiss habitat, adapt Decent Living Standards for Switzerland, use indoor light and air quality as a case study to question and improve building standards, analyze the supply-side changes needed, and propose a 20-year transition plan.

As the recently appointed co-lead of the Wellbeing Working Group of the IIASA EDITS (Energy Demand changes Induced by Technological and Social innovations) project, I aim to compare insights from Switzerland and the SWICE project with the experience and best practices of the EDITS network, including 160 researchers in 25 countries, all working on related topics.

In collaboration with E4S and the SMT master, several ongoing and planned student projects will examine sufficiency from the perspective of communes, regional mobility plans, energy utility companies, or the organization of scientific conferences, today the number one issue in the climate footprint of academia.

Finally, for **deliberative democracy**, it would be interesting to model the deployment of new forms of democracy from local to the country scale and beyond. Even more interesting would be to model the results of possible deliberation processes using artificial intelligence (AI), and to identify suitable topics and assembly questions, assuming a safe research process can be designed. As in many other AI-related developments, there is a significant risk for manipulation.

13.2. Practice

All elements of practice already started in this thesis have a significant development potential.

Discussions on the **Pilot Negative Emissions Fund** are ongoing with several highly visible Swiss organizations, and there is a good possibility a first agreement could be reached this year. There are specific opportunities to start restoring degraded wetlands in several Swiss cantons, as soon as the pilot fund starts operation.

For **international aviation**, it would be important to test elements of the funding and governance scheme we proposed, and compare it to other serious proposals. No testing plan is developed yet, nor are potential partners engaged, but this is essential if we want to make progress in this hard-to-decarbonize sector.

The SWICE consortium includes nine **living labs**, which could be suitable testbeds to evaluate and improve the sufficiency insights of our work. This is actively pursued within SWICE.

To implement **deliberative democracy**, several communes have expressed interest in running a full-scale assembly involving all their residents with voting rights. A similar approach is being discussed for organizations such as universities or companies.

Teaching sustainability could benefit from including action levers. Today's common teaching focus on analyzing problems such as the climate crisis and loss of biodiversity, while quickly summarizing possible solutions in very general terms, and completely avoiding questions of transition – tends to leave students rather frustrated or even depressed, instead of empowered. Questioning students' mental models is all good if some hope and perspective can be offered, and action levers towards sustainable wellbeing are a good candidate: not difficult to understand, can be adapted to any learning level, and are suitable for teamwork.

13.3. Engaging society

This is one of the most important levers, different from the practice examples outlined above, as it involves a dialogue but uses existing governance in society.

The following project was prepared in Q1, 2023, and if funding is approved, the actual workshops will take place in Q4, 2023 and Q1, 2024. It is included under "engaging society" as it corresponds better to a societal engagement than a traditional scientific research project.

Climact Starting Grant: Towards new renewable energy developments in Switzerland that preserve biodiversity: since the beginning of the Ukraine invasion, there is a heightened awareness of the Swiss dependency on imports of electricity and fossil energy, reinforced by much higher electricity prices in winter 2022-23. This price increase is almost entirely independent of the war and is mainly caused by the failure of liberalizing the electricity market, but this is poorly understood. Nevertheless, the momentum to develop renewable electricity generation capacity has sharply increased, especially for Alpine PV, leading to political pressure to weaken biodiversity protection. In the resulting political debate, little consideration is given to the most biodiverse and intact areas, nor the danger of increasing pressure on fragile or already weakened ecosystems. To avoid resistance to new project development, some politicians are trying to oppose biodiversity protection and climate action and their respective scientific communities.

In this context, our project aims to bring together the Swiss climate and biodiversity communities in a series of workshops, and political outreach events, summarizing the existing relevant knowledge, and producing a white paper outlining recommendations. Importantly, conditions will be identified under which renewable energy capacity can be developed, while simultaneously reducing pressure on fragile ecosystems, by removing some of today's pressure.

The project idea was born in a series of discussions during regular Climact calls, which I then refined in collaboration with Antoine Guisan. On this basis, I coordinated the proposal writing and outreach to possible co-applicants, and submitted for Climact starting grant financing in early March. If approved, the project will start in June, for a total of 10 months, details in Appendix F.

We could learn a lot from this project.

A similar approach might be suitable for other action levers, especially properly integrating negative emissions into Swiss climate policy, and developing society-wide guidelines for sufficiency, based on broad sectors, perhaps starting with the Swiss habitat, building on SWICE.

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Appendix

A - Stakeholder workshops on sufficiency

A1 - Stakeholder workshops on sufficiency

A2 - Workshops in Lausanne, June 2022

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E1 - Planetary Boundaries - summary and implications for policymakers

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A1 - Stakeholder workshops on sufficiency - introduction

This section provides a summary of the context and the main findings, based on the first six months of workshops organized to date.

Chapters 8-9 defined sufficiency and its link to satisfiers, provisioning, and wellbeing. Chapter 10 applied these principles to the Canton of Vaud, both as a high-level energy estimate, and in more detail by sector, identifying the specific assumptions compatible with ambitious climate action strongly based on sufficiency.

Most assumptions describe a radically different society in less than 20 years, with significant changes already in place by 2030, such as a new construction moratorium and reduction in car-km by half, in addition to energy efficiency and clean energy development.

Clearly, based on their voting record on much more modest proposals, Swiss politicians are not ready to pass such legislation anytime soon, at the cantonal or federal level. So is there a chance at all for the country to move towards sufficiency?

Pressure to change could come from the civil society, if a non-negligible minority of the population is aware and sees potential in the topic. Given its complexity, potential for misunderstanding, and different logic from today's dominant organization of society, sufficiency is not a suitable topic for a popular initiative and would be unlikely to pass, assuming the usual disinformation campaign which is likely to materialize in response. However, deliberative democracy has the potential to develop needed understanding and lead to a high level of convergence, and as a result, workable proposals (chapter 11). But before reflecting on such a deliberative process, what would be its starting point? In other words, it would be useful to know **what are the attitudes, knowledge, thoughts and emotions of the Swiss population about sufficiency?**

We conducted three workshops between June and October in Lausanne and Zurich on this topic, asking six distinct questions. The complete results, around 15 pages, are reproduced in Appendix A2-A3-A4, including original group worksheets.

Methodology - all three stakeholder workshops broadly followed the same method in four steps: (1) A brief introduction to sufficiency, including what sufficiency is not and how it is different from efficiency, including a Q&A and short discussion; (2) Group deliberation in groups of around 7-10 people, with a facilitator and a note-taker; (3) A brief discussion and sharing of first impressions, with clarification questions and reactions; and (4) A written report based on group notes and final discussion, sent to all participants usually within a week, with feedback received incorporated in the final workshop report. Appendix A2-A3-A4 describes the specific structure, timing, place, and number / profile of participants for each workshop, anonymized but otherwise unedited group notes, and the final workshop report for each of the three workshops.

First results

When people think and speak about sufficiency, we found a number of patterns:

1. **Thoughts**: People tend to think about certain aspects in a certain order:
    a. Goals, priorities, time
    b. Inequality, inclusion, fairness
    c. Limits, restrictions, sharing
    d. How to understand sufficiency? (this comes late, people first respond intuitively and later reflect more deeply)
2. **Emotions:** Mix of positive and negative aspects, following the aspects above:
    a. Happy / enthusiastic: more time, empathy, connecting to nature and people, common good, hope, excitement, alignment with values
    b. Fear: unknown, lacking, authoritarianism, more inequality
    c. Mixed: both fear and freedom of living with less
3. **Words**: Two broad categories are covered:
    a. Descriptive: sustainable lifestyles, soft mobility, plant-based diets, library of things, food sharing, cooperatives, open source, non-profit
    b. Perspective and goals: collective goals and wellbeing, solidarity, degrowth, time / freedom / health as the real purpose of life
4. **Spaces**: Clearly three types of spaces emerge:
    a. Private: minimized, flexible, multigenerational, integrated into shared spaces
    b. Shared practices and spaces: kitchen, dining and living room, guest rooms, offices
    c. Public: local foundational services, meeting spaces, local food production, repair cafés / services, green spaces, public transport, 15-min city
5. **Economic system, public policy, governance**: dozens of proposals, broadly:
    a. Transition from “economy of desires” to “economy of needs”, wellbeing for all
    b. Degrowth, advertising ban, reduce working time, no planned obsolescence
    c. Sharing and exchange economy
    d. Repurpose car infrastructure for bicycles and public transport, adapt taxes
    e. Make buildings flexible, reduce average living space, adapt taxes to support this
    f. Make vegan food the standard in production and consumption, adapt taxes
    g. Local / neighborhood democratic governance of spaces and services
6. **Identity and freedom**:
    a. Reconnect with nature, with people, with spaces, as a new basis for identity
    b. Intergenerational transmission of knowledge and identity
    c. Rethink the balance of individual and collective freedoms

A2 - Workshops in Lausanne, June 2022

1. Context and goals

The built environment in its broadest sense - “habitat” - including building construction, renovation and maintenance, together with all energy services, associated mobility, local services, governance, and associated manufacturing - is responsible for well over half of all energy and material resources used in Switzerland, and other rich countries.

The project SWICE (Sustainable Wellbeing for the Individual and the Collectivity in the Energy transition), launched in May 2022 and conducted by a consortium led by EPFL, aims to reduce Switzerland’s energy use by adapting buildings and urban environments, facilitating low energy lifestyles, and ultimately improve wellbeing with a much lower resource footprint. The “work package 2” (WP2) of which this workshop was part focuses on alternative provisioning systems and frameworks, as well as demand- and supply-side analysis, transition roadmaps and public policy instruments. Working closely with stakeholders is a key part of the project, when possible using living labs.

This first Action Lab focused on the basics, such as how people understand sufficiency, how they feel about it, how they discuss (or don’t) this topic, and who should be at the table for future rounds. It was named “Sufficiency in the Swiss Habitat”, and participants were informed that “*we will look into one of the most promising (and ignored) ways to reach high wellbeing with a low resource consumption, essential to stop the climate and biodiversity crisis. After a short overview of the latest science, we’ll explore language, associations, emotions, examples, obstacles, and stakeholders to engage on the way to a sufficient Swiss habitat - producing a first action plan of this journey*”.

2. Structure, process, participants

The action lab took place on Monday 13.06.2022, 15:00-17:00 at the SwissTech Convention Center, in a well-equipped windowless room with 6 tables and 48 chairs. It was organized within the context of “Showcase 2030”, a large two-day free event covering “Scaling solutions for a net positive planet” with hundreds of participants. Being part of the larger event had both good sides (excellent organization, top-quality venue, many potentially interested participants), and less good aspects (79 registered participants, of which only 21 joined, an audience rather broad but not representative of society).

The two-hour action lab started with the IPCC perspective of sufficiency in buildings, presented by Yamina Saheb, the IPCC AR3 WG3 author leading IPCC’s sufficiency work, which was included in IPCC’s recommendations for the first time. Yamina’s presentation was the only part via Zoom, everything else took place in person.

The first estimates of energy use in the Swiss habitat were shared by Sascha Nick, his analysis based on a master project by Amaia Soubelet, in turn built on the Decent Living Standards framework. As an illustration for our work, Sascha also presented some elements of possible public policies.

After the initial presentations lasting together about 20 minutes, 3 successive workshops took place, each about 30 min:

- W1: Sufficiency and habitat: language, thoughts, emotions
- W2: Sufficiency and its absence in public discourse and public policy
- W3: Stakeholders, action, and the way forward

We had a total of 21 participants, mostly from academia (researchers, master and doctoral students, many disciplines), architects, and several representatives of public administration, but no elected politicians, companies, housing cooperatives, investors, citizens organizations or NGOs.

3. Results

Workshop 1: Sufficiency and habitat: language, thoughts, emotions

- **How people talk about sufficiency**
    - **Words used to describe sufficiency**
        - sustainable lifestyle, degrowth, mobilité douce, plant-based diets, library of things, food sharing, cooperative, open source, non-profit, less profit
        - Policies, co-benefits
        - Quotas / rationing of resources, sharing
        - Unavoidable, the point of non-return has passed, anticipate chaos, accompany change
        - Deconstruct status and habits
    - **Collective and individual perspective**
        - From individual to collective wellbeing
        - From individual freedom to group solidarity
        - Collectivism, communism, socialism, open flow of ideas, removing restrictions based on IP rights, direct democracy
        - “Kibbutz” ideals -- collective well-being, holistic view of life, life-balance, less competition, universal basic income -- a floor that lets people relax
    - **Rethink goals**
        - Re-establish time/freedom/health as the real purpose of life and community
        - Behavioral changes, think about life in a different way, move away from a materialistic society, rethink businesses, profits, etc.

- **How people think about sufficiency**
    - **Goals, priorities, time**
        - Rethink priorities
        - Reconnect with yourself, family, humans, nature

        - More time for living, culture, sport, associative work, …
        - Less time working / 4-day working week?
        - No monetary goals
        - Less individualism, more collective way of living and thinking
        - Cooperation becomes the dominant organizing principle, replacing competition; people build on each other's ideas
    - **Inequality vs. inclusion, fairness**
        - Need to support people in the transition
        - Unequal responsibilities: if so, on what basis?
        - Quotas, sharing, resource allocation: if unequal, on what basis? By market (example carbon tax) or non-market governance (examples: completely equal, democratic allocation, allocation by algorithm)?
        - Which services should be human rights, which can be market commodities?
        - Need some freedom and flexibility in allocation (examples: "less personal space is stressful for introverts", "younger people may need a larger clothes ration")
        - Give people individual responsibility; yet how to ensure the transition still happens?
        - How to ensure the rich and powerful do not get around the rules, and undermine the whole transition?
    - **Limits, restrictions, sharing**
        - Very attractive, restriction does not mean reduction in wellbeing
        - Quantity vs Quality - Positive narrative associated to a limiting environment
        - What happens to status / social class if no longer materially based?
        - How to build a shared understanding on collective wellbeing?
        - How to overcome social inertia and gain acceptability?
        - Can (or should) capitalism survive?
        - Attention not to get into authoritarianism
    - **How to understand sufficiency?**
        - Who defines sufficiency?
        - PB, UBI, doughnut economics, needs, satisfiers, … also political economy?
        - How to create universal awareness at every level: individual, family, organization, commune?
        - How to help less educated people catch up quickly on essentials?

- **Emotions provoked**
    - **Fear**: lacking, authoritarianism, unequal distribution between social classes, losing comfort; fear vs. freedom of living with less
    - **Happy / enthusiastic**: having more time, empathy, connecting to nature, returning to collectivity and social activities, common good, hope, excitement, fulfillment and alignment with your values and planetary boundaries, acting and being connected with reality (people, nature…)

    - Urgency, apprehension, longing
    - Doubtful, unsecure, suspicious, ecstatic, frustrated, disappointed
    - Additional emotions:
        - Suffocation if enforced, despair of it working if it's not enforced
        - Loss of freedom - but great to enforce for companies
        - Insecurity: is my work valued less? Retirement accounts shrink, pay goes down
        - Frustration and powerlessness, as we are aware that we can do something individually, but we are also victims of a system serving and manipulated by the powerful, who do not want to change

Workshop 2: Sufficiency and its absence in public discourse and public policy

- **Positive examples of sufficiency**
    - Buildings and neighborhoods
        - Neighborhoods where most destinations are within walking distance
        - Build less / revise land-use and zoning rules to promote sufficiency in habitats
        - Impose construction and operating energy in building standards
        - Subsidies to renovate buildings, solar panel, e-bike, to encourage individuals
        - Occupancy rules in cooperatives to redistribute space
        - Energy communities, citizen energy
        - "2000 Watt society" principles adopted by cities
    - Mobility, nutrition, packaging, sharing
        - CO_2 tax to reduce individual cars and promote public transport, car sharing (mobility.ch), improve public transport (new network + adapted corridors)
        - A meat-free day in institutional catering
        - Enforce reusable containers, ban single use plastic bags, enforce a % of recycled material in new feedstock (plastic in packaging, recycled fiber in paper, etc…)
        - Government/communes encourage sharing initiative (LoT)

- **Obstacles to systematically including sufficiency**
    - Fear of change, difficulties of changing habits at all levels, slow social acceptance, cultural pressure to accumulate wealth and status
    - Politicians' fear of public opinion, short-term focus, lobbying, lack of interest from politician party, too strong connections with industry
    - Is sufficiency anti-progress? Lack of positive narrative around sufficiency
    - Who are our heroes / people admired by society? How do they live?
    - Politico-administrative system designed for stability, very slow
    - Growth and profit-based economic system and power structures, the opposite of sufficiency; dominance of neoclassical economic thinking

- Ethical validity to impose sufficiency restrictions (people felt stuck in narrow spaces during Covid)
- Are shelter, health care, etc. a human right or a market-based commodity? Cannot be both

- **Ideas to overcome obstacles**
    - Citizens' assemblies (random draw, or not?)
    - Change economic system, move away from profit and accumulation of capital, reduce inequality
    - Economic instruments (like CO_2 tax) that would legitimize sufficiency
    - Awareness campaigns, debunk fake ideas, workshops, imagine new futures, share success stories, create inspiration
    - Show people impact of climate change to put in perspective their "loss of freedom"
    - Ban: lobbying, advertising (all or only "bad" products),

Workshop 3: Stakeholders, action, and the way forward

- **Would you like to be involved in this process, and how?**
    - Almost all: YES! … for future workshops, surveys, etc.

- **Who else should be involved? Can you please provide an introduction?**
    - Scientific experts from different disciplines incl behavioral scientists & anthropologists, schools, universities, transdisciplinary approach
    - Elected politicians and policymakers, people working at the city, canton and federal level
    - Architects & designers, builders, building owners / investors, companies linked to construction and renovation (cement, wood)
    - People who work on sufficiency in other countries
    - Sustainability and climate activists, NGOs, associations
    - Press and media
    - Families… everyone from different social background, different jobs, people who care and people who don't care
    - Cooperatives, libraries: Le Vorace, La Mule; la Manivelle, Maison de la Durabilité

- **How could we work together?**
    - Citizens' assembly
    - Work together on collective intelligence, share knowledge, involve a very broad public, create bridges between different people
    - Series of workshops. Should be a continuous process over a period time to allow going to the bottom of things, leading to concrete and actionable recommendations.
    - Press: create more content and awareness on the topic of sufficiency and whether the local government is doing enough to support it.

- Scientific experts from different disciplines to derive solutions from the workshops and present them to the general public/policy makers
- International collaboration, apply similar methods in different countries, especially policies that already work elsewhere
- Make it easy to take action, provide tangible changes for people who do want to make changes

- **Proposed next steps**
  - Ask people their dream scenarios on the topic (what do they want the most in the world) and then question why they have these aspirations and whether we can disconnect it from consumption
  - Other participants' opinion on proposed next steps/ideas to solve the problem (for e.g. would you be happy to have a communal area in exchange for a smaller apartment? etc.)
  - Do multiple workshops with all stakeholders mentioned above, include surveys
  - Benchmark sufficiency measures beyond Switzerland
  - Canton could give people one day off if they attend a workshop on sufficiency -- focused on actionable steps
  - Citizens' assembly
  - Talk to the team of collectif 43m2
  - Create bridges between people who think in systems
  - Workshops on non-violent communication

4. Discussion and next steps

This first small-scale action lab, in majority composed of academic participants, nevertheless provided a broad range of highly interesting insights, summarized in the "Results" section, and can provide a good starting point for subsequent work.

In preparation for future stakeholder workshops and actions labs, we propose to focus on the following:

1. Representativity of participants, how to broaden next time, whom to include and how
2. Define a clear expectation of the expected output (each workshop / actions lab should have a clear and distinct focus) and what would count as success
3. Provide a more structured setting for discussion, perhaps following the framework developed to summarize "**How people think about sufficiency**" in the previous section:
   a. Goals, priorities, time
   b. Inequality vs. inclusion, fairness
   c. Limits, restrictions, sharing
   d. How to understand sufficiency?
4. In preparation for future labs, two documents could be prepared, to read before meeting:

   a. A summary of main facts, sources, models and frameworks of sufficiency
   b. Suggestions of possible ways to structure the outputs, being careful not to impose any particular model, just help participants more effectively structure their results
5. Finally, a clearer process what happens after the workshop / actions lab

The results will remain online and accessible; the short link go.epfl.ch/sufficiency should remain operational.

A3 - Workshops in Lausanne, October 2022

Samedi 01.10.2022, EPFL-LEURE et PUHI ont co-organisé un atelier participatif autour de la sobriété avec les associations vaudoises engagées pour un habitat suisse plus durable, couvrant les thèmes de l'urbanisme inclusif, espaces publics, protection des écosystèmes - notamment les membres du Collectif de la Valleyre et de l'Association MontAvenir au Mont-sur-Lausanne, de l'Association pour la Sauvegarde des Grands-Prés, de l'Association Pour un Urbanisme Harmonieux et Imaginatif (PUHI) à Pully, Les Robin des Bois de Sion, et du Quartier du Vallon.

L'atelier a réuni 18 participants en trois groupes de six, tous engagés dans les associations, dans le "Vallon Garage", un espace associatif dans la Rue de l'Industrie 10 à Lausanne, pendant environ deux heures, précédé d'une visite des initiatives du Quartier du Vallon, et suivi d'un apéritif-repas co-créé. L'atelier était structuré en deux parties d'une heure environ, les groupes restants inchangés pour les deux parties :

- La première partie : **Comment imaginer et décrire un monde sobre et désirable ?**
- La deuxième partie : **Comment mettre en place ce monde sobre et désirable ?**

[Ce rapport a été envoyé aux participants de l'atelier le 21.11.2022 pour relecture et validation ; leurs remarques et suggestions ont été intégrées dans la présente version finale]

Résultats

1. **Espaces**
    - Privés (logements) :
        - Surface : diminution / “minuscule”, si on a besoin de plus grand, il existe l’espace communautaire ; la taille de la tiny house est l’unité de base
        - Mutualiser : les espaces communs (cuisine, salle de bain, salon etc.), sans que cela soit subi par les habitants grâce à de la communication/ sensibilisation en amont
            - Variante possible : vie intergénérationnelle : grands-parents, parents, enfants dans le même logement, avec des espaces adaptés
        - Pas d’espaces vides : interdire les résidences secondaires, ré-attribuer les logements vides, pénaliser le propriétaire si un logement reste vide
    - Communs (dans le bâtiment, accès limité) :
        - Partage d’espaces : buanderie, mais aussi cuisine, salle de bain, salons etc.
        - Partage ou échange d'objets (outils, skis, four,)
        - Garde communautaire des enfants, intergénérationnelle
        - Créer des rencontres : repenser les espaces dans ce but
        - Animaux de compagnie : peut-être un chien communautaire, dont le groupe s’occupe
    - Publics (extérieur, accès ouvert) :
        - Services locaux : cordonnier, dentistes, médecins, épicerie, fitness, …
        - Repair café / échange des savoirs (par exemple savoir réparer son vélo)
        - Culture
        - Travail
        - Ecole avec jardin collectif
        - Production alimentaire locale et partagée
        - Espaces verts (transformer les parkings, sauver les arbres)
        - Espace de rencontre pour discuter et réfléchir à la sobriété (comme le Vallon)
        - Transport public (fréquent, gratuit ?)
        - «Ville à 15 minutes» ; enlever les voitures

2. **Système économique**
    - Passer d’une économie de désirs à celle des besoins ; identifier les manques dans les quartiers en fonction du type d’habitant.es. Fin du système de surabondance : tous les besoins sont satisfaits, on n’a pas beaucoup plus
    - Ne pas travailler à 100% pour être disponible en temps et énergie, pour des thématiques et actions qui nous tiennent à cœur
    - Revenu de base inconditionnel + revenu maximum (afin de limiter la consommation)
        - Créer de la solidarité, des réseaux pour se soutenir ; mettre en commun le revenu (groupes de 30-40 personnes?), responsabilité commune pour que chacun.e puisse vivre dignement

- Système de troc, banque du temps (On met dans la banque 10 heures de conseil juridique, dix heures de massage, dix heures de travail de la terre, 10 heures de coiffure. Ainsi chacun apporte à cette société ce qu'il sait faire, aime faire, retour de l'altruisme, du don de soi, du travail passion, etc.)
- Supply-side
    - Suppression de la publicité
    - Repenser les objets afin qu'ils soient plus adaptable et durables dans le temps
    - Produire moins de déchets
    - Food waste : obliger les supermarchés de mettre à disposition du quartier leurs invendus
- Consommation “one-in-one-out” : pour acheter un objet, vêtement, etc, apporter l'ancien

3. **Gouvernance**
    - Consultation des habitant.es pour se mettre d'accord sur la distribution des services
    - Vote communautaire, gouvernance partagée
    - Créer des assemblées participatives au sein d'un quartier ou immeuble pour mettre en pratique les idées
    - Gestion des conflits liés à la vie collective

4. **Identité**
    - Sentiment d'appartenance à un lieu permet de s'y investir
    - Retrouver l'émerveillement à notre environnement
    - Prendre conscience de la position de l'humain dans la nature / éducation à l'environnement des enfants et des adultes
    - Casser les discours stigmatisants sur la vieillesse, moins survaloriser la jeunesse
    - Transmission de savoir, s'instruire les un.es les autres, inter-générationnelle

5. **Libertés**
    - Les libertés changent, les libertés individuelles ne vont pas au-delà des droits humains
    - La collectivité prime, tout doit être vu en termes de communauté

A4 - Workshop / mini citizens' assembly in Zurich, September 2022

This report summarizes the process, results, and insights of the Academic Citizens' Assembly held at the K3 Kongress zu Klimakommunikation 2022 in Zurich on Wednesday 14.09.2022: academiccitizensassembly.ch

A draft of this report was sent on 09.10.2022 to all participants for comments and suggestions, which were integrated in the final report. Thanks to all participants who contributed.

1. Context and goals

The **Academic Citizens' Assembly – K3 Kongress** (ACA K3 2022) took place on Wednesday 14.09.2022 at the K3 Kongress zu Klimakommunikation 2022 in Zurich, on the topic of "How to make sufficiency central to the national climate strategy?", with two distinct goals:

- Identify climate action proposals around sufficiency supported by a supermajority (>85%) of participants, who were all reasonably well informed about both the climate crisis and climate action
- Familiarize leading climate communication professionals with a promising approach to engage the broad public for climate action

Since the 1980s, citizens' assemblies have been successfully conducted dozens of times in many countries, almost always leading to recommendations of high quality. Most assemblies had between 20 and 150 participants, and the main challenge was acting on the result by the government, parliament, or popular referendum. To overcome this issue, the Academic Citizens' Assembly (ACA) is specifically designed to scale to hundreds of thousands of participants, building on the Swiss tradition of participatory direct democracy.

ACA is entirely based on academic principles: evidence-based, lobby-free, no ideology. In contrast to many assemblies, interest groups do not get a special platform to defend their "interests" during the preparation phase, which is limited to science-based information.

Citizens' assemblies ensure representativity by a process called "stratified sortition", where participants are randomly selected to maintain a representative proportion of all subgroups considered significant, such as age, gender, education, and sometimes nationality, income, size of city, political views or other. In contrast, the ACA is designed to be representative by full inclusion. ACA K3 2022 was not representative of the broader society, as participants were self-selected from participants to K3 Kongress zu Klimakommunikation.

The main partners of the Academic Citizens' Assembly are EPFL and Business School Lausanne (BSL), supported by CLIMACT and E4S.

2. Structure, process, and tools

ACA K3 2022 was a one-session, 2-hour mini-assembly, in a 100-seat auditorium at the Toni-Areal Zurich, a former milk factory, today the Zurich University of Applied Sciences (ZHAW) and the Zurich University of the Arts (ZHdK). The group deliberation and proposal writing was in fixed groups, voting was individual and anonymous. Each group was seated in a corner of the auditorium. The assembly took place on Wednesday 14.09.2022, 16:15-18:15, of which the last 30 min extended beyond the official end of the conference schedule, as it was the last workshop of the day.

Each group had a volunteer facilitator (to ensure respect, focused participation, and timely output) and observer (to note each group's social dynamic). Both facilitators and observers could participate in the deliberation and vote, in addition to their roles.

ACA K3 2022 was somewhat unusual as it compressed the learning phase of the assembly into a quick introduction of about 15 min at the beginning of the session. This choice was justified by the context within the K3 Kongress zu Klimakommunikation, with a professional audience well informed about the topic, and the very limited time we had for the single session.

Most of the time, around 85 min, was spent deliberating and writing proposals, with the vote taking the last 15 min.

Access to all needed tools (opening form, team documents, proposal voting software - pol.is, and the closing survey) was provided in a "Tools" section on the ACA K3 2022 page of the ACA website. It could be accessed on any device including mobile phones, but laptops were generally used for typing proposals and observer notes.

3. Participation - surveys, statistics, observers

ACA K3 2022 had a total of **21 participants in 3 groups**, 7 per group.

A total of **29 proposals** were submitted, **672 votes** cast.

The **Participant Survey**, 43% response rate, indicated participant composition and satisfaction and feedback to the assembly. The relatively low response rate was probably due to the survey timing, late in the day.

Participants were 57% female, 43% male; 44% communication professionals, 22% scientists, with others being consultants, students, or concerned citizens. 44% worked in Switzerland, 22% in Germany, 22% in Austria, and 11% in Liechtenstein.

Inclusion and respect were very high: (range (lowest to highest vote) 0-10, "mode" is most common reply

- Overall organization: average 6.4, with 33% voting "6" and 22% voting "8"
- "Was the goal of the ACA clear to you?": average 6.4, mode 7
- "Was the process of the ACA clear to you?", average 6.4, mode 6
- "Did the voting work well?", range 6-10, average 8.2, mode 9
- "Could you express yourself, and were you heard?", average 8.0, mode 9
- "Were you treated with respect?", average 9.0, mode 10
- "Quality of discussion?", average 7.6, mode 8
- "Quality of proposals?", average 6.8, mode 7
- Most people reported feeling energized, great experience, excited, interested
- Several people though more time would have been beneficial
- Group size (7 people) was generally considered good; for a short assembly, 5-6 might be better

An analysis of all 3 **observers' sheets** (3 groups, 1 session, total 3 sessions) indicates good quality of discussions:

- The atmosphere was relaxed 0%, mixed 100%, tense 0%
- Soft power prevailed 100% (100% rather, 0% clearly), hard power did not prevail at all

- Symmetry of the discussions during the session (participants treated each other as equals): 100% (67% very symmetric, 33% symmetric)
- Participants were not open to change positions 67% of the time (never or generally), only 33% were open
    - Noteworthy comment: “no position changes observed, rather change subject”
- Participants provided justifications for their claims: mostly 100%
- Reciprocity (referring to others’ positions): medium 67%, high 33%
- Active participation: 90, similar for male and female participants
- Facilitators provided active facilitation 33% of the time
- Polarization occurred about 67% of the time, evenly split between 2 and 3 polarized sub-groups

4. Voting results: accepted proposals

Top proposals reaching **>85% support**, translated from German and slightly edited for clarity:

Focus: Transport+Urban Planning-Agriculture+Food-Buildings-Degrowth

100%

13. Modular architecture and forms of living - “breathing” apartments, with the aim of reducing m^2 per person

95%

14. CO_2 tax on fuels, make transport more expensive, abolish subsidies on fossil fuels
15. Change the use of car infrastructure for pedestrians and bicycles, give pedestrians and bicycles priority
16. Basic needs: vegan dishes as standard in public canteens at the lowest price
17. Create incentives: reverse commuter allowance for short distances, holidays nearby
18. Create incentives: differentiated taxation for communal living space

90%

19. Support multi-generational housing projects financially and politically, build/modernize energy-efficiently
20. Make parking more expensive
21. Strengthen communities, promote sharing models
22. Cap subsidies for insufficiency (e.g. single-family house) or make conditional (energy efficiency, etc.)

85%

23. Progressive taxation of living space per person above a certain size
24. Reduce working hours to increase self-sufficiency and reduce consumption

5. Discussion - insights and learnings

What can we conclude about the effectiveness of the ACA K3 2022?

Based on this analysis, especially clarity of goals and process, inclusion and respect, as well as multiple quality-of-discussion observers' indicators, the pertinence of proposals, and the functioning of a complex tool setup, with limited time and a small team, we conclude that the proposed process and voting tools worked well.

Initially, there was some confusion about the purpose: a demonstration or actual assembly designed to produce recommendations. Indeed it was intended to be both, and given the quality of proposals and limitation of time, this was reasonably well accomplished.

There was also some confusion about the focus of proposals: broad policy goals or specific measures, or even how to ensure such measures are integrated in actual national climate policy. The focus should be better defined in future assemblies. To make the assembly as useful as possible, the focus should be on specific measures: reasonable people will not disagree that transport emissions need to fall over 90%, but might well disagree how to get there; these challenging decisions are precisely the area where past citizens' assemblies have produced broad convergence towards meaningful proposals.

Finally, the topic of sufficiency is new in climate policy and public discourse, and for this reason, should have been better defined and perhaps narrowed to one sector (such as buildings or mobility), given the time constraints.

Overall, the level of engagement and energy in the room was very high, until the end of a long day, most participants having a feeling of accomplishment and motivation to support this democratic process, as captured in the participant survey, feedback emails, and numerous discussions.

How well did the ACA K3 2022 reach its first objective, to identify climate action proposals around sufficiency supported by a supermajority (>85%) of participants? The quality of the 12 top proposals, supported by 85% to 100% of participants, is such that they would represent a **significant improvement to the current climate policy** in any of the four countries represented. While these measures would not alone reach net zero, they could be a very meaningful first step which could be implemented immediately, given the supermajority support.

Are these insights applicable outside the climate-informed circles present at the K3 Kongress? Experience in past assemblies shows that randomly selected citizens, given adequate preparation and sufficient time for deliberation, reach the same quality of reasoning as experts, with the added major benefits of bringing multiple perspectives to the table and providing democratic legitimacy. This suggests that **similar proposals could be reached in a fully inclusive universal assembly, given adequate preparation**, which would certainly need to be much more extensive than in this expert group.

6. Next steps

To build on the momentum and learnings of the ACA K3 2022, we propose the following next steps:

- Share this report with participants, academia, public administrations, journalists, social media
- Outreach to cities, communes, cantons to adapt a future assembly to their context and language
- Integration in scientific research as a way to better engage citizens
- Include a similar workshop in the 2024 K3 Kongress zu Klimakommunikation in Graz, 18-19.09.2024
- Exchange experience with other deliberative democracy initiatives

7. Supplementary material

All statements and detailed results of all votes are available in the Annex.
Please contact us for any additional information or exchange.

B1 - Results and insights of the April 2022 Academic Citizens' Assembly

This report summarizes the process, results, and insights of the Academic Citizens' Assembly held at EPFL and online on Saturday 02.04.2022: academiccitizensassembly.ch

A draft of this report was sent on 12.04.2022 to all participants for comments and suggestions; numerous suggestions were received and integrated in the final report. Thanks to all participants who contributed.

B1.1 - Context and goals

The second **Academic Citizens' Assembly** (ACA) took place on Saturday 02.04.2022 at EPFL and online, on the topic of "Climate action, the way forward: Building a societal consensus for 1.5°C", with two distinct goals:

- Propose climate actions supported by a large majority (>75%) of participants
- Test the process and tools for a future universal assembly, scaling to include the whole population

Since the 1980s, citizens' assemblies have been successfully conducted dozens of times in many countries, almost always leading to recommendations of high quality. Most assemblies had between 20 and 150 participants, and the main challenge was acting on the result by the government, parliament, or popular referendum. To overcome this issue, the Academic Citizens' Assembly is specifically designed to scale to hundreds of thousands of participants, building on the Swiss tradition of participatory direct democracy.

ACA 2022 was open to academia, arts, administrations, civil society, and companies, and entirely based on academic principles: evidence-based, lobby-free, no ideology. Differently from many assemblies, interest groups do not get a special platform during the preparation phase, which is limited to science-based information.

Citizens' assemblies ensure representativity by a process called, "stratified sortition", where participants are randomly selected to maintain a representative proportion of all subgroups considered significant, such as age, gender, education, and sometimes nationality, income, size of city, political views or other. In contrast, the ACA is designed to be representative by full inclusion. ACA 2022, being small scale, was not representative in this sense, as participants were self-selected from the mostly academic and climate communities we could reach.

The main partners of ACA 2022 were EPFL and Business School Lausanne (BSL), additional support was provided by CLIMACT, E4S, and EPFL Sustainability.

B1.2 - Structure, process, and tools

The 2022 ACA was a one-day assembly, 9-17h, simultaneously in person at EPFL and online. The opening and closing plenary sessions were hybrid EPFL+online; group deliberation and proposal writing was in fixed groups, voting was individual and anonymous. Each group was entirely in-person or online.

A short "Introduction to Climate Action", preparatory material summarizing most relevant scientific knowledge was shared with participants, presented and discussed in an online workshop 8 days earlier on 25.03.2022. The document and video recording were shared with participants who missed this workshop.

The physical infrastructure was a 218-seat amphitheater at EPFL and several breakout rooms; online groups used Zoom breakout rooms. Coffee and lunch were provided in the restaurant located in the same building.

The opening and closing plenaries lasted around 40 min each, between which were three group sessions of 90 min each. Each group selected a facilitator and an observer; these roles typically changed every session.

The whole process was designed to converge, with best-voted results of one session being the input for the next one, from which each group could choose what they wished to work on, with the purpose to go in depth on the most promising proposals.

In addition to the preparatory material and workshop, all participants received a participants' guide prior to the ACA. Each group had access to an online group folder, containing a group discussion document (notes and formulation of proposals), a "Convergence Document" (results of previous votes to better focus group work in each session), and an observer sheet (to capture group dynamics, inclusion, and nature of deliberation).

Access to proposal voting software (pol.is) and final quadratic voting software (qv.geek.sg) was provided in a "Tools" section on the ACA website.

B1.3 - Participation - surveys, statistics, observers

ACA 2022 had a total of **70 participants in 8 groups**: 53 people in 6 groups of 8 or 9 were present in person, and 17 people in two groups of 8 and 9 were online.

Based on the **opening survey** (67 responses), participants were 52% female, 48% male; broadly representative in terms of age (except: no children, and age 25-49 overrepresented with 57%); highly educated (10% bachelor, 60% masters degree, 30% PhD); 92% Swiss residents and 65% residents for >10 years, 60% Swiss citizens. Only 18% had in-depth knowledge or had participated in citizens' assemblies; 45% "had an idea", and 28% never heard of them before the ACA. To enable Swiss-wide participation without translation, ACA 2022 was held in English; this obviously affected the self-selection of participants, those present generally had a high English proficiency, with 34% at C2 and 28% at C1 levels.

Proposal writing and voting statistics - total **216 proposals** submitted, **11'971 votes** cast:

- Session 1: 83 proposals submitted, 4254 votes cast
- Session 2: 68 proposals submitted, 4096 votes cast
- Session 3: 65 proposals submitted, 3621 votes cast

The **closing survey** shows high inclusion and respect:
(59 responses, range (lowest to highest vote) 0-10, "mode" is most common reply, in-person participants slightly overrepresented with 80%)

- 97% participated in all three sessions
- Overall organization: average 7.20, with 29% voting "7" and "8" each
- "Was the goal of the ACA clear to you?": range 4-10, average 6.73, mode 7
- "Was the process of the ACA clear to you?", range 3-10, average 6.56, mode 8
- Group size (8-9 people) was generally considered optimal; yet for a short assembly, 5-6 might be better
- "Did the voting work well?", range 5-10, average 7.05, mode 8
- "Could you express yourself, and were you heard?", range 7-10, average 8.69, mode 10
- "Were you treated with respect?", range 9-10, average 9.85, mode 10
- "Did you learn about climate action, during preparation and the ACA itself?", range 5-10, average 6.64, mode 8
- "Did you develop an appreciation / empathy for different perspectives?", range 5-10, average 6.90, mode 8

- “How would you rate the quality or proposals developed by your group?”, range 4-10, average 6.53, modes 6, 7
- Most people reposted feeling well / great, collaborative, relaxed, stimulated, listened to, tired
- 91% are willing to be contacted for clarification, 44% are willing to help organize the next edition

An analysis of all 24 **observers' sheets** (8 groups, 3 sessions, total 24 sessions) indicates good quality of discussions:

- The atmosphere was relaxed 63%, mixed 37%, tense 0%
- Soft power prevailed 96% (71% rather, 25% clearly), only 4% of time hard power prevailed
- Symmetry of the discussions during the session (participants treated each other as equals): 80% (38% very symmetric, 42% symmetric)
- Participants were open to change positions 96% of the time
- Participants provided justifications for their claims: mostly 88%, about half the time 12%
- Reciprocal discussions during the session: mostly 58%, about half 13%, no justification 29%
- Facilitators provided active facilitation 96% of the time
- Polarization occurred about 25% of the time, evenly split between 2 and 3 polarized sub-groups

B1.4 - Voting results

In light of the ACA 2022 goals, session and final voting results are listed, slightly edited for clarity, typos corrected.

Focus: Transport+Urban Planning-Agriculture+Food-Education+Engagement-Buildings-Investments

Session 1: # of proposals >75% accepted and >50 people voted: **23**, top proposals (grouped and shortened):

1. Reallocate climate-harmful transport subsidies towards clean and affordable transportation
2. Encourage biking and walking by replacing car lanes with bike and pedestrian spaces trees + Improve bike culture/skills/behaviors
3. Concept of city in 15’. Everything reachable within 15’ + Encourage sust. urban planning (services, living & work are concentrated)
4. Promote good food production practices, Reduction of pesticides and fertilizers, education of farmers in alternatives
5. Encourage through education to grow local gardens
6. Food labeling system for carbon emissions of food + Carbon tax on imported food
7. A quota in mainstream media (some minutes per day, advertising space) to raise awareness on climate change and on solutions
8. Engage young adults into an “Environmental service’ (like civil service)

Worth mentioning, slightly below the 75% threshold:

9. Replace housing heating in Switzerland within 5 years (73%)
10. Fund the production of cultural life (or events) that promote a sustainable lifestyle (73%)

Session 2: # of proposals >75% accepted and >40 people voted: **21**, top proposals (grouped and shortened):

11. Cultural change: Citizen assemblies with random selection for bottom-up solutions and build consensus for local policies for sust.
12. Include young people in decision-making on environmental issues, consult schools to pass binding resolutions
13. We need to create a new paradigm shifting from a material growth economy to a social service based economy
14. National day for sustainable policy, organize discussion events around the country and create working groups for local policy

15. Promote culture and arts to change paradigm from consumption society to sustainable one; different media (movie, books, theater)
16. Training: Mandatory training for public employees on sustainability issues, mentorship, consider sufficiency
17. Change public investment rules to make sustainability criteria the most important
18. Filling the gaps in public transport (shuttle from stations to factories) + Increase frequency and service coverage to rural / suburban
19. Distance work: coworking spaces available in residence proximity, local communities enable it through re-zoning

Worth mentioning, slightly below the 75% threshold:

20. Advertisement: Banning commercial products ads in public space and use spaces for free cultural events (71%)

Session 3: # of proposals >75% accepted and >50 people voted: **21**, top proposals (grouped and shortened):

21. Raising awareness: Every Swiss resident (CH, permit B, C) participates in a Citizens Assembly organized by municipality
22. Climate Change Citizens assembly event for younger generations regionally/nationally
23. invest in more comprehensive climate change & planetary boundaries education in schools + Involve youth in syllabus generation
24. Implement a 4-day working week and dedicate the 5th one for sustainability projects (environmental and social)
25. Enforce that any project supported by public funds is based on sustainability criteria
26. Legally impose that Swiss banks and insurance companies gradually move their investments to carbon-free + add to SNB mandate
27. Adopt Paris/NL model of expanding bike lanes and replacing car lanes with bike lanes
28. Link subsides to good farming practices (biodiversity and carbon footprint) + shift from large-scale to micro-farming
29. Reduce meat consumption in schools by introducing progressively more vegan options, until 100% vegan, bio, regional, seasonal
30. Adapt food-type consumption to anticipated future conditions (much less meat, select climate-resistant crops)

Final quadratic voting (participants allocate 100 points each, per proposal 1 vote “costs” 1 point, 2 votes: 4 points, 3 votes: 9 points etc.. Most participants allocated 2-4 votes per proposal they supported, over 5 votes were extremely rare, details in the Annex):

31. Enforce that any project supported by public funds is based on sustainability criteria (guided by experts), 163 votes
32. Link subsides with good farming practices (biodiversity and carbon footprint), 139 votes
33. Make part of the Swiss National Bank mandate to decarbonize their portfolios (in addition to financial security), 126 votes
34. Legally impose that swiss banks (especially BNS) gradually move their investments to carbon-free alternatives, 120 votes
35. Every Swiss resident (CH, permit B, C) participates in a Citizens Assembly organized by municipality (1 day off/year), 114 votes
36. Add sustainability as an obligatory subject to the school curriculum (primary, secondary schools), 111 votes.
37. Banks must follow certain (inter)national env. sustainability standards before placing investments, 102 votes
38. Adapt food-type consumption to anticipated future conditions (much less meat, select climate-resistant crops), 99 votes
39. Increase investment into schools for more comprehensive education in climate change & planetary boundaries, 95 votes
40. Incentivize (e.g. label or taxation) companies to decarbonize their business operations, 91 votes

B1.5 - Discussion - insights and learnings

What can we conclude about the effectiveness of the ACA 2022?

Based on this analysis, especially clarity of goals and process, inclusion and respect, as well as multiple quality-of-discussion observers' indicators, the pertinence of proposals, and the functioning of a complex tool setup, with limited time and a small team, we conclude that the proposed process and voting tools worked well.

With every element of this process and tools scalable, we can reasonably expect the whole ACA to be scalable to city- or country-wide size with minor adaptations. Deployment and distribution of the polling and quadratic voting software on a local server would allow faster report generation, improve stability of links, and the possibility of customization such as character limit (140 in the standard version we used) or number of votes per person. The organizers would be more effective if process and technical roles (voting, participation, audiovisual) were completely separated; this was only partially the case here. The schedule should ensure sufficient time to read, understand, and vote on each proposal. Step-by-step instructions indicating timing and which tools to use will save time, especially in the first session.

The convergence process, to produce a short list of proposals reflecting all the highly voted ideas, may require more time and manual input; it cannot be completely automated. For future assemblies, we recommend one of two possible options:

1. Similar statements could be grouped by an independent panel, clearly documenting what was grouped. Such grouping would save time and reduce possible confusion.
2. If grouping of similar proposals cannot be done in a legitimate way, more (partially overlapping) proposals could be included, perhaps 30, as long as each selected proposal got at least 75% of the vote. This process would produce longer convergence documents, but would provide a broader and more legitimate basis for the following session.

This issue of eliminating highly-voted proposals happened after session 1, in this case related to food, and again after session 2. This led several participants to request a correction, which was briefly discussed in an unplanned mini-plenary lasting about 10 minutes. It was a self-correcting process, requesting the inclusion in session 3 of deliberation of both food (discussed at length in session 1) and bank regulation (not previously discussed). Concerned that even slightly modifying the process mid-assembly was dangerous, we collectively decided to remain focused on previously accepted proposals. Yet two groups "disobeyed", proposing bank regulation, which was widely accepted by voting participants. As a result, proposals 33-34-37, while democratically robust, did not follow the convergence process. We believe that adapting the convergence process as above will solve the issue.

This is a very interesting case of democratic and academic legitimacy diverging, the first being strongly felt by participants and fully respected, the second being limited by groups diverging from the agreed process. As organizers, we recommend de-emphasizing proposals 33-34-37 in the communication of results.

Regarding the topic selection, a narrower topic than "Swiss climate action" (which touches absolutely all aspects of society) would have helped participants focus and avoid that groups start somewhere almost by accident and have difficulties getting beyond the initial sub-topic. In session 1, several groups almost entirely focused on mobility, inspired by the FOEN charts showing highest emissions in this sector, neglecting areas they later felt should have been included. With a narrower topic, preparation would be simplified and could be made more specific. Additionally, any essential subtopic that must be included should be explicitly part of the "mandate" of working groups, with adequate preparation, especially for issues which are important but mostly ignored by the general public. An overview of existing solutions at communal, cantonal, and federal levels should be included.

This is a clear recommendation for future assemblies, and will avoid the need for later “corrections”.

Somewhat counterintuitive for a multilingual society like Switzerland, the use of English outside academia surprised a few actual and potential participants. This is obviously a matter of (a potentially big) budget, but unless we want to run separate assemblies in German, French, and Italian (where people only vote on proposals in one language), simultaneous translation for all proposals is required, together with a multilingual proposal management in the voting software and simultaneous translation of plenary sessions. One of the 8 groups held discussions in French, translating proposals before submission. Naturally, this is less of a problem at the city, communal or cantonal level, where a one-language assembly would be perfectly adequate in most cases.

Finally, a number of participants did not use the “license” to get into a truly creative mindset, including both out-of-the-box thinking, being disruptive, or ambitious. It is important to promote such thinking, given the scale and urgency of change. We wish to highlight the challenge of finding a balance between general proposals, unusually popular, and very specific ones, where some people might not fully understand (leading to less votes, even for excellent but specific proposals). Both challenges can be addressed through better preparation before, and restating expectations at the beginning of the assembly.

Overall, the level of engagement and energy in the room was very high, until the end of a long day, most participants having a feeling of accomplishment and motivation to support this democratic process, as captured in the closing survey, feedback emails, and numerous discussions.

B1.6 - Next steps

To build on the momentum and learnings of the ACA 2022, we propose the following next steps:

- Share this report with participants, academia, public administrations, journalists, social media
- Statistical analysis of voting, survey, and observer data
- Outreach to cities, communes, cantons to adapt a future assembly to their context and language
- Integration in scientific research as a way to better engage citizens
- K3 Kongress zu Klimakommunikation 14-15.09.2022 in Zurich: conduct a mini-assembly as workshop
- Exchange experience with other deliberative democracy initiatives

B1.7 - Supplementary material

All statements and detailed results of all votes are available in the Annex.
Participants received the Introduction to Climate Action, and the Participants’ Guide.
Please contact us for any additional data.

B2 - Results and insights of the April 2023 Academic Citizens' Assembly - MYBLUEPLANET 2023

This report summarizes the process, results, and insights of the Academic Citizens' Assembly (ACA) organized by MYBLUEPLANET (MBP), with support from the Climate Reality Project Europe, on Wednesday 26.04.2023 in Lausanne.

B2.1 - Context and goals

The **Academic Citizens' Assembly – MYBLUEPLANET** (ACA MBP 2023) took place on Wednesday 26.04.2023 at the Impact Hub Lausanne in Beaulieu, on the topic of "How to organize Lausanne 2030 for energy sufficiency?", with two distinct goals:

- Identify promising proposals on the urgent and essential topic of local action for sufficiency, supported by a supermajority (>70%) of participants
- Understand which sufficiency actions are intuitively acceptable to a general audience, not having invested much time working on this topic

Since the 1980s, citizens' assemblies have been successfully conducted dozens of times in many countries, almost always leading to recommendations of high quality. Most assemblies had between 20 and 150 participants, and the main challenge was acting on the result by the government, parliament, or popular referendum. To overcome this issue, the Academic Citizens' Assembly (ACA) is specifically designed to scale to hundreds of thousands of participants, building on the Swiss tradition of participatory direct democracy.

ACA is entirely based on academic principles: evidence-based, lobby-free, no ideology. In contrast to many assemblies, interest groups do not get a special platform to defend their "interests" during the preparation phase, which is limited to science-based information.

Citizens' assemblies ensure representativity by a process called "stratified sortition", where participants are randomly selected to maintain a representative proportion of all subgroups considered significant, such as age, gender, education, and sometimes nationality, income, size of city, political views or other. In contrast, the ACA is designed to be representative by full inclusion. ACA MBP 2023 was not representative of the broader society, as participants were self-selected from the broader MBP and Impact Hub communities.

The main partners of the Academic Citizens' Assembly are Business School Lausanne (BSL) and EPFL, supported by CLIMACT and E4S.

B2.2 - Structure, process, and tools

ACA MBP 2023 was a one-session, 3-hour mini-assembly, in the Circularium space of Impact Hub Lausanne in Beaulieu. The group deliberation and proposal writing took place in fixed groups, while voting was individual and anonymous. Each group was seated at its own table in the hall. The assembly took place on Wednesday 26.04.2023, 14-18h. This included a welcome, a presentation and discussion on energy and sufficiency, group formation, one hour of deliberation, and the summary and restitution of preliminary results.

Each group had a volunteer facilitator (to ensure respect, inclusion, focused participation, and output, within the scheduled time) and observer (to note each group's social dynamic). Both facilitators and observers could participate in the deliberation and vote, in addition to their roles.

ACA MBP 2023 was the second short, one-session ACA we organized, and the first one with a general audience. This ACA included a one-hour learning session (presentation and discussion), this could only cover the basics of energy and sufficiency, and one session is really short to start producing proposals on this complex topic.

Access to all needed tools (opening form, team documents, proposal voting software - pol.is, and the closing survey) was provided in a "Tools" section on the ACA MBP 2023 page of the ACA website. It could be accessed on any device including mobile phones, but laptops were generally used for typing proposals and observer notes.

B2.3 - Participation - surveys, statistics, observers

ACA MBP 2023 had a total of **31 participants in 4 groups**, 7-9 per group.

A total of **23 proposals** were submitted, **633 votes** cast.

The **Participant Survey**, based on 24 replies (77% response rate), focused on the process of the ACA and the satisfaction with various aspects of organization, as well as feedback for future improvement.

The survey was included in the process, resulting in a high response rate.

Participants were 58% female, 42% male; covering a broad range of roles and professions: engaged citizens, students, entrepreneurs, educators, public officials, professionals, engineers, researchers, and journalists.

Main stated **motivations around energy and sufficiency**: stopping climate change, promoting sustainability, taking responsibility, innovation, education, and concern for future generations' well-being, but also reflecting, learning, and connecting with others.

Level of **prior knowledge**, self-declared: range 1-10, average 6.6, mode 8

Emotions associated with sufficiency: neutrality, positivity, hopefulness, joy, freedom, conscientiousness, contentment, satisfaction, security, stress, and a mix of hope and disappointment.

Here is a summary of **sufficiency measures already practiced** by participants: reducing heating, limiting air travel and car use, eating less meat, recycling, growing own herbs, buying local and second-hand, and making conscious decisions when purchasing.

However, **practicing sufficiency is hard**, according to our participants, due to financial costs, need for lifestyle changes, limitations on travel and food choices, challenges in influencing others, and the complexities of the global economy and political system.

Organization of the ACA: inclusion and respect were very high (range of votes 0-10, "mode" is most common reply)

- Overall organization: average 8, mode 8 (54% of votes)
- "Was the goal of the ACA clear to you?": average 8.1, mode 8
- "Was the process of the ACA clear to you?", average 8.5, modes 8 and 10 (33% each)
- "Did the voting work well?", average 8.1, mode 10 (46%)
- "Could you express yourself, and were you heard?", average 9.2, mode 10 (58%)
- "Were you treated with respect?", average 9.6, mode 10 (79%)
- "Quality of discussion?", average 8.5, mode 10 (42%)
- "Quality of proposals?", range 3-10, average 7.1, mode 8 (33%)
- People reported positive feelings: energized, engaged, happy, thankful, excited, interested
- Several people though more time would have been beneficial
- Group size (7-9 people) was considered good or perfect in all responses

An analysis of all four **observers' sheets** (4 groups, 1 session, total 4 sessions) indicates good quality of discussions:

- The atmosphere was relaxed 75%, mixed 25%, tense 0%
- Soft power prevailed 75% (50% rather, 25% clearly), hard power prevailed 25% (25% rather, 0% clearly)
- Symmetry of the discussions during the session (participants treated each other as equals): 100% (75% very symmetric, 25% symmetric)
- Participants were open to change positions 100% of the time (generally 75%, always 25%)
  - Noteworthy observation: the only female group was the most open
- Participants provided justifications for their claims: mostly 100%
- Reciprocity (referring to others' positions): high 75%, medium 25%
- Active participation: >90%, similar for male and female participants
- Facilitators provided active facilitation 75% of the time, passive 25%
- No polarization was observed or reported

B2.4 - Voting results: accepted proposals

Out of the total 23 proposals submitted, below are the top proposals reaching **>70% support**, edited for clarity:

Focus: Education-Buildings-Agriculture+Food-Transport+Urban Planning

>90%

1. Mandatory sustainability courses for all elected officials
2. Replace high fossil energy use heating in old buildings

>85%

3. Make public transport accessible for bikes

>80%

4. More comprehensive sustainability education for everyone, obligatory at all levels
5. Roof greening mandatory for new buildings, incentives for existing buildings
6. Incentivize remote work for companies in the tertiary sector

>70%

7. Product label to make buyers aware of the adverse effects of their actions
8. Pop-up truck shops for fresh food in local neighborhoods
9. Expand public transports in Lausanne to reduce needs of car
10. Tax on energy-inefficient cars to fund public transport

B2.5 - Discussion - insights and learnings

What can we conclude about the effectiveness and the outcome of the ACA MBP 2023?

Motivation, energy, engagement: Based on the participant survey, feedback emails, and numerous discussions, the level of engagement and energy in the assembly was very high, with most participants expressing a feeling of joy, engagement, accomplishment, and motivation to support this democratic process.

Process and organization: ACA MBP 2023 largely integrated the learnings and insights of the first three assemblies (ACA 2021, ACA 2022, ACA K3 2022), the organization was almost flawless, all tools worked as planned, and the process was well structured. People felt heard, respected, and the whole process was well documented by the observers and the closing survey of participants. On the basis of this and the previous point, we conclude that the process and tools worked well.

Quality and implementability of proposals: While the retained proposals are meaningful and somewhat innovative, especially #1-4-5-8 (sustainability education, roof greening, pop-up fresh food shops), all lack specificity needed for implementation, such as time-frame, who acts or who pays. Given the short time, this is inevitable; perhaps a two-session process could first define the focus and then implementation. Especially the mobility proposals (#3-6-9-10) are too general to be useful.

Ignored examples: In the introduction session, participants were given three examples, to use as inspiration or build upon, if they wished. It is interesting that none of the elements of the examples were developed in the proposals, nor did they serve to elevate the level of ambition of the deliberation. Provided examples:

- Ensure local provisioning of food, health and child care, basic repair services, social and admin support, and co-working.
- Close neighborhood streets for cars, except emergency services. Use slow electric carts for deliveries.
- Cover main pedestrian pathways city-wide with plant-covered roofs to protect against rain, snow, heat, and filter air pollution.

Level of ambition: This is the biggest limitation of the assembly, reflecting the complexity of the sufficiency topic, the limited time of the preparation phase, and the difficulty of most participants to imagine a different future. Even if the proposals were properly defined and fully implemented, their collective impact would be a tiny fraction of what is needed. No serious attempt was made to restrict the high consumption of mobility, floor space, heating, or general consumption. Our main challenge is precisely how to do this at a societal level, while ensuring high wellbeing. To meet this challenge, a future ACA will need a suitable preparation, perhaps a facilitation more oriented towards high-impact proposals, and more sessions, perhaps to progressively increase ambition.

General vs. specialized audience: When it comes to specialized topics like sufficiency policy, a specialist audience can quickly engage in effective deliberation, as long as the objectives and process are well-defined. However, it takes a general audience much longer to reach a consensus. The outcomes of the last three assemblies, including ACA 2022 (general audience, three sessions), ACA K3 2022 (specialist audience, one session), and ACA MBP 2023 (general audience, one session), highlight the importance of preparation and time allocation. While ACA 2022 was able to converge on ambitious proposals after a separate preparatory session and three deliberation sessions, ACA K3 2022 was effective with little preparation and only one session, as it was linked to participants' daily work. ACA MBP 2023, despite being better organized based on past experience, was constrained by the short time allowing a single session. More preparation and at least two sessions could have resulted in more ambitious and precise proposals.

C - Ethical considerations of a climate-neutral aviation

During the peer review process of the aviation paper (chapter 7), reviewers suggested that all considerations and ethical aspects related to climate-neutral aviation should be removed and developed into a separate paper. Additionally, reviewers advised that citing Herman Daly might be counterproductive, from the perspective of a majority of likely readers of the journal, and was not central to the logic of implementing NEFA.

The main arguments related to inequality, globalization, purpose of aviation, and ethics are nevertheless complementary to the main arguments developed in the published paper. I hope to develop them further into a separate paper. A short management article published in “I by IMD” provides a summary (Nick 2022), here reproduced in Appendix E.

This section provides additional arguments and sources, which will serve as a basis for future work, but is consistent and relevant to be included here.

C1 - Inequality

Despite its large scale and impact, air travel involves a tiny minority of humans. Only 1% of the world's population are frequent flyers, accounting for half of all aviation emissions, and another 10% fly in a given year, of which only an estimated 2-4% take international flights, with the lower end of the range being much more likely (Gössling and Humpe 2020).

Air travel exhibits the highest inequality of all consumption, with a Gini coefficient reaching 0.82 for the “package holidays” category in a broad sample of 86 countries including all incomes, and the richest 10% of the population using 75% of air travel in 56 developing and emerging countries (Oswald, Owen, and Steinberger 2020).

Air travel truly follows an exponential function of income (Gössling and Humpe 2020): $RPK = 435.47\ e^{0.00005\ GDP/cap}$.

Chancel and Piketty (2015) estimate that the richest 1% of Americans annually emit 318 t CO_2e, around 50 times the world average, with a disproportionate contribution of air travel. They further consider the figure of 300 t CO_2e as a plausible value for the richest 1% people worldwide. This makes a strong case for a progressive tax on air travel, which we discuss in the conclusion.

It is time for global aviation to seriously start solving its biggest problem, the climate crisis, and by being a pioneer, help other parts of society with less resources - and earn its social license in the process.

C2 - Globalization, covid-19, moral hazard

Aviation is both a major driver and prime beneficiary of globalization. Therefore, if the “optimal” level of globalization is lower than today’s, the optimal size of aviation must also be smaller. While we are not aware of a scientific estimate of this optimal level of globalization, there is much evidence suggesting today’s level is too high.

Herman Daly defines “uneconomic growth” as environmental and social costs exceeding production benefits, and identifies mechanisms by which a high level of globalization stimulates uneconomic growth, mainly by preventing nations from internalizing environmental and social costs, as mobile capital escapes environmental taxes, higher wages, or redistribution policy. He distinguishes globalization from “inter-national” trade, which preserves national sovereignty, and the ability to internalize external costs. Daly concludes that in a globalized world, for a country to be rich, a majority of its people must be poor and live in a degrading environment (Daly 1999). The step-by-step logic is easy to follow, and certainly corresponds to observed reality.

Covid-19 has been highly damaging due to at least three major consequences of globalization:

1. Human pressure on remaining wildlife habitats, leading to more intense contact between humans and mammals and birds, and more opportunity for zoonoses to flourish. Globalization’s limiting of countries’ ability to internalize external costs is a major enabler.

2. Excessive level of travel, helping the virus spread within days to a level well beyond any country’s ability to contain it, clearly visualized by the NY Times based on Johns Hopkins and other data (Wu et al. 2020)

3. Poor resilience of modern societies, even rich ones, on multiple dimensions: unhealthy lifestyles and poor resulting health; air pollution; unequal access to health care; poor working conditions and discrimination against “essential” workers; supply chains, including in health care, designed for profits and “efficiency”, not resilience.

Aviation has played a major role enabling all three impacts and making the problem worse. Of course, it has also contributed towards solving the problem, in particular supporting vaccine production and distribution.

The high level of globalization leads to reduced resilience, and also strongly impacts identity and culture. These together support conditions for populism to thrive. Dani Rodrik proposes four pathways (Rodrik 2018) by which globalization leads to populism: (a) direct preference, such as increased imports leading to a preference for protectionism, (b) insecurity leading to cultural identification with “insiders”, (c) populist opportunism by politicians as a result of power shifts due to globalization, and (d) right-wing political parties shaping culture and identity to their advantage. Two of the four levers directly shape culture and social identity. As populism tends to be a pseudo-satisfier for identity, this suggests globalization is well over the “optimal” level.

Finally, unless there is a broadly accepted, clear in detail, deep decarbonization pathway for the whole society, there is the moral hazard of many polluters considering themselves in the last 10%, as particularly “important”, “essential”, or hard to decarbonize. Additionally, many polluters count on the availability of future cheap offsets.

C3 - Purpose of aviation, past and future

The Air Transport Action Group (ATAG) lists tourism, trade, connectivity, economic growth, jobs, poverty reduction, and disaster response among the benefits of air transport, and has published a 96-page report (ATAG 2020) on this topic.

From the perspective of strong sustainability, i.e. meeting all human needs within the planetary boundaries, most flights must be questioned, as (a) the energy and material metabolism of the world economy has already transgressed at least 4 planetary boundaries, so clearly it should not grow any more, (b) wellbeing requires better inclusion and synergistic satisfiers of fundamental human needs, not growth, (c) today’s globalization is almost certainly well beyond the optimal level, (d) most benefits of aviation are captured by a tiny fraction of the world’s population and generally further increase inequalities, and (e) disaster response and other direct action to save human lives is a tiny part of today’s aviation. Large-scale international tourism is very hard to justify given all social and environmental ills and costs it generates.

While almost no-one is questioning the existence and utility of aviation, most benefits, which include “optimal” globalization and immediate saving of human lives, could be reached with a much smaller aviation, and a much lighter footprint, compared to 2019, not to mention expected growth to 2050. This is important, as making aviation sustainable with technology likely to be deployed in the next 3-4 decades will almost certainly require deep and rapid reductions in passenger kilometers, as we will show in the next sections.

C4 - Direct benefits and co-benefits; acceptance by key stakeholder groups

As a luxury (in economics: high income elasticity) activity serving 1% of the world population as regular customers, already contributing 3.5% of net anthropogenic effective radiative forcing (Lee et al. 2021) and growing fast, aviation clearly cannot be exempted from seriously contributing to global decarbonisation, especially when basic energy services serving billions of people, such as electricity generation, heating, cooking, food production, or local mobility are under pressure to massively reduce their emissions.

Continued growth of aviation would put even more pressure on resources needed for basic services, by for example using the same biomass or clean electricity to produce alternative fuels, or mobilizing a disproportionate share of nature based solutions for negative emissions, or by directly displacing other uses via commodity markets, such as palm oil, or by demanding significant government subsidies to decarbonize, limiting those governments’ ability to help other sectors serving far more people for much more essential uses.

This sounds like a straightforward case. Yet, by serving the economic and political elite, the airline industry has a small but powerful constituency to defend its interests.

Still, with the worsening climate crisis, aviation's growth will have to stop, and today's complete uncertainty is not in the interest of airlines, airports, suppliers, and of course investors.

This could limit the role of states to setting the rules and objectives, and auditing the process and accounts.

Citizen engagement and deliberative democracy will be needed to ensure the best moral, scientific and cultural use of a smaller aviation; in addition such engagement may be needed to start the reforms, given the almost universal support for continuing past trends among the political and economic elite, aviation's main customers.

C5 - Risks, fairness, and moral hazard

Another key aspect we'd like to highlight is the risk of partial implementation, for example of the fund and CO_2 payments only, without requiring airlines to reduce flights 2.5% p.a. Such a setup would only remove CO_2 and do nothing for short-lived climate effects, responsible for ⅔ of aviation's warming. Or omitting the required aggregate annual 7.3% reduction, which is needed to ensure aviation contributes its fair share to global climate action. Given the luxury, "1%" character or aviation, over-consuming its fair share of resources could create a serious backlash against the whole industry.

Additionally, for the part of aviation remaining under market governance, in the section "Inequality", we made the case for a progressive tax on frequent flyers, as largely overlapping with the world's richest 1%. The implementation of such a tax must take into account local specificities and could contribute a significant share of the annual payment to NEFA of each airline.

D - I by IMD article: Towards climate-neutral aviation

Towards climate-neutral aviation: fewer flights, benefits for biodiversity and society, and renewed legitimacy for airlines

by Sascha Nick

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To play its part in global efforts to solve the climate crisis, global aviation would need to reduce passenger flight volumes to 1984 levels and set up a new fund to finance carbon removal projects. This would require significant adjustments for companies and agricultural communities across the world, but it could also give airlines renewed legitimacy.

Global aviation is responsible for a billion tons of CO2 emissions and another two billion tons CO2 -equivalent of non-CO2 emissions – but the sector has set a clear target of reaching net zero by 2050 with the International Air Transport Association (IATA), representing airlines, and the International Civil Aviation Organization (ICAO), representing countries, both officially adopting this goal. Sadly, however, current and planned actions fall far short of what is required.

My colleague Philippe Thalmann and I recently published a **paper** exploring the measures needed to enable the aviation sector to reach the goal set by IATA and ICAO and contribute to the wider global effort to avoid dangerous levels of global warming. In this paper, we developed and modeled an emission reduction pathway for aviation to cut its CO2 emissions by 90% by 2050 from 1 gigaton to 100 megatons per year, with the remaining 10% of emissions being taken out of the atmosphere through high-quality carbon removal projects.

Plans by airlines and aviation organizations for emissions reductions rely heavily on the replacement of kerosene with alternative fuels such as synthetic aviation fuels and biofuels, which the industry misleadingly refers to as “sustainable aviation fuels”, even though they are often more polluting than kerosene. However, given the limited availability and competing uses of suitable biomass restricting the future supply of biofuels, and the very high energy requirements for synthetic fuels combined with their current low technology readiness, such fuels are likely to play only a limited role in the next three climate-critical decades.

We therefore focused on the most promising actionable lever – a reduction in the number of flights taken. Our simulation shows that it is perfectly feasible to achieve the necessary 90% reduction in emissions through an 85% decrease in the number of flights along with improvements in efficiency. This would clearly involve significant changes from today. Passenger transport activity would need to contract to 1.32 trillion passenger kilometers by 2050, about the same level as in 1984, representing an annual reduction of around 7.3%, while average load factors would need to rise to 90% compared with 82% before COVID-19.

To pay for the removal of the remaining 10% of emissions, we propose the creation of a Negative Emissions Fund for Airlines (NEFA) with a contribution by airlines of $230 per ton CO2, which is entirely affordable for typical frequent flyers. NEFA could invest $3.3 trillion over 40 years in high-quality removal projects with significant biodiversity and societal co-benefits. This mechanism would truly neutralize all direct climate impacts of global aviation while avoiding crowding out other sectors which also need negative emissions.

We also propose a financing and governance model for the fund suited to the international context in which airlines operate, with aviation treated as a virtual country with its own nationally determined contributions (NDCs) within the United Nations Framework Convention on Climate Change (UNFCCC) process.

While our proposal may stand out in its scale and ambition, it builds on established foundations of international cooperation and “polluter-pays” principles. But even if NEFA can be implemented in the real world, as we argue in the paper, how would it affect practitioners?

If low-cost flights stop, the average flight cost doubles to fund climate neutrality, and the number of available flights is 15% of the 2019 level, what would it mean for large companies, academia, agricultural communities, or airlines themselves?

Large companies

Most obviously, the total cost of flying would go down by two thirds, and videoconferencing would be used even more than today. Over time, globalized supply chains might be at a disadvantage and could be reconfigured to become more regional or local, with only a few components truly globally sourced – for example, specialized microprocessors. As this would happen over two decades, there is time to adjust, and in the process make supply chains more resilient, circular, and sustainable. Now is the time to rethink business models, eliminate planned obsolescence, and start curbing extraction, material, and energy use. However, given the time needed to reconfigure supply chains, planning should start immediately, starting with new products and services.

Academia

In terms of operations, reducing academic staff travel would just be the beginning. This would mean more local or regional conferences, with fewer participants, remotely connected to related events elsewhere when needed, but little flying. Executive or other learning programs could be planned in ways that would minimize travel – adjusting schedules, combining events, on-site teams remotely connected to other teams, and longer and more local gatherings incorporating multiple activities. More fundamentally, helping society to rapidly adjust to a post-fossil fuel, limited extraction world could become an essential focus of research and teaching, especially in business education.

Agricultural communities

Any transition towards sustainability will only work if it benefits communities and wins their support. Climate change, biodiversity loss, soil depletion, and very different precipitation patterns are already affecting almost every agricultural community in the world, and they must adapt to these threats in order to survive. A limitation in air transport capacity will also impact global food exports, reducing the markets available to many agricultural communities, which would be extremely challenging, especially for disadvantaged populations. On the other hand, continuing today's agricultural trajectory will lead to a collapse in ecosystem services, including food production, which would disproportionately affect such communities. There is no single solution, but our proposal mobilizes around $100 billion each year for decades to invest in nature-based solutions, with most carbon removal projects managed by and for the benefit of local communities in participating countries. Restoring and protecting wetlands, mangroves, corals, forests, and other ecosystems would all qualify, as would soil health projects, which would also improve food production resilience.

Airlines

Surprisingly, aviation is perhaps the easiest sector to adapt, even though it is the one that will be transformed most by the transition to climate-neutral aviation. Predictable flight reductions would facilitate investments and asset management, hiring and training, flight route planning, ultimately ensuring service quality. Reporting guidelines developed for the current Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) could be adapted. The 25-year transition period is longer than the timeframe airlines had for previous adaptations, even before COVID-19. The 1980s, the reference period for the number of flights, was a profitable and predictable period for airlines. Most importantly, in a world of constrained resources, becoming climate neutral would renew airlines' social license and ensure the future of the aviation sector.

E - Planetary Boundaries - summary and implications for policymakers

E1 - Planetary Boundaries - summary and implications for policymakers

Respecting planetary boundaries is essential to preserve the stability of ecosystems and human societies, including in Switzerland. Incorporating this principle into our legal system is consistent with the pursuit of our national and international interests.

What are Planetary Boundaries?

“Planetary boundaries” represent our current scientific understanding of the stable conditions necessary for a habitable Earth. Planetary boundaries include climate, ecosystems and their biodiversity, the ozone layer, as well as planetary cycles for water, nitrogen and phosphorus. Planetary boundaries indicate thresholds where large-scale or irreversible change will move the Earth away from the stable conditions of the last 12 thousand years, the only conditions we know can support a complex human society. Six of the nine boundaries are already transgressed, including climate, biodiversity, land-system change, phosphorus and nitrogen cycles, pollution (novel entities), and freshwater use. Remaining within planetary boundaries is a prerequisite for any stable and civilized human society.

Importance for Switzerland

Switzerland is highly exposed to the effects of transgressing the planetary boundaries, with its warming to date of >2°C or twice the global average, and its high human pressure on small, fragile, and partly high-altitude ecosystems, leading to a high risk to food supply, ecosystem functioning and human health. At the same time, Switzerland has significant responsibility in transgressing multiple planetary boundaries also outside Switzerland, both directly and indirectly, through consumption, travel, trade, and finance. Switzerland’s relation to planetary boundaries thus needs to be rebalanced.

Benefits of ambitious action

Preserving the stability of the planetary system that we all depend upon is the fundamental basis of protecting our society. Without planetary stability, Switzerland cannot prosper. By adopting this initiative, Switzerland will demonstrate leadership to the world, and show a clear way forward for all countries. We know, from top international scientific reports like the IPCC (intergovernmental panel on climate change) and IPBES (intergovernmental science-policy platform on biodiversity and ecosystem services) that it is possible to make our economies climate-neutral, preserve biodiversity, and ensure wellbeing for all. Because of the planetary boundaries framework, we know it is not only possible but necessary for our national and international interest.

Public policy for planetary boundaries

The public policy encouraged by placing planetary boundaries within Swiss decision-making will support, in all possible ways, the transformation of Swiss society to a future-fit society: encouraging societal changes through sustainable innovation, top-level education, and investments towards a resilient and prosperous economy. Politically, scientifically and pragmatically, this is the most coherent way forward.

Signed by the following established Swiss-based scientists

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110. Sylvia Martinez, UNIBAS
111. Tanja Schwander, UNIL
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113. Thomas Sattler, Vogelwarte
114. Thomas Wohlgemuth, WSL
115. Veronica Petrencu, EPFL
116. Veruska Muccione, UZH & UNIGE
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119. Yves Jackson, UNIGE

E2 - Limites planétaires - résumé et implications pour les décideurs politiques

Le respect des limites planétaires est essentiel pour préserver la stabilité des écosystèmes et des sociétés humaines, y compris en Suisse. Inscrire ce principe dans notre système légal est cohérent avec la poursuite de nos intérêts nationaux et internationaux.

Que signifient les limites planétaires ?

Les "limites planétaires" représentent la compréhension scientifique actuelle des conditions de stabilité nécessaires au maintien d’une Terre habitable. Les limites planétaires comprennent le climat, les écosystèmes et leur biodiversité, la couche d'ozone, ainsi que les cycles planétaires de l'eau, de l'azote et du phosphore. Les limites planétaires définissent des seuils au-delà desquels des changements irréversibles à grande échelle feraient sortir la Terre des conditions stables qu’elle a connues durant les douze derniers milliers d’années. Ce sont les seules conditions avérées capables de soutenir une société humaine complexe. Six des neuf limites sont déjà dépassées, notamment le climat, la biodiversité, la déforestation, les cycles du phosphore et de l'azote, la pollution, et l'utilisation de l'eau douce. Rester dans les limites planétaires est une condition préalable à toute société humaine stable et civilisée.

Importance pour la Suisse

La Suisse est fortement exposée aux effets du dépassement des limites planétaires, avec un réchauffement jusqu'à présent de plus de 2°C, soit deux fois la moyenne mondiale, et une forte pression humaine sur les écosystèmes fragiles et de petite taille, notamment en haute altitude. Cela entraîne un risque élevé pour l'approvisionnement alimentaire, le fonctionnement des écosystèmes et la santé humaine. D’autre part, la Suisse possède une responsabilité importante dans le dépassement de plusieurs limites planétaires, à la fois directement et indirectement, par la consommation, les voyages, le commerce et la finance. La relation de la Suisse aux limites planétaires doit donc être rééquilibrée.

Avantages d'une action ambitieuse

La préservation de la stabilité du système planétaire dont nous dépendons tous est la base fondamentale de la protection de notre société. Sans stabilité planétaire, la Suisse ne peut pas prospérer. En adoptant l’initiative parlementaire, la Suisse fera preuve de leadership dans le monde, et montrera une voie claire à tous les pays. Nous savons grâce à des rapports scientifiques internationaux de premier plan, comme ceux du GIEC (Groupe d'experts intergouvernemental sur l'évolution du climat) et de l'IPBES (Plateforme intergouvernementale scientifique et politique sur la biodiversité et les services écosystémiques), qu'il est possible de rendre nos économies climatiquement neutres, de préserver la biodiversité et de garantir le bien-être de tous. Cela est non seulement possible mais aussi nécessaire à la défense de notre intérêt national et international.

Politiques publiques respectant les limites planétaires

Les politiques publiques encouragées par l'inscription des limites planétaires dans le cadre légal suisse ouvriront de nombreuses possibilités pour transformer la société suisse en une société prête pour l’avenir : encourager les changements sociétaux vers la durabilité par l'innovation, l'éducation de haut niveau et les investissements en faveur d'une économie résiliente et prospère. Politiquement, scientifiquement et pragmatiquement, c'est la voie la plus cohérente à suivre.

E3 - Planetare Grenzen - Zusammenfassung und Bedeutung für politische Entscheidungsträger

Die Einhaltung der planetaren Grenzen ist für die Erhaltung der Stabilität der Ökosysteme und der menschlichen Gesellschaften, einschliesslich der Schweiz, von entscheidender Bedeutung. Die Verankerung dieses Prinzips in unserem Rechtssystem steht im Einklang mit der Verfolgung unserer nationalen und internationalen Interessen.

Was sind planetare Grenzen?

"Planetare Grenzen" stellen unser derzeitiges wissenschaftliches Verständnis der stabilen Bedingungen dar, die für eine bewohnbare Erde erforderlich sind. Zu den planetaren Grenzen gehören das Klima, die Ökosysteme und ihre biologische Vielfalt, die Ozonschicht sowie die planetarischen Kreisläufe für Wasser, Stickstoff und Phosphor. Planetare Grenzen zeigen Schwellenwerte an, bei denen sich die Erde durch grossflächige oder unumkehrbare Veränderungen von den stabilen Bedingungen der letzten zwölf tausend Jahre entfernt. Dies sind die einzigen Bedingungen, von denen wir wissen, dass in ihnen komplexe menschliche Gesellschaften gedeihen können. Sechs der neun Grenzen sind bereits überschritten, darunter das Klima, die biologische Vielfalt, der Landnutzungswandel, die Phosphor- und Stickstoffkreisläufe, die Verschmutzung (neuartige Substanzen) und die Wassernutzung. Der Verbleib innerhalb der planetaren Grenzen ist die Voraussetzung für jede stabile und zivilisierte menschliche Gesellschaft.

Bedeutung für die Schweiz

Die Schweiz ist von den Auswirkungen der Überschreitung planetarer Grenzen stark betroffen. Die bisherige Erwärmung von mehr als 2°C, die dem Doppelten des globalen Durchschnitts entspricht, sowie kritisches Einwirken des Menschen auf kleinflächige, empfindliche und teilweise alpine Ökosysteme führen zu einem hohen Risiko für die Nahrungsmittelversorgung, das Funktionieren der Ökosysteme und die menschliche Gesundheit. Gleichzeitig trägt die Schweiz eine erhebliche Verantwortung für die Überschreitung zahlreicher planetarer Grenzen auch ausserhalb der Schweiz, sowohl direkt als auch indirekt, durch Konsum, Reisen, Handel und Finanzen. Das Verhältnis der Schweiz zu den planetaren Grenzen muss also neu ausgerichtet werden.

Vorteile eines ehrgeizigen Handelns

Die Erhaltung der Stabilität des Systems Erde, von dem wir alle abhängen, ist die grundlegende Basis für den Schutz unserer Gesellschaft. Ohne planetarische Stabilität kann die Schweiz nicht prosperieren. Mit der Annahme dieser Motion wird die Schweiz eine Führungsrolle übernehmen und einen klaren Weg für andere Länder aufzeigen. Wir wissen aus führenden internationalen wissenschaftlichen Berichten wie dem IPCC (Intergovernmental Panel on Climate Change) und dem IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services), dass es möglich ist, unsere Wirtschaft klimaneutral zu betreiben, die biologische Vielfalt zu erhalten und das Wohlergehen aller zu sichern. Aufgrund der planetaren Grenzen wissen wir, dass dies nicht nur möglich, sondern in unserem nationalen und internationalen Interesse auch notwendig ist.

Öffentliche Politik für planetare Grenzen

Eine Schweizer Politik, die planetare Grenzen bei ihren Entscheidungen respektiert, wird alle Möglichkeiten eröffnen, die Schweiz zukunftsfähig zu machen: sie fördert gesellschaftliche Veränderungen durch nachhaltige Innovation, Bildung auf höchstem Niveau, und Investitionen in eine widerstandsfähige und florierende Wirtschaft. Politisch, wissenschaftlich und pragmatisch ist dies der kohärenteste Weg nach vorne.

F - Climact Starting Grant: Towards new renewable energy developments in Switzerland that preserve biodiversity

Center for Climate Impact and Action (CLIMACT) Starting Grant

Call for proposals

Deadline for applications: Monday 6 March 2023 (17:00 CET)

Part 1: General information

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Co-applicant 2 Name, Position, Institution, Contact details	Prof. Stéfanie Prezioso, UNIL, stefanie.prezioso@unil.ch
External partner(s) Institution, Name, Position, Contact details	Sascha Nick, EPFL, sascha.nick@epfl.ch
External partner(s) Institution, Name, Position, Contact details	Prof. Raphaël Arlettaz, UNIBE, raphael.arlettaz@unibe.ch
Project title	Towards new renewable energy developments in Switzerland that preserve biodiversity
Keywords	Alpine energy generation, climate policy, biodiversity protection
Time frame	Start (as early as 1 June 2023): 01.06.2023 Duration (up to 12 months): 31.03.2024 Please note that no extension will be granted.
Requested grant (CHF)	49’970.- (see separate detailed budget)

Part 2: Project description

2.1 Summary of the project proposed for funding

As scientific and political awareness develops on the need to solve the biodiversity and climate crises jointly [Guisan et al. 2022], the increasing pressure to develop renewable energy (RE) facilities to satisfy winter demand and move toward a negative-emission society [Li et al. 2020] is currently shaping the Swiss policy debate, and is creating pressure which could lead to a weakening of biodiversity protection [Niebuhr et al. 2022] in order to facilitate the rapid development of RE capacity, especially in Alpine regions [Salak et al. 2019, Wissen et al. 2019]. Protecting ecosystems on 30% of land area is a Swiss commitment under the December 2022 COP15 biodiversity conference, and effective climate mitigation requires resilient, functionally intact ecosystems, but poorly planned energy developments could have a counter effect on achieving this target [Niebuhr et al. 2022]. Following studies on the perception by the Swiss population of how renewable-energy could affect landscapes in Switzerland [Salak et al. 2019, Wissen et al. 2019], many research and science-policy dialog projects are currently starting in Switzerland, such as "Sustainable Pathways towards Net Zero Switzerland'' (SPEED2ZERO - ETH Domain), or the SCNAT project "Planifier le développement des énergies renouvelables dans le respect de la biodiversité et du paysage". EPFL has also developed the energyscope platform for modeling the energy infrastructure in various scenarios. This model highlights conflicts between distributed PV production on existing buildings and the development of large production fields to be connected to the transportation grids. At UNIL (together with other Swiss universities), the ValPar project aims at evaluating how and where to optimally set-up a functional national ecological infrastructure, and which additional surfaces should be set as biodiversity priority areas.

Our initiative aims to organize a series of scientific workshops complementary to the above-mentioned ongoing or planned projects. It will aim particularly to (i) foster the discussion among various scientists in Switzerland on potential energy-biodiversity conflicts (e.g. Alpine solar plants versus Alpine biodiversity preservation), and instead (ii) promote an integrated approach to plan the needed energy developments, accounting for biodiversity preservation and climate mitigation. It will do so by bringing together the Swiss climate, energy, and biodiversity scientific communities in order to identify challenges and synergies, and find a common strategy that will allow shaping more effective public policies. This objective requires identifying the key data and knowledge to be integrated, and producing and communicating an initial set of guidelines to overcome RE-biodiversity tensions, and then lead a national and regional dialogue. A key new data used in this integration will be the use of the ecological infrastructure (EI) currently in development for Switzerland.

2.2 Description of the project

The workshops will combine experts, data, and knowledge from the three following fields:

Energy: The project will combine seasonal Swiss energy scenarios [EP2050+, Li et al. 2020, OFEN 2021], and sufficiency potential estimates adapted to Switzerland [Barrett et al. 2021], to produce a space of credible configurations of the main levers (sufficiency, PV, wind). [Barrett et al. 2021, 2022] . It will also address the security/supply risk for Switzerland in case of a too slow implementation of renewables, which should be alleviated e.g. by installation of wind and solar e.g. in the Alpine environment.

Biodiversity: The most intact, unique, essential and biodiverse ecosystems will be identified from existing data [infospecies data, national biotops [OFEV 2019], national map of habitats [WSL 2019], ecological infrastructure mapping [OFEV 2021; ongoing EI mapping by ValPar, valpar.ch; Rey et al. 2022]. For these, an initial set of guidelines and methodology will be proposed to ensure human pressure remains limited and allow Switzerland to fulfill its international commitments. Biodiversity criteria will be included in the energy systems models [Li 2022]. On this basis, already degraded areas will be identified, where the impacts of energy development would be low or reasonable. For example, considering the large potential of rooftop PV, what is the additional need for PV capacity in the Alps? Or under which conditions would replacing a ski resort and access roads with Alpine PV and wind reduce total pressure on biodiversity?

Climate: New energy developments will also need to be done in a way that does not affect the Swiss climate change adaptation and mitigation capacities, especially through the preservation and restoration of those natural ecosystems that are most efficiently sequestering carbon (e.g. peatlands, forests, natural meadows/pastures/grasslands).

A particular effort will be made to invite participants from the most important ongoing initiatives, such as the ValPar project funded by OFEV, the SPEED2ZERO project funded by ETH domain, and the new SCNAT project on planning energy developments with minimal harm to biodiversity and landscapes.

Interdisciplinary coordination team: Antoine Guisan, Raphaël Arlettaz, conservation biology; Christophe Ballif, PV systems; Michael Lehning, Alpine energy systems; François Maréchal, energy system integration; Julia Steinberger, political economy; Stéfanie Prezioso, history and member of parliament; Sascha Nick, energy economics and policy; Florian Altermatt, president of the Forum Biodiversity, and Nick Zimmermann jointly for SPEED2ZERO, biodiversity, climate extremes, sustainable energy developments.

Process: After a launch meeting of the interdisciplinary coordination team, a series of 2-3 workshops will be organized with a wide range of additional participants (academic and practitioners from the energy, climate, and biodiversity communities, as well as SCNAT representatives) in different regions of Switzerland between 09-2023 and 02-2024, and together with key literature insights, summarized in a White Paper. Main outputs: (1) White Paper on Alpine RE, (2) An urgent action research agenda, (3) A “red list” of ecosystems and possible developments, (4) Propose and prototype a model of dialogue between the scientific energy, climate, and biodiversity communities.

Outreach: Finally, an outreach event will be organized in Bern, bringing together science, politics, and the broader society, presenting the main results and demonstrating the proposed model of dialogue.

2.3 Timeline and milestones

- Project start; internal team workshop: 06-2023
- Stakeholder workshops in different regions of Switzerland (2-3), building on each other and on literature: 09-2023 to 02-2024
- Writing the White Paper: 02 to 03-2024
- Final outreach event in Bern: 03-2024 (→ adapt to Swiss political calendar)

2.4 Interdisciplinary and interinstitutional approach and its added value

The project aims to solve a problem created by decades of lack of interdisciplinary and interinstitutional dialogue: (1) energy-climate-biodiversity issues can only be solved together, (2) Integrating instruments in different policy areas towards a common system goal is the only way to overcome current conflicts.

2.5 Scientific relevance

The project is at the intersection of main environmental challenges (biodiversity, climate), main societal responses (biodiversity and climate action, sufficiency, integrated policy), and requires a new type of dialogue based on learning and deliberation, which we will prototype.

2.6 Societal relevance, chosen actions and engagement strategies

The project addresses the most pressing issues of our time, and aims specifically to identify under which conditions it is possible to both protect biodiversity and develop RE. In doing so, it will bring the Swiss climate, energy, and biodiversity communities closer together, developing capacity and connections to rapidly address future issues.

2.7 CO_2 emissions reduction

At this stage, it is impossible to estimate likely CO_2 reductions. The main levers will be (1) Bringing sufficiency in the societal dialogue, and (2) Reducing existing human pressures as a precondition of RE development.

Curriculum Vitae

SNSF CV format

Personal information

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ORCID 0000-0002-2122-1676

Swiss and Austrian citizen
Languages: English, French, German

Education and training (net academic age = 0)

EPFL, PhD, expected 06/2023

Topic: *Action Levers towards Sustainable Wellbeing: Re-Thinking Negative Emissions, Sufficiency, Deliberative Democracy*

INSEAD, Master of Business Administration, 06/1990

University of Belgrade / Tokyo Institute of Technology: Electronics Eng., BSc+MEng, 12/1983

Online courses with: Johan Rockström, Katherine Richardson, Jeffrey Sachs, Agustín Rayo

Previous and current employment

Business School Lausanne (BSL)
since 2016: Associate Professor of Sustainability
since 2019: Scientific Director

EPFL, Laboratory of Environmental and Urban Economics
since 2019: Researcher, lecturer, and PhD candidate

UNIL, FGSE, Institut de Géographie et Durabilité (IGD)
since 2016: Lecturer in sustainability

CO2-monitor AG, Lausanne and Zurich
since 2008: Founder and CEO

World Climate Credit / MySollars, Lausanne
2012-2015: Co-founder and sustainability director

Idtect SA, Paris
2001-2006: Co-founder and CEO

Schneider Electric, Paris and Chicago
 1991-2000 Director, then VP strategy

Siemens, Vienna and Munich
 1985-1989 Project manager, real-time OS development

Client Team Member: McKinsey (1993), Banque Lazard (1994), Booz-Allen & Hamilton (1997)

B Leader, B Lab Switzerland, since 2020

Major achievements with selected works

- Proposed a new 1.5°C-compatible climate policy for Switzerland as well as global aviation, reaching annual net zero around 2040, and removing all past emissions from 2030, entirely financed by polluters, based on a public fund, investing in nature-based solutions for negative emissions projects. Setting up a voluntary pilot fund at the 1% scale of the full Swiss fund. Publications:
  - Swiss Negative Emissions Fund – paying for Net Zero, E4S, 2022
  - Carbon removal, net zero, and implications for Switzerland, E4S, 2021
  - Towards True Climate Neutrality for Global Aviation: A Negative Emissions Fund for Airlines, Journal of Risk and Financial Management, 2022

- Developed and successfully organized three Academic Citizens' Assemblies, scalable to millions of participants, as a new form of fully inclusive deliberative and participatory democracy: academiccitizensassembly.ch

- Developed and taught since 2017 the BSL bachelor course "SDG Explorer", selected as best practice in teaching sustainability by UN SDSN

Full publication list: Google Scholar, EPFL Infoscience